Energy-Water Nexus Knowledge Discovery Framework: An integrated platform for integration, analysis, and synthesis of spatiotemporal data

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BER Program: Multi-sector Dynamics

Project: Energy-Water Nexus Knowledge Discovery Framework

Project Website:

Project Abstract:

Understanding the physical, engineered, and human system responses to changing climate, extreme weather events, and the local, regional and global distribution of energy and water resources and infrastructure is required for the building of a national capability for ensuring energy assurance and resiliency. Successful evolution of the energy-water infrastructure not only relies on efficient operations of its individual components, but also on the effective harmonization with other enabling critical infrastructures. No data system exists now to serve the multidisciplinary highly diverse needs of scientists, engineers, and decision makers faced with understanding the dynamics of the water and energy system. The development of an integrated multi-layered, federated knowledge framework provides an unprecedented opportunity for users to interrogate a single information system for robust data driven analysis and visualization capability to assess and describe the critical characteristics of the energy-water nexus. Observation and simulation data are coupled with a broad range of analytical, modeling, and visualization tools to enable a systematic measurement, assessment, and evaluation capabilities. This new system requires broadly diverse data and tools focused on a robust representation of past and present dynamics of the energy-water systems also capable of making rigorous projections of possible future states. Moreover this system will capture the complex interactions that entail a comprehensive and integrated perspective across the energy-water-infrastructure systems which, in turn, requires a data and information system capable of robust representation and characterization of past, present, and future energy systems infrastructure. Finally, an increasing integration of our energy, water, transportation, communication, and cyber

networks compels an integrated view that allows evaluation and assessment of the energy system resiliency.

Urban Systems: Impacts of Urban Morphology on Microclimate and Building Energy Use

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BER Program: Multisector Dynamics
Project: This is an LDRD project related to Energy-Water Dynamics
Project Website: http://evenstar.ornl.gov/autobem/chicago

Global and regional climate are primary drivers of heating and cooling demand for buildings. The United States, which is the second largest energy consumer in the world (19%), accounted for 85% of total greenhouse gas (GHG) emissions in 2014 (EIA, 2014), with buildings (through electricity consumption) responsible for about 45%. Residential buildings such as single-family homes, apartments, manufactured housing, and others account for slightly more than one-half of buildings-related emissions, and commercial buildings (offices, businesses, hospitals, hotels, and others) are responsible for the remainder (EIA 2014). Urban microclimate--determined by local meteorology, solar irradiation and reflection, and surface temperatures of buildings and ground--can strongly affect building energy demand. Buildings within an urban setting must generally respond to higher ambient temperatures due to radiation exchange between neighboring buildings, convective heat transfer due to wind patterns within a configuration, thermal mass of city infrastructure, and other Urban Heat Island effects (Dorer et al., 2013). This situation can offset heating demand during colder months, but may lead to higher demand for cooling in the summer (Hadley et al., 2006).

In anticipation of emerging global urbanization, better understanding and quantification of climate effects on energy use in cities are needed, requiring coordinated research of microclimate impacts on and from the city structure. Integrating multiple modeling approaches at different scales, we present a new method for evaluating energy use projections and savings for different city morphologies and projected urban expansion. We assimilate high-resolution (10-meter) urban terrain into a regional weather model for determining building-by-building meteorology, and into an extremely fast building generation model to produce an entire neighborhood's or city's buildings for energy use analysis with the DOE Energy Plus model. Results of this work suggest that new additions to cities can change the microclimate within an existing city and, as a result, the magnitude of the whole city's energy use. They also demonstrate a first step toward calculating city energy use at neighborhood resolution, and the potential for including its effects within an earth system science workflow (New et al., 2018).

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New, Joshua Ryan, Mahabir S. Bhandari, Som S. Shrestha, and Melissa R. Allen. *Creating a Virtual Utility District: Assessing Quality and Building Energy Impacts of Microclimate Simulations*. Oak Ridge National Lab.(ORNL), Oak Ridge, TN (United States), 2018.

Title: **Land-Atmosphere Coupling in an Ensemble of Regional Climate Simulations**

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BER Program: RGCM

Project: A Hierarchical Evaluation Framework for Assessing Climate Simulations Relevant to the Energy-Water-Land Nexus (Cooperative Agreement)

Project Website: https://facets.agron.iastate.edu/display/ds/FACETS+Homepage

Project Abstract:

Modeling and observational studies suggest that coupling of the atmosphere with land surface properties such as soil moisture and temperature can have important implications for local weather and regional climate. We have examined land-atmosphere coupling over the continental United States in an ensemble of regional climate simulations developed in conjunction with the NA-CORDEX and DOE FACETS (Framework for Assessing Climate Simulations Relevant to the Energy-Water-Land Nexus) projects. This ensemble of regional climate simulations includes two different regional climate models (RCMs; WRF and RegCM4), driven with lateral-boundary conditions from three different GCMs. Downscaling experiments with each combination of RCM and GCM were performed at three different resolutions (12 km, 25 km, and 50 km) and run for historical and future climate time periods. The 12km simulations were performed specifically for the DOE FACETS project. Past studies of land-atmosphere coupling have used both models and observations, but to our knowledge this is the first comparative evaluation using a systematic ensemble of regional climate models. This suite of RCM simulations allows us to explore the relative importance of driving GCM, RCM, and resolution on the strength of land-atmosphere coupling over the United States. Multiple land-atmosphere coupling diagnostic metrics are used to assess regional and seasonal variations in land-atmosphere coupling within this RCM ensemble. Initial results show that there are systematic differences in land-atmosphere coupling strength between the RCMs examined in the study. We also find less pronounced differences corresponding with variations in the horizontal grid spacing and choice of model used to drive the RCMs. Comparison of current and end-century projections suggest that land-atmosphere coupling will be reduced in the southeastern U.S. but stronger coupling in the western and central U.S. will persist later into the fall. Differences in land-atmosphere coupling strength between the simulations provide insight into sources of model bias and drivers of future changes in precipitation and temperature.

Title: Comparing Dynamically Downscaled Regional Climate Models Using a Low-Level Jet Metric

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BER Program: RGCM

Project: A Hierarchical Evaluation Framework for Assessing Climate Simulations Relevant to the Energy-Water-Land Nexus (Cooperative Agreement)

Project Website: https://facets.agron.iastate.edu/display/ds/FACETS+Homepage

Project Abstract:

Understanding model biases regarding the low-level jet (LLJ) is crucial to realizing areas of uncertainty in future climate scenarios, due to the role of the LLJ in the initiation and sustenance of mesoscale connective systems in the Great Plains of the United States. As part of the FACETS project sponsored by the US DOE RGCM program we have established a low-level jet metric which categorizes low-level wind maxima based on the maximum wind speed and low-level shear, consistent with previous work by Bonner (1968). This metric is applied to a matrix of dynamically downscaled regional climate models (RegCM4 and WRF-ARW) with varying horizontal grid resolutions (50km, 25km, and 12km) driven by three global climate models (GFDL-ESM2M, HadGEM2-ES, MPI-ESM-LR) and one reanalysis dataset (ERA-Interim), in conjunction with the CORDEX-North America and DOE FACETS projects. The LLJ metric is used to evaluate the performance of each combination of regional climate model, driving global climate model, and grid resolution and to diagnose model inconsistencies. Preliminary results suggest that increasing the horizontal grid resolution increases the peak frequency of the LLJ. In addition, discrepancies between the global climate model driven simulations are evident, specifically in the northward extent of the highest LLJ frequencies.

Title: **Robustness of Projected Trends in Warm Season Precipitation Extremes over the Central United States**

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BER Program: RGCM

Project: A Hierarchical Evaluation Framework for Assessing Climate Simulations Relevant to the Energy-Water-Land Nexus (Cooperative Agreement)

Project Website: https://facets.agron.iastate.edu/display/ds/FACETS+Homepage

Project Abstract:

During the late 20th and early 21st centuries the frequency of extreme precipitation increased markedly over the central United States despite only modest changes in mean annual precipitation. Although climate projections indicate that extreme precipitation will increase further in coming decades, the robustness of this result to the model used and to changes in model resolution has not been fully explored. In support of the DOE-sponsored FACETS project we use a systematic matrix of dynamically downscaled climate projections in a three-dimensional parameter space (regional climate model, global climate model, and resolution) to evaluate the robustness of projected increases in extreme precipitation over the central U.S., informed by model performance for the current climate. The matrix includes two regional climate models (WRF-ARW and RegCM4), each driven by three global models (HadGEM2-ES, MPI-ESM-LR, and GFDL-ESM2M), with each combination of regional and global model run using three grid spacings (50 km, 25 km, and 12 km). Results show complex interactions among the regional model, global model, and resolution. As an example, RegCM4 is more sensitive to the choice of global model than is WRF-ARW, and this sensitivity in turn varies with resolution. We also found some unexpected results such as a tendency for the frequency of heavy precipitation to decrease with finer grid spacing in RegCM4. Nevertheless, the trend in precipitation extremes is robust: warm-season extreme precipitation over the central U.S. becomes more common in future climates for every model configuration tested.

Validation of Ice Sheet--Ocean Interactions in Simulations from E3SM's Cryosphere Science Campaign

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BER Program: ESM
Project: SFA

The Energy Exascale Earth System Model (E3SM) is an ideal tool for studying the relationship between smaller-scale regional phenomena and the global climate. E3SM also includes the ability to simulate ocean circulation in ice shelf cavities, and dynamic ice sheet–ocean interactions are under development. These new capabilities are critical for projecting Antarctica's potential future contributions to global sea level, one of three main scientific foci of the E3SM project. Here, we compare global E3SM simulations with and without ice-shelf cavities under various conditions. By comparing simulations with prescribed atmospheric and land forcing at two mesh resolutions, nominally 30 and 10 km near Antarctica, we show that simulations with ice-shelf cavities produce melt rates broadly consistent with observations, and that melt biases are reduced at higher horizontal model resolution. We show the effects of resolution and of including melt fluxes under ice shelves on the vertical distribution of temperature and salinity in the region around Antarctica, as well as their impacts on the broader climate. We also explore the influence of ice-shelf cavities in a pre-industrial control simulation with fully coupled atmosphere, land, sea-ice and ocean components.

High Mountains of Asia: Moisture sources and Contribution to Summer Monsoon

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BER Program: RGMA
Project: WACCEM
Project Website: N/A

Abstract:

High Mountains of Asia (HMA), include mountain ranges of Himalayas, Karakoram, Hindukush in South Asia, and Pamir and Tian Shan in Central Asia, are home to the largest glaciers outside polar regions, which provide sustainable water source for river flows as they buffer extreme weather conditions in year to year precipitation variability. With the exception of central and eastern Himalayas, most of the precipitation over HMA is received during cold season. While this source of freshwater is now considered threatened due to persistent rise in the global mean temperatures, it is relatively unknown that how moisture is sourced over these mountains during the cold season precipitation and that how much of this precipitation and/or glacier melt becomes a moisture source during the summer season over South Asia. In this context, we use an ensemble of global reanalysis (MERRA2, ERA-Interim, JRA25, CFSR) and a Lagrangian based moisture tracking algorithm to identify major sources of moisture during the cold season and the moisture contribution from HMA to the summer monsoon precipitation over South Asia. Our results identify Mediterranean Sea, Mediterranean land, North Atlantic and local recycling as the major contributors towards cold season precipitation while contribution from South Atlantic and Arabian Sea becomes prominent during positive phases of ENSO and Siberian High respectively. A disagreement exists between MERRA2 and other reanalysis datasets regarding prevailing trends in moisture contribution from various sources, which highlights the challenges related with data quality over this region. We also note that HMA is among top three moisture contributors for summer monsoon over South Asian region north of 20˚N. This significant moisture contribution from HMA during summer season has not been identified in earlier studies. Overall, these findings have strong implications for understanding the impacts of climate change on freshwater sources in Asian countries. Moreover, new understanding towards the moisture sources over Asia should help in the development of validation metrics for the next generation of GCMs.

Title: Containerized E3SM Workflows

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BER Program: ESM

Project: E3SM

Project Website: https://e3sm.org

Project Abstract:

With recent developments in operating systems, containers allow a process and all of its dependencies to be isolated. Containers are a file archive format that allow for packaging the entire application environment above the level of the Linux kernel. This makes running software across many diverse environments more straightforward, reducing the need for installing many different dependencies for various software to work together in harmony. The goal of this work is to introduce container technology into E3SM workflows starting with diagnostics and analysis.

There are various container runtime environments such as Docker, Shifter, Singularity, and udocker, all present on different machines and which provide some degree of interoperability. We present an overview of containers technology, detailing advantages of containerizing software. The process of containerizing a software package, e3ms_diags, across these diverse container runtime environments is also covered.

Title: Hurricane Rapid Intensification: 30-Year Trends and Significance of Ocean Salinity for its Prediction

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BER Program: RGCM

Project: Water Cycle and Climate Extremes Modeling (WACCEM) SFA

Project Website: https://climatemodeling.science.energy.gov/projects/water-cycle-and-climate-extremes-modeling

Project Abstract: Rapid intensification (RI) of hurricanes is extremely difficult to predict and can contribute to severe destruction and loss of life. RI played a prominent role during the recently concluded hyperactive 2017 Atlantic hurricane season, which was the costliest on record for the United States. While past studies examined the frequency of RI occurrence, changes in RI magnitude were not considered. Here we explore changes in RI magnitude over the 30-year satellite period of 1986–2015. In the central and eastern tropical Atlantic, which includes much of the main development region, the 95th percentile of 24-hr intensity changes increased at 3.8 knots per decade. In the western tropical Atlantic, encompassing the Caribbean Sea and the Gulf of Mexico, trends are insignificant. Our analysis reveals that warming of the upper ocean coinciding with the positive phase of Atlantic Multidecadal Oscillation, and associated changes in the large-scale environment, has predominantly favored RI magnitude increases in the central and eastern tropical Atlantic. These results have substantial implications for the eastern Caribbean Islands, some of which were devastated during the 2017 hurricane season.

The RI index of NHC combines largescale environmental parameters using a linear discriminant analysis to predict the probability of RI occurrence. When it comes to the ocean, the metrics used in the RI index are the sea surface temperature (SST) and the tropical cyclone heat potential (TCHP). However, neither of these parameters accurately represent the effects of upper-ocean stratification on hurricane intensification. This is especially true in the Amazon-Orinoco plume region where the ocean's density is dominated by salinity effects. We propose the use of an ocean dynamic temperature (T_{dy}) that incorporates the effects of upper-ocean stratification, including salinity, on hurricane intensification. Using data for the 15-year Argo period 2003-2017 in the Amazon-Orinoco plume region, we show that only T_{dy} shows a statistically significant difference for situations with RI when compared to situations without. Furthermore, using a logistic regression model, we show that using T_{dy}, in addition to SST and TCHP, may significantly improve RI forecasts. Finally, we show that similar results may be obtained in other regions of the global oceans where near-surface salinity effects are strong.

Title: Climate impacts from wind turbine arrays: Dependence on installed capacity and wind farm parameterization

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BER Program: RGCM

Project: FACETS: A Hierarchical Evaluation Framework for Assessing Climate Simulations Relevant to the Energy-Water-Land Nexus (Cooperative Agreement)

Project Website:
http://www.geo.cornell.edu/eas/PeoplePlaces/Faculty/spryor/DoE_FACETS/index.html and https://facets.agron.iastate.edu/display/ds/FACETS+Homepage

Project Abstract: Wind turbines work by extracting kinetic energy from the air and converting it into electrical power. Thus, some disturbance of the flow field and potentially near-surface climate downstream of wind farms is inevitable. However, questions remain about the magnitude of this effect and the sensitivity of modelled effects to the assumptions inherent in the way in which the wind turbine aerodynamics are described (i.e. the wind farm parameterization). We have conducted high resolution simulations of interactions between wind turbines (WTs) and the atmosphere using the Weather Research and Forecasting (WRF) model for two domains; one focused on the US state with highest WT deployments (Iowa) and the second covering the entire eastern USA. A key innovation of our research is that we use actual geolocations for all (nearly 20,000) wind turbine and actual turbine specifications (e.g. power and thrust curves for each individual WT). Simulations over the Iowa domain are used to assess the sensitivity of the climate impacts to the wind farm parameterizations. Simulations over the entire eastern USA use a single wind farm parameterization and are designed to examine whether climate effects scale with deployed capacity. We first simulate (at 4 km) the climate of each domain in the absence of WT, then with the current WT deployments (using two wind farm parameterizations) and then for the eastern domain increase WT deployments in two steps upto the amount necessary to achieve the goal of 20% electricity from wind. Scenarios employed herein to increase installed WT capacity focus on replacing older WT with higher name-plate power production WT (via 'repowering') in order to avoid land-use conflicts.

Our multi-year simulations indicate that for both WT parameterizations impacts on temperature, specific humidity, precipitation, sensible and latent heat fluxes from current wind turbine deployments are of very small magnitude and are highly localized. Further, use of the relatively recently developed new wind farm parameterization results in faster recovery of full array wakes than the more commonly parameterization and thus weaker climate effects. Even quadrupling WT installed capacity results in only minor downstream climate impacts beyond the grid cells in which WT are located, and a modest decrease in the overall efficiency of electrical power production. Our research thus implies that further expansion of wind turbine deployments can likely be realized without causing substantial downstream impacts on weather and/or climate or sizeable decreases

in system efficiency.

Publications:

Pryor S.C., Barthelmie R.J. and Shepherd T.J. (2018): The influence of real-world wind turbine deployments on local to mesoscale climate. *Journal of Geophysical Research: Atmospheres* **123** 5804-5826 doi: 10.1029/2017JD028114.

Pryor S.C., Barthelmie R.J., Hahmann A., Shepherd T.J., Volker P. (2018): Downstream effects from contemporary wind turbine deployments. *Journal of Physics: Conference Series* **1037** 072010 doi :10.1088/1742-6596/1037/7/072010.

Title: **Future Response of Tropical Cyclones and Mid-latitude Storms in High and Low Resolution Versions of CAM5-SE**

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BER Program: RGCM

Project: CATALYST, Cooperative Agreement

Project Website: http://www.cgd.ucar.edu/projects/catalyst/

Project Abstract: In this study, high and low resolution ensembles of present day (1979-2012) and future (RCP8.5, 2070-2099) time-slice simulations are examined for insight into tropical cyclones and mid-latitude storms. We employ the SE-dynamic core version of the CESM1.3 model to simulate AMIP-style configurations at 0.25° and 1° resolution. The present day ensemble was forced with observed sea surface temperature (SST), and the future ensembles were forced with bias-corrected SST obtained from previously conducted, fully coupled RCP8.5 future simulations. This bias-corrected, time-slice approach is suitable for investigating climate and weather extremes because it removes the long-term model bias and provides improved statistics over a single, long future scenario simulation. We have found that both tropical cyclones and mid-latitude storms are expected to diminish in number in the future with tropical cyclones becoming stronger. In this study, we explore the mechanisms responsible for this response to future forcing in addition to examining the impact of increased resolution.

Notes on abstract:

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- If you have questions, please contact Bob Vallario (bob.vallario@science.doe.gov; Renu Joseph (renu.joseph@science.doe.gov); or Dorothy Koch (dorothy.koch@science.doe.gov).

Title: **"Do dynamical and statistical downscaling fundamentally disagree on climate change?"**

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BER Program: RGCM

Project: Developing Metrics to Evaluate the Skills and Credibility of Downscaling

Project Website: NA

Project Abstract: Many previous studies have shown that dynamical and statistical downscaling techniques often produce quite different future projections for a given region. Two principal reasons help explain these differences. First, regional climate model (RCM) output for the historical climate can be very different than the historical observations used to train a statistical model. In this case, there is no plausible way for the statistical model to align with the RCM for either historical and future time periods. Second, the statistical model may represent different relationships between coarse and fine scales than dynamical downscaling. Differences of this second type are independent of the training data. Instead they reflect different assumptions in the dynamical versus statistical models themselves. The typical comparison of dynamical versus statistical downscaling is to compare RCM output to a statistical model trained on gridded observations. Therefore, previous comparisons have not been able to differentiate between these two sources of disagreement; it's unclear if dynamical and statistical output differ more because of the training dataset or the statistical model itself.

In this project, we distinguish between these sources by using RCM output as a training dataset to a statistical model. We compare four downscaled products over California's Sierra Nevada to examine differences based on training data and differences based on model relationships. The products are (1) dynamically downscaled results from the Weather Research and Forecast (WRF) model; (2) statistically downscaled results using Localized Constructed Analogues (LOCA) trained on historical WRF output ("LOCA-WRF"); (3) statistically downscaled results using LOCA, this time trained on a station-based gridded observational dataset ("LOCA-Livneh"); and (4) statistically downscaled results using bias correction with spatial disaggregation (BCSD), also trained on the gridded observational dataset ("BCSD-Livneh"). By comparing WRF and LOCA-WRF, we remove the effect of training dataset and isolate disagreements between WRF and LOCA. On the other hand, comparing LOCA-WRF and LOCA-Livneh isolates disagreements due choice of training dataset (WRF versus Livneh). Finally, comparing the LOCA-Livneh and the BCSD-Livneh simulations sheds light on how the choice of statistical model changes downscaled outcomes.

Exploring the use of Kokkos in HOMME to achieve performance on multiple architectures

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BER Program: ESM
Project: CMDV Software Modernization
Project Website: `https://climatemodeling.science.energy.gov/projects/...`
`.../cmdv-sm-global-climate-model-software-modernization-surge`

In the last decade we have seen an increase in the variety of HPC architectures, some of which featured very peculiar characteristics, which set them apart from conventional CPUs (e.g., MICs and GPUs). This diversity reflected into new HPC facilities built all around the world, and softwares like E3SM have faced the big challenge of efficiently using the new HPC facilities, and preparing for ongoing disruptions in computer architectures.
Different solutions have been proposed to tackle this challenge: use of directives, such as OpenACC or OpenMP, use of Domain Specific Languages (DSL), such as Claw or GridTools, and the use of performance portability libraries, such as Kokkos, Raja, or OCCA. The first solution is currently the main option used inside E3SM. It has the advantage of being fast to implement, with a minor disruption of the original code. On the other hand, DSLs and performance portability libraries require more refactoring effort, but have the advantage of hiding most of the performance technicalities, delegating to a third party the duty of interfacing with current (and future) architectures. Ideally, if a new (and substantially different) architecture arises in the future, the directive approach requires another refactoring effort (with possibly a lot of code duplication), while the other two approaches would not require (significant) changes in the code.
Here we present an effort aimed at exploring the feasibility of using the Kokkos library to achieve performance portability across a variety of architectures. Our effort focused on a limited part of E3SM, namely the hydrostatic model in HOMME. We compare the performance of the refactored code against the original one (which was highly optimized on conventional CPUs and MICs), and study performance across a variety of architectures, including conventional CPU, Power, ARM, MIC, and GPU.

Harmonizing Structurally Different Models to Develop Consistent Scenarios of Future U.S. Electric Power Capacity Expansion

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BER Program: Multi-sector Dynamics (MSD)

Project: Integrated Multi-sector Multi-scale Modeling (IM^3), Pacific Northwest National Lab

Project Website: https://im3.pnnl.gov/

A wide range of energy-economic models have been used to produce long-term scenarios of the energy system. These models differ in many ways, including model structures; spatial, temporal, and process resolutions; and assumptions. Previous studies have explored a range of future scenarios for the U.S. power sector with large ensembles of capacity expansion models that vary across these dimensions (Cole et al., 2017; Fawcett et al., 2009; Fawcett et al., 2014; Iyer et al., 2017; Murray et al., 2018). However, the models in these intercomparison studies sometimes produce inconsistent quantitative outcomes and contradictory insights, partly because of aforementioned model differences. While inconsistencies in model outcomes are useful to characterize uncertainties, an increasing number of multi-model integration activities and the associated decision-making require consistent scenarios of the future.

We explore this issue by using two state-of-the-art power sector models with starkly different representations of the power sector (GCAM-USA, a multi-sector human-Earth system model, and ReEDS, an electric sector only model). We harmonize assumptions around the representations of key drivers of electricity capacity expansion in the two models under a reference scenario as well as a range of alternative future scenarios which vary in technological innovation, fossil fuel resource availability, and socioeconomic conditions. We then examine the sensitivity of the consistency between the solutions of the two models to changes in assumptions surrounding the drivers. Our initial results suggest that solution consistency is most sensitive to assumptions about fuel prices and renewable resource characteristics. Additionally, despite best efforts, irreconcilable structural differences in the representations of key drivers (e.g., electricity trade) lead to variations in the degree of solution consistency across space, time, and technology.

Our work facilitates a systematic exploration of potential options for, and obstacles to, harmonizing structurally different models in order to simultaneously take advantage of the relative strengths of each model in the context of common scenarios.

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Development and verification of a numerical library for solving global terrestrial biophysical multi-physics problems: Application in ELM for the soil-plant hydrological continuum

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Land Surface Models (LSMs) are multi-physics simulators that compute exchanges of water, momentum, energy, and nutrients at the Earth's surface. Current generation LSMs routinely omit several critical biophysical processes such as lateral transport of water, energy, and nutrients in the subsurface; transport of water through the soil-plant continuum; and advective transport of energy in soil. The numerical techniques used in current generation LSMs to obtain solution of the combined linear and nonlinear system of equations are often outdated and inaccurate. The global terrestrial model community actively participates in model intercomparison projects for model validation (i.e., evaluating how well model simulations compare with observations), but mostly ignores model verification (i.e., the correctness of the numerical implement of the model). The goals of this study are to (1) develop a numerically robust standalone library for solving global terrestrial biophysical process with support for flexible coupling strategies; and (2) verify the multi-physics library for various problems, including coupled soil and plant hydraulics.

To achieve the objectives of our study, we developed a sequential, open source Multi-Physics Problem (MPP) library for solving global terrestrial biophysical processes, and have integrated MPP with ELMv1. The MPP library has a flexible framework for coupling multiple physics processes (e.g., conservation of mass, conservation of energy, etc.) in multiple physical domains (e.g. soil, root, xylem, etc.). The underlying numerical engine of the MPP library is PETSc, whose DMComposite subclass provides an interface for individual modules to assemble parts of a global matrix for solving a tightly coupled multi-component/process problem. We use the Method of Manufactured Solutions (MMS) to verify the MPP library for a range of problems comprising of single and multiple components/processes in one or multiple physical domains. We conclude by advocating for implementation of MMS approaches to verify all components of the next generation of ELM.

2018 Modeling Principal Investigator's (PI) Meeting
November 5 – 9, 2018

Title: Development of a Terrestrial Dynamical Core for E3SM

Authors:
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Abstract

Predictive understanding of the terrestrial water cycle at local to global scale is essential for accurate assessment of water resources, agricultural production, and energy generation given the current climate variability. Increase in the spatial resolution of the land and river components of the Energy Exascale Earth System Model (E3SM) alone is insufficient to meet the U.S. Department of Energy's (DOE's) 10-year vision of achieving a sub-kilometer resolution in terrestrial components. The next generation hyperresolution E3SM Land Model (ELM) needs to include scale appropriate two- and three-dimensional physics formulations. ELM's subsurface thermal hydrology (TH) model currently uses a two-point flux approximation for spatial discretization that is only accurate for orthogonal grids. Furthermore, the time integration scheme of ELM's TH model is hard-coded to be a Crank-Nicolson scheme.

The Phase-1 of this project is aimed at developing a rigorously verified, spatially adaptive, scalable, multi-physics dynamical core (dycore) for global-scale modeling of three-dimensional subsurface hydrologic and thermal processes in ELM. The dynamical core will use the Portable, Extensible Toolkit for Scientific Computation (PETSc) library to parallelize and numerically solve the governing equations. In this presentation, we will report progress on the development of prototype codes that use higher-order spatial discretizations to accommodate non-orthogonal grids with improved accuracy. Concurrently, we are exploring the use higher-order time integration schemes available in PETSc and will report on the trade-offs between higher- and lower-order time integration methods for solving variably saturated subsurface flow. Finally, we will present multiple verification benchmark problems that will be used to build confidence in the high-fidelity, high-resolution dycore.

Potential Climate Effects on Agriculture

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BER Program: EESM

Agriculture will need to undergo major transformations (structural, value-chain and technology transformations) in the coming decade as demands grow and climate changes. While the pace and direction of these changes are uncertain, they will be essential, especially for the successful development of lower-income countries. To estimate the potential impact of climate change on agriculture, we simulate crop yield and livestock productivity impacts on agricultural production, the economy (measured as welfare change), and emissions from land-use change using the Economic Projection and Policy Analysis (EPPA) model, an economy-wide model which includes agricultural projections. The resolution of our standard model includes crops, livestock and output of the food sector. While we do not model all agricultural transformations explicitly, we impose continued productivity improvements for land (i.e. yield increases) and increasing productivity of labor, capital and energy. We deduce a set of comprehensive productivity effects of climate change (affecting all crops and all livestock) intended as an interpretation of central estimates for possible 2050 impacts that appear in the literature reviewed by the IPCC. An alternative strategy consists of using output from statistical emulators of gridded crop models. A novel aspect of this approach is that cropland (or other land types) can be created from other land uses, which is one adaptive response to yield declines. It also simulates substitution of other inputs to make up for yield losses and regional shifts in production and agricultural trade.

Statistical emulators of crop yields from global gridded crop models

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BER Program: EESM

This project provides statistical emulators of crop yields based on global gridded crop model simulations from the Inter-Sectoral Impact Model Intercomparison Project Fast Track project. The ensemble of simulations is used to build a panel of annual crop yields from five crop models and corresponding monthly summer weather variables for over a century at the grid cell level globally. This dataset is then used to estimate, for each crop and gridded crop model, the statistical relationship between yields, temperature, precipitation and carbon dioxide. This study considers a new functional form to better capture the non-linear response of yields to weather, especially for extreme temperature and precipitation events, and now accounts for the effect of soil type. In- and out-of-sample validations show that the statistical emulators are able to replicate spatial patterns of yields crop levels and changes overtime projected by crop models reasonably well, although the accuracy of the emulators varies by model and by region. This method therefore provides a reliable and accessible alternative to global gridded crop yield models. The computational efficiency of the statistical emulators make them specifically suited to integrated assessment model (IAM) frameworks. Within IAMs, emulators can help account for feedback loops from the agricultural sector and can help account for modeling uncertainty to ultimately provide a better representation of the agricultural sector

Title: **Modernization of the E3SM Single-Column Model**

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BER Program: ESM

Project: CMDV-SM

Project Website: https://climatemodeling.science.energy.gov/projects/cmdv-sm-global-climate-model-software-modernization-surge

Project Abstract:

This presentation will discuss the modernization of the E3SM single-column model, which had received little upkeep since it was developed as part of the Community Atmosphere Model more than a decade ago. We will discuss the changes to the SCM we found necessary for producing scientifically credible results. We will also introduce our audience to the online library of run scripts, input data, and validation data we made available for a variety of case studies. This data includes several new multi-year SCM case studies from ARM sites. Finally, we will discuss the major modernization task of the SCM, which involves allowing the SCM to be run with the Spectral Element dynamical core instead of requiring SCM simulations to use the outdated Eulerian dycore. This development will finally make it feasible to “replay” a column of an E3SM run. This capability is extremely useful for debugging GCM crashes, but would also be useful for investigating stubborn biases in E3SM (for example, poor marine stratocumulus), and for investigating why SCM sensitivity to perturbations hasn’t always been a good proxy for GCM sensitivity.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 IM Release Number LLNL-ABS-758561.

Title: Forced Changes in Temperature and Precipitation and their Influences on Global Changes in Vegetation Distribution or Aridity

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BER Program: ECM; RGMA

Project: Early Career Research Program (ECRP); Program for Climate Model Diagnosis and Intercomparison (PCMDI), LLNL

Project Website: https://climatemodeling.science.energy.gov/projects/early-career-detection-and-attribution-regional-climate-change-focus-precursors-droughts

Project Abstract:

For the past 20 years, scientists have developed and applied detection and attribution (D&A) techniques that combine rigorous statistical analysis and model interrogation to better understand the contribution of human activity on the climate system. LLNL scientists have contributed to the detection of a discernible human influence on observed changes in both surface temperature and the thermal structure of the atmosphere, and on various aspects of the hydroclimate (e.g. in global-scale rainfall, water vapor, as well as in snowpack and river runoff of the western U.S.).

It is unclear however whether man-made and natural influences can be identified in global changes in vegetation distribution or aridity. One difficulty is that both systems result from combined changes in temperature, precipitation, and related variables (atmospheric evaporative demand, soil moisture availability, etc…), themselves governed by the large number of large-scale mechanisms that can vary through time (e.g., the "wet get wetter" and the "warmer get wetter" mechanisms, the poleward displacements of current zonal-mean wet and dry patterns…). Quantifying how natural and man-made factors have influenced these two systems during the historical period is however crucial to increase our confidence in future projections of precipitation and temperature, and to better inform decisions regarding water supply, food security, infrastructure and policy planning.

In this study, we investigate the influence of time-varying external natural or human forcings (such as changes in the sun's energy output, volcanic dust, sulfate aerosols, or greenhouse gas concentrations) in climate simulations on large-scale changes in temperature, precipitation, and we determine how these large-scale precursors impact the changes in distribution of vegetation and aridity at regional scale. We also explore whether we can identify a human influence in the observed historical changes in vegetation distribution and aridity using the LLNL detection and attribution technique.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

The Monsoon Extremes Project: Understanding Synoptic-Scale Monsoon Vortices

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BER Program: RGMA

Project: University Award

Project Website: https://boos.berkeley.edu/MonsoonExtremes

Monsoons dominate the hydrology of low-latitude land, delivering water to billions of people in Africa, Asia, and the Americas. Yet most monsoon precipitation is produced not by steady ascent in the rising branch of a thermally direct, continental-scale monsoon circulation, but by synoptic-scale (2-12 day) vortices and waves superimposed on that time-mean monsoon flow. The Monsoon Extremes project aims to improve understanding of these synoptic-scale disturbances, the precipitation extremes they produce, and their interactions with larger-scale monsoon winds. Here we discuss the fundamental mechanisms of synoptic-scale low pressure systems in the South Asian monsoon, showing that the dynamical structure of these systems is inconsistent with prior hypotheses of baroclinic instability, even when modified by precipitating convection. We argue that the amplitude of monsoon lows and depressions is maintained by barotropic growth, which transfers energy from the low-level monsoon westerlies into the kinetic energy of the synoptic-scale storms. We present a statistical model for the climatological mean genesis frequency of monsoon lows and depressions that supports this argument, and we discuss plans for creating more refined statistical models that can help understand and project synoptic-scale variability in multiple monsoon regions on subseasonal, interannual, and longer time scales.

Title: Empirical Strategies for Understanding Interactions among Infrastructural, Socioeconomic, and Natural Systems.

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BER Program:

Project:

Project Abstract: Quantifying interactions among socioeconomic systems and the natural environment we live within has long been a major scientific challenge. A better empirical understanding of dynamic interactions between the natural environment and urban socioeconomic structure and function is especially important for scientific insights into how cities may respond to changing weather patterns and extremes, including climate change; ensure energy and water security for their residents; and to facilitate urban sustainability and resilience, particularly in the context of increasing urbanization and changing urban morphologies. I describe how census data from middle income countries can be used to describe spatial heterogeneity in access to infrastructure within urban environments and across nations. This heterogeneity is consistent with urban scaling theory and provides specific quantitative expectations on changes in urbanized area as city populations grow larger. Additionally, I describe how novel data sources such as twitter and other digital trace records can be used to measure how socioeconomic systems respond to extreme events, using as a case study the online crowd-sourcing system available during Japan's response to the Tohoku earthquake and tsunami in March 2011. These corresponding papers describe two empirical strategies for developing quantitative models of interactions between socioeconomic and physical systems, and can contribute to the development of models and theory that increase our understanding of multisector dynamics under a multitude of stressors and influences.

Title: Empirical Strategies for Understanding Coupled Social and Physical Systems.

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BER Program:

Project:

Project Abstract: Quantifying interactions between social systems and the physical environment we live within has long been a major scientific challenge. A better empirical understanding of dynamic interactions between the physical environment and urban social structure is necessary to support predictions of how cities will respond to climate change, ensure energy and water security for their residents, and to facilitate urban sustainability and resilience, particularly in the context of increasing urbanization and changing urban morphologies. I describe how census data from middle income countries can be used to describe spatial heterogeneity in access to infrastructure within urban environments and across nations. This heterogeneity is consistent with urban scaling theory and provides specific quantitative expectations on changes in urbanized area as city populations grow larger. Additionally, I describe how novel data sources such as twitter and other digital trace records can be used to measure how a social system responds to extreme events, using the online social system during Japan's response to the Tohoku earthquake and tsunami in March 2011 as a case study. These papers describe two empirical strategies for developing quantitative models of interactions between social and physical systems, and can contribute to the development of models and theory which will increase our understanding of multisector dynamics which include human social systems.

Title: **Land cryosphere biases and their impact on atmosphere-surface exchange in E3SMv1**

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BER Program: ESM

Project: University

Project Abstract:

The presence of snow on the land surface fundamentally changes the surface energy exchange and affects the annual cycle of land hydrology. Global climate models and Earth system models like E3SM can simulate snow cover fairly well, but the accurate simulation of snow depth (SD) and snow water equivalent (SWE) remains elusive. Such biases in historical SD and SWE put future projections of snowpack into doubt. We compare SD and SWE simulated by E3SMv1 in the low-resolution AMIP and historical simulations with our 4-km snow product that consistently assimilates all in situ (SNOTEL and COOP) measurements across the contiguous U.S. (CONUS) constrained by the PRISM precipitation and temperature data . Maximum SWE and SD are both underestimated by E3SMv1 across the higher terrain of the Intermountain West but are overestimated across the Upper Midwest and New England. The effect of these snow biases on the simulated atmosphere-surface energy and water exchange will be explored.

The E3SM-simulated snowpack provides the surface mass balance forcing for the Greenland and Antarctic ice sheet models when the ice sheet model is active. We investigate near-surface air temperature (SAT) over the Greenland ice sheet in order to understand how surface-atmosphere interactions and atmosphere model biases can affect snowpack and ice sheet mass balance. We also demonstrate that choice of downscaling method affects the SAT assessment and therefore could similarly affect the modeled ice sheet surface mass balance.

From Descriptive to Explanatory: Using Metrics to Identify Candidate Phenomena for Process-Level Evaluation

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BER Program: RGCM

Project: A Hierarchical Evaluation Framework for Assessing Climate Simulations Relevant to the Energy-Water-Land Nexus (Cooperative Agreement)

Project Website: https://facets.agron.iastate.edu/display/ds/FACETS+Homepage

The Framework for Assessing Climate's Energy-Water-Land nexus by Targeted Simulations (FACETS) is a program funded by the U.S. Department of Energy that aims to develop a hierarchical framework for the evaluation of different climate models and downscaling methodologies and their added value for decision-making related to climate impacts, adaptation, and mitigation. Simulations from the North American branch of the Coordinated Regional Downscaling Experiment (NA-CORDEX) feature prominently in FACETS.

Central to the FACETS program is the concept of a hierarchical cascade of quantitative metrics of increasing complexity. Simple, standard descriptive metrics are used to identify regions of interest for the application of more complex explanatory metrics that indicate where and how the model may be simulating the weather and climate incorrectly. Specific phenomena-based diagnostics are then combined with the descriptive and explanatory metrics to provide a more complete process-level analysis of the simulations. Finally, integrated regional metrics combine all of these metrics in a targeted manner for specific regions.

We demonstrate the evaluation process for this hierarchy of metrics, focusing on the first cascade. We use standard descriptive metrics to evaluate the quality of NA-CORDEX and other regional climate simulations in several study locations of interest across North America. We evaluate the distributions of daily precipitation and daily minimum, maximum, and average surface air temperature and their seasonality for both raw model output and output bias-corrected using quantile mapping via Kernel Density Distribution Mapping (KDDM). We then use these evaluations to identify locations where explanatory metrics can be applied to characterize model errors and guide the choice of process analysis and phenomena-based metrics.

Title: **Capturing Weather-Driven Extremes in Building Energy Demand Using a Process-Oriented Aggregated Building Model**

Casey Burleyson[1*], Ian Kraucunas[1], Todd Taylor[1], Nathalie Voisin[1], and Yulong Xie[1]

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BER Program: Multi-Sector Dynamics

Project: Integrated, Multi-sector, Multi-scale Modeling (IM3) Scientific Focus Area (SFA)

Project Website: https://im3.pnnl.gov/

Project Abstract: A large direct societal cost of climate change could come from the need to build an energy system capable of meeting future peak energy demands that are constantly evolving in response to changes in weather, population, economics, and technology. Understanding and predicting how building energy demand responds to dynamic and at times non-linear changes in these forcing factors is critical to understanding the best combination of technologies required to meet this demand. The technologies will impact human systems such as the distribution and magnitude of water uses, which in turn cascade into impacts on the integrated earth system. We will provide an overview of PNNL's Building ENergy Demand (BEND) model, which bridges scales important to both climate assessment and human systems decision making. BEND is designed to capture weather-dependent hourly building energy demand over a range of spatial and temporal scales using physically-based numerical simulations of ~100,000 representative residential and commercial buildings. The BEND model, once calibrated using known electric loads in one historical weather year, estimates aggregate annual and hourly peak building electric loads in another year with different weather that compare reasonably with those of a purely statistical model. Finally, we will discuss an ongoing experiment to test the sensitivity of aggregate and peak building energy demand in the western U.S. to a set of natural and anthropogenic forcing factors using both the physically-based BEND model and the more statistical Global Change Assessment Model that also includes cross-sectoral and economic impacts. Both models will be forced with standard scenarios of population change and future climate projections from a downscaled earth system model.

Title: **Data Preservation and Dissemination in a Large Collaborative Multi-Sector Dynamics Project**

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BER Program: Multi-Sector Dynamics

Project: Integrated, Multi-sector, Multi-scale Modeling (IM3) Scientific Focus Area (SFA)

Project Website: https://im3.pnnl.gov/

Project Abstract: The Integrated Multi-Sector, Multi-Scale Modeling (IM3) Scientific Focus Area (SFA), which includes collaborators from multiple national laboratories and universities, is developing a flexible and extensible modeling framework that can be used to study the resilience of coupled human and natural systems. One component of the framework is a tool for preserving data generated by the project in a publicly-accessible data repository. We will discuss several roadblocks we overcame in the development of the archive such as serving a geographically- and institutionally-distributed team, determining metadata standards that apply across our diverse models, balancing flexibility and ease of implementation, and collecting metadata throughout the production process as opposed to waiting until the final data product is complete. We will also look forward at new capabilities that could be incorporated in a future Multi-Sector Dynamics (MSD) community data platform that would enhance the overall benefits of the data archive to the end-user. These new capabilities could include building an event-driven messaging system into the architecture of the archive that can reduce the overhead of multi-model coupling exercises by externalizing the communication between two or more models.

Improving Representation of Deforestation Effects on Evapotranspiration in the E3SM Land Model

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BER Program: RGCM

Project: RUBISCO SFA

Project Website: https://www.bgc-feedbacks.org

Evapotranspiration (ET) plays an important role in land-atmosphere coupling of energy, water, and carbon cycles. Following deforestation, ET is typically observed to decrease significantly accompanying the dramatic changes in land surface characteristics, which may affect large-scale atmospheric dynamics. However, the default Energy Exascale Earth System Model (E3SM) Land Model (ELMv1) predicts an increase in ET after deforestation, likely leading to incorrect estimates of the effects of deforestation on land-atmosphere coupling. We used observations from a recent synthesis of 29 pairs of adjacent intact and deforested FLUXNET sites to improve model parameterization regarding stomatal characteristics, photosynthesis activity, and soil water function. We found that the calibrated model accurately represented the FLUXNET observed deforestation effects on ET. More importantly, the search for global optimal parameters converged at values consistent with recent observational syntheses, confirming the reliability of the calibrated physical parameters. On applying this improved model parameterization to the globe, we found the predicted effects of deforestation on ET changed from an increase of 136.5 mm yr^{-1} to a decrease of 266.7 mm yr^{-1} for the tropical rainforest regions during 1960-2010, which experienced the most dramatic deforestation. Future model development to improve ET simulation should focus on stomatal resistance and soil water related parameterizations. Finally, our predicted differences in seasonal ET changes from deforestation are large enough to substantially affect land-atmosphere coupling and should be considered in such studies.

Exponential Time Differencing for the Tracer Equations Appearing in Primitive Equation Ocean Models

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BER Program: ESM
Project: University Award

We consider the tracer equations that are part of the primitive equations used in ocean modeling. These equations describe the transport of tracers, such as temperature, salinity or chemicals, in the ocean. Depending on the number of tracers considered, several equations may be added to and coupled to the dynamics system. In many relevant situations, the time-step requirements of explicit methods caused by the transport and mixing in the vertical direction are more restrictive than the ones for the horizontal. We propose an exponential time differencing (ETD) solver where the vertical transport is treated with a matrix exponential, whereas the horizontal is dealt with in an explicit way. We investigate numerically the accuracy and computational speed-ups that can be obtained over an explicit or a fully exponential method. Results for the complete set of primitive equations are also shown, where a tracer system is coupled to the dynamics. Here, the tracer and dynamics equations are decoupled in each time-step, and a second-order ETD solver is employed for the dynamics system.

Title: High-Resolution Modeling using E3SM
Authors: Peter Caldwell, Luke Van Roekel, Dave Bader, Chris Golaz, Noel Keen, Wuyin Lin, Mat Maltrud, Az Mametjanov, Qi Tang, and Jon Wolfe

Note to conveners: this talk is an update on E3SM progress. As such, it fits best in the E3SM sessions on days 3-5. To the extent that exascale is synonymous with high resolution, this talk also fits in the exascale session as an update on E3SM's current high-res status. We propose it for the exascale session because we feel that it would be useful for people not attending the E3SM sessions to hear about E3SM status.

Abstract: The Energy Exascale Earth System Model (E3SM) project was borne of a desire to create a high-resolution climate model which runs well on DOE's Leadership-Class machines. In this presentation, we will describe some of the characteristics of a multi-decadal simulation comprised of atmosphere and land components using a 25km grid, and ocean and sea ice on a grid that varies from 18km at the equator to 6km near the poles. The latter two components are based on the MPAS (Model for Prediction Across Scales) framework and are represented here for the first time in a fully coupled eddying simulation. The simulation exhibits tropical cyclones with realistic structure and dynamics, ocean eddy energy levels, and current transports. On the other hand, Arctic sea ice appears to be too thin, Arctic winters are too warm, and ocean mixed layers show significant regional biases. We will present preliminary analyses from this run with comparisons to observations and previous simulations.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. It is supported by the Energy Exascale Earth System Model (E3SM) project, funded by the U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research. IM Release LLNL-ABS- 758598.

Title: A Simple Cloud-Resolving E3SM Atmosphere Model

Authors: Peter Caldwell, Luca Bertagna, Peter Bogenschutz, Andrew Bradley, Aaron Donahue, Jim Foucar, Chris Golaz, Oksana Guba, Jorge Guerra, Ben Hillman, Andy Salinger, Andrew Steyer, Mark Taylor, and Paul Ullrich

Note to conveners: This talk is a summary of the “non-hydrostatic NGD” project which is the focus of session E3. Because this effort is also central to E3SM’s exascale plans and I’m unclear whether E3SM updates are desired during days 1-2, I’m submitting it to the exascale session. I leave it to you to decide where you want it.

Abstract: E3SM plans to replace the current atmosphere model with a global cloud-resolving model written in C++. A clean rewrite will allow us to embrace modern software engineering practices and to remove legacy code. To ensure computational performance across the spectrum of next-generation machines, parallelism will be abstracted using Kokkos templating. The initial focus is on computational efficiency; by making the model as simple as possible we can explicitly resolve more scales for a given number of core hours. Explicitly resolving processes (like deep convection) which were previously parameterized is important because it removes important sources of uncertainty from model predictions. However, even at the target grid of ~3km some processes need to be parameterized. We will use the Simplified Higher-Order Closure (SHOC) macrophysics/turbulence scheme, Predicted Particle Properties (P3) microphysics, and Rapid Radiative Transfer for Energetics/Radiative Transfer for GCMs – Parallel (RTE-RRTGP) radiation. In this talk, we will provide an overview of our plans for and progress on developing this new model.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. It is supported by the Energy Exascale Earth System Model (E3SM) project, funded by the U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research. IM Release LLNL-ABS-758567.

Title: **Modeling Land Use and Land Cover Change: Using the Past to Inform the Future**

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BER Program: Multi-Sector Dynamics

Project: Integrated Human Earth System Dynamics (iHESD), PNNL

Project Website:

Project Abstract:

Historic changes in population, income, diet, technology, and crop yield have had a dramatic effect on the land surface. For example, global cropland area grew from ~3 million km^2 in 1700 to ~15 million km^2 in 2000 (Klein Goldewijk et al. 2010). Future land use and land cover change (LULCC) has implications for energy production, water supply and water use, biogeochemistry, and other Earth system dynamics. The GCAM model includes a representation of LULCC (Wise et al. 2014) and its interactions with the energy and water systems. We have isolated the land allocation portion of the GCAM into a separate model. Using this model, we have generated a large (~30,000 member) perturbed parameter ensemble, calculating LULCC in the United States over the historical period (1971-2010). The parameters varied include those dictating substitutability of different land types and those governing how land owners form expectations about the yield and price for crops. We compare each ensemble member to historical observations of land in the United States and calculate the likelihood those parameters are true. Preliminary results suggest that substitution among crops is relatively low compared to substitution of crops for other land types, there are multiple parameter sets that can explain historical LULCC, and historical uncertainty in land use decisions propagates into uncertainty future LULCC. Future directions include (1) testing new explanatory variables (e.g., crop insurance) and decision-making frameworks, (2) updating the parameters in GCAM based on this analysis, and (3) use the offline land model in other multi-sector modeling frameworks (e.g., PCHES).

Klein Goldewijk, K., A. Beusen, G. van Drecht, and M. de Vos, 2010: The HYDE 3.1 spatially explicit database of human-induced global land-use change over the past 12,000 years. *Glob. Ecol. Biogeogr.*, **20**, 73–86, doi:10.1111/j.1466-8238.2010.00587.x. https://doi.org/10.1111/j.1466-8238.2010.00587.x.

Wise, M., K. Calvin, P. Kyle, P. Luckow, and J. Edmonds, 2014: Economic and Physical Modeling of Land Use in Gcam 3.0 and an Application To Agricultural Productivity, Land,

and Terrestrial Carbon. *Clim. Chang. Econ.*, **5**, 1450003, doi:10.1142/S2010007814500031. http://www.worldscientific.com/doi/abs/10.1142/S2010007814500031.

Title: **CAM5 Representation of Mesoscale Convective Systems over the Continental United States during Springtime in a Warming Climate**

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BER Program: CATALYST

Project: Cooperative Agreement

Project Website: www.cgd.ucar.edu/projects/catalyst

Project Abstract: We have previously shown the presence of Mesoscale Convective Systems (MCSs) in the Community Atmospheric Model Version 5 (CAM5) and the Community Earth System Model Version 1 (CESM1), primarily during the Springtime (April-May). These systems are important to represent correctly in models, since they are responsible for more than 60% of the warm season precipitation over the central United States (Carbone and Tuttle 2008). The Great Plains Low-level Jet (LLJ) is known to play an important role in the formation of eastward propagating MCSs, (Tuttle and Davis 2006). Furthermore, Cook et al 2008, found that there is a springtime intensification of Midwest precipitation and the LLJ in greenhouse gas-induced GCM simulations of the 21st Century. Additionally, Feng et al 2016 show that in the observational record, increased total springtime precipitation and increased extreme rainfall in the Central United States is associated with MCSs and an increase in the frequency and intensity of long-lived MCSs. In CAM5 we show that in a future warming climate there is an increase in precipitation over the Central United States, associated with MCSs in springtime. We look at the partitioning in convective versus stratiform precipitation as well as the atmospheric environment, including moisture transports and the low-level jet to determine if the model agrees with the results found in Feng et al 2016 and Cook et al 2008.

Downscaling global land use and land cover projections from GCAM: Calibration and uncertainty analysis

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BER Program:

Project: iHESD and IM3

Project Abstract:

Demeter is a community spatial downscaling model used to disaggregate land use and land cover changes projected by integrated human-Earth system models, like those used to develop scenarios of future land use change, to finer spatial resolutions. While Demeter has been successfully applied regionally and globally, its sensitivity to key parameters and the parameter uncertainties are still lacking. In this paper, we developed a framework to conduct a Monte-Carlo ensemble experiment for Demeter. We used a time series of global land cover records from the European Space Agency Climate Change Initiative to calibrate key parameters in Demeter. Results of the ensemble experiment identified the global optimal parameter values for Demeter and showed that the parameterization of Demeter substantially improved the model's performance in downscaling global land use and land cover change. A model comparison has also been conducted between Demeter and the Land Use Harmonization version 2 dataset (LUHv2) utilized in the Land Use Model Intercomparison Project (LUMIP). Demeter's downscaled products more closely matched with GCAM's projected land area per land class subregionally as compared to the LUHv2 dataset for both GCAM LUMIP scenarios. We found that of the six key parameters, intensification ratio and selection threshold were the most sensitive and need to be carefully tuned, especially for regional applications. Further, the small uncertainty range of parameters after calibration can result in considerably larger uncertainties in the results when propagated through Demeter. This suggests that Demeter users should consider equifinality in parameters to better account for uncertainties in Demeter downscaled land use and land cover change products. Our study provides a key reference for Demeter users in terms of model parameterization to reduce errors in downscaled land use and land cover change products.

Implications of this research ultimately contribute to reducing the uncertainties in Earth system model simulations and projections of future climate.

Diversity of natural variations of the Atlantic Meridional Overturning Circulation in the Community Earth System Model

Wei Cheng[1,2*], John Chiang,[3] Wilbert Weijer,[4] Dongxiao Zhang[1,2], Gokhan Danabasoglu[5], Steve Yeager[5], Who Kim[5], Peter Gent[5], Jiaxu Zhang[4]

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BER Program: RGCM

Project: this work is jointly funded by University Awards (NA16OAR4310169, NA16OAR4310170, NA16OAR4310171) and the HiLAT Science Focus Area

Project Website: hilat.org

Project Abstract:

The Atlantic Meridional Overturning Circulation (AMOC) contributes significantly to the global redistribution of heat and freshwater. As such, its natural variability, trend under imposed forcing change, and nonlinear threshold behavior have been studied extensively using earth system models, since direct measurements of AMOC are too short to address these questions. Yet, the simulated AMOC natural variability shows a rich diversity in terms of its spatial and temporal features, but characterizing this diversity and the underlying causes remain relatively unexplored. In this study, we address this question using existing CESM long control simulation and a unique ensemble of perturbed physics runs, in which physical parameters are systematically altered. We combine maximum covariance analysis (MCA), cross-wavelet and wavelet coherence, and pointwise budgets of temperature and salinity with the goal of revealing the interplay between AMOC, North Atlantic Ocean density, stratification and winter mixed layer depth. Preliminary results from a maximum covariance analysis on AMOC stream function and basin-wide zonal mean temperature and salinity extract leading modes that separately suggest a “forcing” and a “response” mode of AMOC variability. Our next step is to quantify the temporal variability associated with these modes and their phase relationship in space-time using cross-wavelet and wavelet coherence analysis. Our ultimate aim is to understand how the interaction between these modes may lead to amplified oscillatory behavior, or alternatively, periods of reduced AMOC variability.

Intensification of the pre-Meiyu rainband in the late 21st century

John Chiang[1*], Johannes Fischer[1,2], Wenwen Kong[1], Michael Herman[1], and Inez Fung[1]

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BER Program: RGCM

Project: University

Previous studies focus on the changing land-ocean thermal contrast and monsoonal flow in diagnosing the dynamical response of the East Asian summer monsoon to projected 21st century climate forcings. Here, we propose an additional and physically distinct enhancement to the East Asian summer monsoon, whereby increased midlatitude northerlies downstream of the Tibetan Plateau intensify the early summer rainfall over southeastern China and drive a stronger moisture convergence, intensifying the East Asian subtropical rainband. This effect occurs robustly across the CESM large ensemble RCP 8.5 simulations, and only for the pre-Meiyu stage (mid-May through late June). Furthermore, extreme rainfall days occur more frequently: by 2100, the probability of daily rainfall over Southern China exceeding 30mm is approximately the same as the probability of the daily rainfall exceeding 20mm in the early 21st century.

The westerly jet impinging on the Tibetan Plateau is positioned anomalously southward during the pre-Meiyu stage, suggesting that a topographic influence on the westerlies is the root cause of the anomalous downstream northerlies. We attribute the southward-positioned westerlies to increased tropospheric meridional temperature gradient at the latitudes of the Plateau, the latter caused by enhanced tropical upper tropospheric temperatures due to the warmer tropical sea surface temperatures. Simulations isolating the influences of the 'fast' direct CO_2 influence and 'slow' sea surface temperature warming support this interpretation. Our results highlight the potential role of the westerlies in determining the East Asian summer rainfall in the 21st century, resulting from the fortuitous positioning of the Plateau at the edge of the tropics.

Title: Scoring Methods in the International Land Benchmarking (ILAMB) Package

Nathan Collier[1*], Forrest M. Hoffman[1], Gretchen Keppel-Aleks[2], David M. Lawrence[3], Minquan Mu[4], William J. Riley[5], Charles Koven[5], James T. Randerson[4]

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BER Program: RGCM

Project: Reducing Uncertainty in Biogeochemical Interactions through Synthesis and Computation (RUBISCO) Scientific Focus Area (SFA)

Project Website: https://www.bgc-feedbacks.org/

Project Abstract:

The International Land Model Benchmarking (ILAMB) project is a model-data intercomparison and integration project designed to improve the performance of the land component of Earth system models. This effort is disseminated in the form of a python package which is openly developed (https://bitbucket.org/ncollier/ilamb). ILAMB is more than a workflow system that automates the generation of common scalars and plot comparisons to observational data. We aim to provide scientists and model developers with a tool to gain insight into model behavior. Thus, a salient feature of the ILAMB package is our synthesis methodology, which provides users with a high-level understanding of model performance. Within ILAMB, we calculate a non-dimensional score of a model's performance in a given dimension of the physics, chemistry, or biology with respect to an observational dataset. For example, we compare the Fluxnet-MTE Gross Primary Productivity (GPP) product against model output in the corresponding historical period. We compute common statistics such as the bias, root mean squared error, phase shift, and spatial distribution. We take these measures and find relative errors by normalizing the values, and then use the exponential to map this relative error to the unit interval. This allows for the scores to be combined into an overall score representing multiple aspects of model performance. In this presentation we give details of this process as well as a proposal for tuning the exponential mapping to make scores more cross comparable. However, as many models are calibrated using these scalar measures with respect to observational datasets, we also score the relationships among relevant variables in the model. For example, in the case of GPP, we also consider its relationship to precipitation, evapotranspiration, and temperature. We do this by creating a mean response curve and a two-dimensional distribution based on the observational data and model results. The response curves are then scored using a relative measure of the root

mean squared error and the exponential as before. The distributions are scored using the so-called Hellinger distance, a statistical measure for how well one distribution is represented by another, and included in the model's overall score.

Title: **Characterization of tropical rainfall extremes and their dynamical and thermodynamic controls**

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BER Program: RGCM

Project: CASCADE SFA (LBNL)

Project Website: https://cascade.lbl.gov/

Project Abstract:

Most studies documenting changes in extreme precipitation use scaling formulas to approximate the large percentiles of the rainfall distribution from average dynamical and thermodynamical variables, called predictors. Here, we instead assess the performance of these formulas as approximations to the rain rates in individual events. We evaluate the accuracies of the scaling relationships as functions of spatial and temporal scales by analyzing tropical rainfall in a superparameterized model. Relationships using full vertical profiles of the predictors are more accurate than those using their values at specific vertical levels because they better characterize the specific dynamics of each event. Both types of scaling relationships perform well over a range of length scales from 200 to 2000 km and time scales from an hour to a week, and their precision is higher in the case of simulations with superparameterization than with parameterized convection. Finally, we argue that these formulas can be used to reconstruct the tail of the rainfall distribution directly from its predictors. By transitioning to a statistical prediction which does not need any prior information on the precipitations rates (a forward approach), it becomes possible to provide estimates of the intensity, frequency and spatial pattern of extremes at mesoscale to synoptic scales.

At scales below the mesoscale, additional analysis is required to understand the transition from convectively parameterized to convection-permitting simulations. We compare the mesoscales and convective scales simultaneously resolved by the Superparameterized Community Atmosphere Model (SPCAM) to understand how the thermodynamic and dynamics processes governing extreme precipitation change in warmer climates. Extremes defined on these two scales behave as two independent sets of rainfall events, with different dynamics, geometries, and responses to climate change. In particular, dynamic changes in mesoscale extremes appear primarily sensitive to changes in the large-scale mass flux, while the intensity of convective-scale extremes is not. These results motivate the need for better understanding the role of large-

scale forcing on the dynamical processes involved in the formation and intensification of heavy convective rainfall.

Title: **Calibrated and Systematic Characterization, Attribution, and Detection of Extremes (CASCADE)**

William D. Collins[1,2]* (LRM), Travis A. O'Brien[2] (TCM), Christina M. Patricola[2], Mark D. Risser[2], and the CASCADE SFA team

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BER Program: RGCM

Project: CASCADE SFA (LBNL)

Project Website: https://cascade.lbl.gov/

Project Abstract:

The CASCADE SFA is a coordinated research program aimed at improving our understanding of extremes by addressing three major and interrelated scientific questions:

1. How have changes in the physical behavior of the coupled system altered the chances of encountering and the nature of extreme climate events?
2. To what degree are environmental drivers responsible for altering the chances of encountering and the nature of extreme climate events?
3. What are the dominant sources of uncertainty in detecting, characterizing, attributing, and modeling extremes, how do these uncertainties change our answers to the first two questions, and how can we minimize or mitigate these uncertainties?

CASCADE advances the state of the science to address several major scientific challenges:

- *Detection & Designation:* Associating changes in the behavior of extreme events to specific environmental drivers requires a systematic characterization of extreme events in the recent past. Recent advances in simulation capabilities and statistical methodologies allow us to focus on the impacts of a wide range of environmental drivers at regional-to-local scales, to focus on factors impacting the spatial and temporal co-occurrence of extremes, and to simulate how we might expect extremes to change in the future.
- *Extreme Events Processes:* Designating and projecting changes in extremes requires a well-developed understanding of the processes that drive changes in extremes. In particular, for the overall goal of the CASCADE SFA, it is necessary to understand *how have changes in the physical behavior of the coupled system altered the frequencies of occurrence and the characteristics of extreme climate events*. The SFA team focuses specifically on the processes that drive multivariate extremes, the processes that drive changes in the spatio-

temporal characteristics of extremes, and the fidelity with which these processes are represented in climate models.

- *Characterization of Uncertainty in Extremes:* Studies that aim to detect and attribute changes in extreme events have numerous sources of uncertainty, including parametric uncertainty, structural uncertainty, and even methodological uncertainty. The SFA team focuses on performing modeling experiments and analyses designed specifically to characterize, and if possible quantify, the importance of structural uncertainty, parametric uncertainty, and methodological uncertainty on our understanding of various classes of events.
- *Statistical and Computational Challenges in Understanding Extremes:* The CASCADE SFA focuses on methodological development for systematic event causation at fine spatial scales, development of a statistical framework for the holistic uncertainty characterization work, and development of the Toolkit for Extreme Climate Analysis (TECA).

Title: **The C-POL Radar Dataset: A Dataset For Testing The Representation of Precipitation**

Scott Collis[1],Robert Jackson[1],Alain Protat[2],Valentin Louf[3], Rob Warren[3]

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BER Program: ESM, CMDV

Project: CMDV-RRM through ANL FWP.

Project Website: https://climatemodeling.science.energy.gov/projects/cmdv-rrm

Project Abstract:

The C-POL dual polarimetric radar has run from 1998 to 2017 near Darwin, Australia in a consistent operational mode. Through a large and open source effort this has enabled a highly quality controlled dataset depicting the temporal and spatial evolution of precipitation to be developed. The presentation details the properties of this 24TB data set which is being made available to the climate modeling community and is ideally suited to metricing the performance of precipitation process. The spatial coverage is a circle of radius 150km giving an area representative to several GCM grid cells. With a temporal resolution of 10 minutes and given the multi-decadal coverage this data set can be used to provide statistical insight into regime dependent performance of E3SM. Our aim in presenting this poster is to actively solicit collaborators in building data driven performance metrics of E3SM.

Title: **The impact of the representation of Antarctic freshwater fluxes on the Southern Ocean in the Energy Exascale Earth System Model (E3SM)**

Darin Comeau[1]*, Matthew J. Hoffman[1], Xylar S. Asay-Davis[1], Mark R. Petersen[1], Stephen F. Price[1], Adrian K. Turner[1], Luke P. Van Roekel[1], Jonathan D. Wolfe[1]
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BER Program: ESM

Project: E3SM

Project Website: www.e3sm.org

Project Abstract: In many ocean/sea ice model configurations, freshwater forcing from Antarctica is typically crudely represented as being prescribed near the coast at the surface, constant in space and time. In reality, this freshwater forcing is driven by two processes, ice shelf basal melting and iceberg calving, which interact with the ocean in ways very different from this simplified approximation. Basal melting has considerable variability between ice shelves and deposits meltwater at depth, and calved icebergs can transport freshwater far from the coast into the Southern Ocean. Simplified model approximations that deposit excessive cool freshwater around the Antarctic coast can lead to increased sea ice growth that blocks polynya formation and suppressing ocean overturning. We have performed global experiments with ocean/sea-ice configurations of the new Department of Energy's Energy Exascale Earth System Model (E3SM) that include ocean circulation beneath Antarctic ice shelf cavities, which allows us to directly model ice shelf basal melt rates. In addition, we use prescribe freshwater forcing due to iceberg calving using steady state iceberg climatology model data. We evaluate the impact of Antarctic freshwater forcing in E3SM's global ocean/sea-ice simulations with various combinations of simplified coastal runoff, modeled ice shelf basal melting, and iceberg freshwater flux data. Prescribed freshwater flux that is too large in magnitude or incorrectly partitioned between subshelf and open ocean locations can lead to unrealistically high modeled subshelf melt rates due to overly vigorous activation of the ice shelf cavity melt pump. Careful treatment of solid and liquid freshwater fluxes around Antarctica is critical for producing realistic Southern Ocean circulation, temperature, and salinity and associated subshelf melt rates in models.

Title: **Predicting regional and pan-Arctic sea ice anomalies with kernel analog forecasting**

Darin Comeau[1]*, Dimitrios Giannakis[2], Zhizhen Zhao[3], Andrew J. Majda[2]
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BER Program: RGCM

Project: HiLAT

Project Website: www.hilat.org

Project Abstract: Predicting Arctic sea ice extent is a notoriously difficult forecasting problem, even for lead times as short as one month. Motivated by Arctic intraannual variability phenomena such as reemergence of sea surface temperature and sea ice anomalies, we use a prediction approach for sea ice anomalies based on analog forecasting. Traditional analog forecasting relies on identifying a single analog in a historical record, usually by minimizing Euclidean distance, and forming a forecast from the analog's historical trajectory. Here an ensemble of analogs is used to make forecasts, where the ensemble weights are determined by a dynamics-adapted similarity kernel, which takes into account the nonlinear geometry on the underlying data manifold. We apply this method for forecasting pan-Arctic and regional sea ice area and volume anomalies from multi-century climate model data, and in many cases find improvement over the benchmark damped persistence forecast. Examples of success include the 3--6 month lead time prediction of Arctic sea ice area, the winter sea ice area prediction of some marginal ice zone seas, and the 3--12 month lead time prediction of sea ice volume anomalies in many central Arctic basins. We discuss possible connections between KAF success and sea ice reemergence, and find KAF to be successful in regions and seasons exhibiting high interannual variability.

Toward an Exascale Land Surface Model: Conceptualization and Infrastructure

Ethan Coon, Scott Painter, and Dali Wang
Oak Ridge National Laboratory

Historically the land surface model was developed as a method for determining fluxes of carbon and water vapor to the atmosphere; the result was a column-based model, which is limited in scope but needs few computational resources. Current generation land surface models are much more than this, providing predictions of ecosystem function, inputs for engineered systems including water, energy, and nutrient transport, and connections to land use/land change models. Despite the increased scope, LSMs have largely kept the same simplified column-based structure, albeit with subgrid models that are not spatially located. As these new capabilities grow and spatial resolution increases, there reaches a point when the column and aspatial subgrid conceptualization becomes untenable. In particular, lateral flows of water and associated transport of chemical components become important as resolution increases, eventually making it necessary to spatially locate subgrid processes [Bierkens *et al.*, 2015].

New changes of E3SM's Land Model are moving to watershed-based grid cells, providing a new organizational unit and a natural framework to enable spatially located, three-dimensional structure. But such a model would greatly increase the computational demands of ELM and necessitate a code that can run on hybrid architectures. It would fundamentally break the current "round-robin" scheduling of land surface columns, requiring a new load-balancing strategy. And it would require new approaches for introducing high-resolution data such as digital elevation maps.

We explore potential conceptualizations of a watershed-based, three-dimensional ELM. Each ELM grid cell is associated with a three-dimensional, spatially explicit mesh on which processes are solved on a single computer hardware node. Task parallel strategies are used to schedule individual watersheds, eliminating the load balancing issue. And a dependency graph is formed to enable flexible configuration of a growing collection of process components. Some of the infrastructure implications of such a conceptualization are being explored as part of the CANGA SciDAC. Specifically, we demonstrate automatic extraction of existing ELM subroutines from the current code base and then wrap those as functional kernels for the purpose of executing on GPUs and potentially other architectures. We consider the performance and software organizational implications of this prototype, and what such a land model means for coupling to the broader Earth System Model.

Bierkens, M. F. P., et al. (2015), Hyper-resolution global hydrological modelling: what is next?, Hydrological Processes, 29(2), 310-320, doi: 10.1002/hyp.10391.

Title: **Understanding the spatial organization of precipitation extremes**

Naresh Devineni,[1, 2, 3*], Ariel Mazor,[1, 2], Nasser Najibi [1, 2, 3]

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BER Program: Early CAREER, RGCM

Project: University/Early CAREER

Project Website: http://url.SpecificToProject.gov NA

Project Abstract:

We introduce the idea of simultaneous heavy precipitation events (SHPEs) to understand whether extreme precipitation has a spatial organization that is manifest as specified tracks or contiguous fields with inherent scaling relationships. For this purpose, we created a database of SHPEs from 1242 Global Historical Climatology Network rainfall stations across the contiguous United States. The SHPEs are investigated for spatial orientation, areal extents and recurrence. Various unsupervised learning techniques and spatial summary metrics applied on the SHPEs reveal that there are distinct spatial characteristics in April-May-June (AMJ) and September-October-November (SON) seasons. These spatial characteristics are in turn related to large-scale earth system controls and land-atmosphere interactions. The preliminary results indicate that the nocturnal and cyclone induced low-level jets are primarily controlling the spatial manifestation in AMJ and the severe tropical cyclones are defining the spatial features of the SON SHPEs across the Midwest and Southern United States. The results are also corroborated with a supplemental CPC/US Unified high-resolution gridded precipitation data. Understanding the spatial patterns of SHPEs and their associated large-scale ocean-atmospheric circulation features can help us in better projecting the flooding risk at multi space and time scales.

The role of Meridional Modes in energizing Pacific Decadal Variability: a climate model challenge

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BER Program: **RGCM**

Project: University Award entitled: "*Mechanisms of Pacific decadal variability in ESMs: the roles of stochastic forcing, feedbacks & external forcing*"

Project Website: http://www.podx.org

Project Abstract:

Decadal fluctuations of tropical Pacific climate are known to control large-amplitude changes in marine ecosystems, climate and weather extremes over the Pacific Ocean, Asia and the Americas with important societal. Furthermore, tropical decadal variability (TPDV) has also been implicated as a driver of the global warming hiatus, yet the mechanisms controlling its phase and predictability remain unclear. Using a seasonally stratified observational reanalysis, we find that stochastic modulations in the strength of extra-tropical trade winds in boreal winter control the largest fraction of the TPDV (~65%) and its phase. Specifically, extra-tropical winds anomalies from both the North and South Pacific, known as "precursors" of the El Niño Southern Oscillation (ENSO), independently trigger the ENSO feedbacks in the tropics and its teleconnections to the extra-tropics. We show that this interaction sequence from extra-tropics (ENSO precursors) to tropics (ENSO) to extra-tropics (ENSO teleconnections) acts as a mechanism to filter (e.g. reddening) the decadal phase of the seasonal precursors and energize TPDV. This process, which contrasts previous theories advocating for a TPDV generated internally in the tropics from ENSO, is inherently unpredictable and not well reproduced in climate models raising challenges for understanding and predicting the role of internal TPDV in future climate change scenarios.

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Title: Evaluating fine-resolution, regional outputs of a variable resolution global climate model

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BER Program: Multi-sector dynamics

Project: Telescopic techniques for multi-scale analysis; Topic area 4: Climate impact modeling, methods, and science for energy-water systems; US-China Clean Energy Research Center for Water-Energy Technologies (CERC-WET)

Project Website: https://cerc-wet.berkeley.edu/research/climate-impact-for-energy-water-systems

Project Abstract:

Climate models have been widely applied to study water resources and regional hydrologic responses under climate change, but climate model outputs need to be downscaled to provide relevant inputs to regional models because it is too expensive to run global models at fine-resolution. However, the accuracy of inputs to regional hydrological and energy analyses is limited by uncertainties across and within downscaling methods, uncertainty across global outputs, and discontinuities at downscaled boundaries. The boundary discontinuities result from the inability of post-processing downscaling methods to capture the reciprocal interactions between local and global processes. A new alternative to traditional downscaling is to use a variable resolution model that incorporates fine-resolution regions directly into a coarse resolution climate simulation. In this study supported by the DOE U.S./China CREC-WET project, we applied the recently developed variable-resolution Community Earth System Model (VR-CESM) to validate regional downscaling within a global simulation and to make fine-resolution regional climate projections for assessing potential impacts on water and energy resources. We have generated one-eighth degree (14 km) fine-resolution outputs for the western U.S. and eastern China from 1970-2006 and will also make projections for these regions from 2007 to 2050. We run the VR-CESM model on the NERSC supercomputer system, at an approximate computational cost of 4 million core hours per 40 years of simulation.

We compare the model outputs with PERSIANN-CDR precipitation data estimated using an Artificial Neural Network and the climate data record and with PRISM gridded weather station data for precipitation and temperature. Seasonal precipitation and temperature biases are greater than annual biases, and overall VR-CESM does a good job of estimating these variables at fine resolution, including improved precipitation accuracy due to new prognostic cloud microphysics. We also evaluate the water availability by large watersheds in both the western U.S. and eastern China, which are particularly important for other studies including groundwater and hydropower. Upcoming work will evaluate additional variables relevant to assessing water and energy

resources, including snowpack, wind speed, and surface solar radiation. We also aim to characterize the frequency and severity of extreme hydrometeorological events projected by VR-CESM relative to an extreme precipitation database developed by project partners. Longer-term goals include the development of efficient post-processing tools for climate model outputs in order to transform them into more widely accessible inputs to regional- and sector-specific water and energy resource impact models.

Title: **Improving performance via parallel physics/dynamics coupling in the E3SM atmosphere model**

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BER Program: ESM

Project: Climate Model Development and Validation – Software Modernization (CMDV-SM),

Project Website: https://climatemodeling.science.energy.gov/projects/cmdv-sm-global-climate-model-software-modernization-surge

Project Abstract: [Limit to 400 words, size 12 Times New Roman font characters]

We will achieve exascale through increased concurrency rather than faster clock speed. To do this, model processes must be computed in parallel. In this project, we modified the E3SM atmosphere model to perform physical-parameterization and fluid-dynamics calculations simultaneously. Doing so allows us to capitalize on the perfect scalability of both the spectral element dycore and the column-based physics parameterizations. By properly balancing the number of computational cores devoted to physics and dynamics, performance can be improved at both low and high core counts with only modest changes to model climate. The greatest impact is at high core counts where the increased parallelism allows us to better utilize the computational resources, providing roughly a 40% improvement in model throughput. Switching to parallel splitting does, however, induce stability and mass conservation concerns which require careful attention.

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ClimBiz Adapt – Climate Projection Tool

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BER Program: RGCM (DOE SBIR)
Project: A Climate Change Information System for Business and Industry (ClimBiz)
Project Website: https://www.climbiz.com/ https://adapt.climbiz.com/

A core effort of the ClimBiz project is to create ADAPT, a climate projection visualization and analysis tool that makes a full suite of CMIP5 climate model-based projections available to a variety of users. The goal of ADAPT is to greatly simplify the complex process of accessing and analyzing future climate projections in ways that will enable visualization and assessment of possible future scenarios.

The presentation will demonstrate how the current version of ADAPT offers a wealth of statistical climate change information to a variety of users. It provides a simple-to-use selection interface to specify a wide range of locations across the globe for time intervals between 2006 and 2100 by month, season, or year. There are menus for 9 environmental variables, 16 CMIP5 models with ensembles ranging from one member to 10, for the 4 CMIP5 greenhouse heating levels.

The website offers a substantial set of locations that can be selected —continents, essentially every nation in the world, and then regions within the geographically larger nations. We seek to continue to improve and broaden the capabilities for selecting and defining locations of interest for this website.

As expected by our DOE Small Business Innovative Research (SBIR) contract, our objective in building ADAPT is to commercialize the solution. This is a difficult task, however, because of similar free government sponsored climate projection services that have become available, such as NOAA's "The Climate Explorer" and the European Copernicus Climate Change Service. Success in this arena requires specialization and customization of the application of climate projection data to address specific sectoral, industry, or company strategies and adaptation plans. ADAPT will become successful and valuable when coupled with models that take advantage of the probabilistic climate projections in a business context, as shown by our companion presentation, *Climate Change Foresight and Resilence for the Electric Power Industry*. We must combine climate simulation results with models of the enterprises we hope to serve.

Climate Change Foresight and Resilience for the Electric Power Industry

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BER Program: RGCM (DOE SBIR)
Project: A Climate Change Information System for Business and Industry (ClimBiz)
Project Website: https://www.climbiz.com/ https://adapt.climbiz.com/
https://www.climbiz.com/climate-foresight-whitepaper/

Climate change poses a variety of challenges for the electric power industry, including new patterns of customer demand, impacts on renewable power generation technologies, and infrastructural risks created by variations in water resource availability, sea level rise, and by changing intensities and frequencies of severe or extreme weather.

Creating climate foresight and attempting to ensure resilience is complicated because proposed courses of actions to meet climate change challenges must satisfy the demands of multiple criteria related to maintaining and maximizing sustainability. It is further complicated because other, perhaps stronger, forces may also shape the future of an enterprise.

The ClimBiz approach to studying generation options combines a mathematical model of an electric utility or network with CMIP5 projections for the relevant atmospheric variables in order to create a wide range of scenarios that depend on climate variations and on exogenous factors such as the cost of the various generation options. The objective is to find an optimum mix of fossil and renewable energy sources that would reduce carbon dioxide emissions while maximizing electricity production and distribution reliability. Desirable strategic pathways to sustainable performance are identified by assessing and weighting the options according to the long-term triple bottom line criteria of prosperity, reliability, and responsibility. A focus on the PJM Interconnection, the large energy balancing operator in the Mid-Atlantic states, provides an example.

Time-dependent climate change ensemble projections for generation and demand variables from the ClimBiz ADAPT system provide a probabilistic view of generation options and their costs. In all, 125 distinct scenarios were considered, each simulated several hundred times to obtain stable statistics. A large set of scenarios depicting 21st century evolution of climate change, energy demand, and generation costs was prepared and then sorted according to long-term corporate goals to identify optimum pathways into the future.

Now ClimBiz is turning toward the more difficult task of creating probabilistic portraits of the infrastructural risks. These were identified by the members of the DOE Partnership for Energy Sector Resilience as their prime concerns. We have a downscaled simulation of water volume variations in the major rivers and streams of the world derived from two CMIP5 models. We are developing methods, including machine learning and analysis of model probability distributions, for detecting changes in the frequency and intensity of extremes and severe weather. And so we are looking forward to the availability of E3SM and CESM2 simulations to advance this effort.

Toward an Exascale Land Surface Model: Conceptualization and Infrastructure

Ethan Coon, Scott Painter, and Dali Wang
Oak Ridge National Laboratory

Historically the land surface model was developed as a method for determining fluxes of carbon and water vapor to the atmosphere; the result was a column-based model, which is limited in scope but needs few computational resources. Current generation land surface models are much more than this, providing predictions of ecosystem function, inputs for engineered systems including water, energy, and nutrient transport, and connections to land use/land change models. Despite the increased scope, LSMs have largely kept the same simplified column-based structure, albeit with subgrid models that are not spatially located. As these new capabilities grow and spatial resolution increases, there reaches a point when the column and aspatial subgrid conceptualization becomes untenable. In particular, lateral flows of water and associated transport of chemical components become important as resolution increases, eventually making it necessary to spatially locate subgrid processes [Bierkens *et al.*, 2015].

New changes of E3SM's Land Model are moving to watershed-based grid cells, providing a new organizational unit and a natural framework to enable spatially located, three-dimensional structure. But such a model would greatly increase the computational demands of ELM and necessitate a code that can run on hybrid architectures. It would fundamentally break the current "round-robin" scheduling of land surface columns, requiring a new load-balancing strategy. And it would require new approaches for introducing high-resolution data such as digital elevation maps.

We explore potential conceptualizations of a watershed-based, three-dimensional ELM. Each ELM grid cell is associated with a three-dimensional, spatially explicit mesh on which processes are solved on a single computer hardware node. Task parallel strategies are used to schedule individual watersheds, eliminating the load balancing issue. And a dependency graph is formed to enable flexible configuration of a growing collection of process components. Some of the infrastructure implications of such a conceptualization are being explored as part of the CANGA SciDAC. Specifically, we demonstrate automatic extraction of existing ELM subroutines from the current code base and then wrap those as functional kernels for the purpose of executing on GPUs and potentially other architectures. We consider the performance and software organizational implications of this prototype, and what such a land model means for coupling to the broader Earth System Model.

Bierkens, M. F. P., et al. (2015), Hyper-resolution global hydrological modelling: what is next?, Hydrological Processes, 29(2), 310-320, doi: 10.1002/hyp.10391.

Wildfire impact on environment thermodynamics and severe convective storms

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BER Program: DOE Early Career Research Program

Project: Understanding Severe Convective Storms in the Central United States ("SCS" project)

Wildfire is a type of climate extremes, and its frequency, burning season and area have been increasing globally over the past decades. Besides serving as a globally important source of aerosol particles that could impact cloud, precipitation and radiation, biomass burning can heat the environment significantly and perturb the environmental thermodynamics when the burned area is large. However, this impact on environment thermodynamics and the subsequent influence on severe convective storms has never been investigated. In this study, we developed a new model capability based on Weather Research and Forecasting model coupled with Chemistry (WRF-Chem) by considering heat fluxes from wildfires in the atmosphere. We evaluate the model development with several wildfire events in simulating the thermodynamics observed from soundings. Particularly, we conduct model simulations for the Mallard fire pyrocumulonimbus event occurring in Texas and Oklahoma on May 11-12, 2018, and explore how the large fire that began in early May in the region modify the thermodynamics of atmosphere and aerosol properties and how these changes affect the initiation and development of the pyrocumulonimbus clouds, which produce quite amount of lightning and some hailstones. We evaluate our model simulations with observations from radar, sounding, satellite measurements of lightning, and severe weather reports from NOAA Storm Prediction Center (SPC). With the thermodynamic effect of fire plumes considered, the initiation and intensity of the convection as well as the lightning and maximum hail size are much better simulated. This suggests the importance of accounting for impact of wildfire to environment thermodynamics in severe storm simulation and prediction.

Three-Dimensional Characteristics of MCSs East of the Rocky Mountains and Their Large-scale Environments

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BER Program: CMDV

Project: Use of Remote Sensing and In-Situ Observations to Develop and Evaluate Improved Representations of Convection and Clouds for the ACME Model

Project Website: https://climatemodeling.science.energy.gov/cmdv

Project Abstract:
Mesoscale convective systems (MCSs) account for 40%-60% of warm-season precipitation over the central U.S. MCS activities in the cold seasons and outside of the central U.S. have received much less attention climatologically. To improve understanding of MCSs and their role in the regional water cycle of the U.S., we characterize the 3-D structure of MCSs and their associated large-scale environments by synthesizing three high-resolution observation datasets for 13 years (2004-2016) (geostationary satellite infrared temperature, 3-D NEXRAD mosaic radar reflectivity, Stage IV precipitation estimates) and the North American Regional Reanalysis. Long-lived and intense MCSs are tracked throughout all seasons using a newly developed FLEXTRKR algorithm (Feng et al. 2018). Three key regions east of the Rocky Mountains frequented by MCSs are identified: Northern Great Plains, Southern Great Plains, and Southeast. MCSs show a clear seasonality across these regions, accounting for over 60% of rainfall in the Great Plains during spring/summer and over 40% of rainfall in the Southeast during winter. Large-scale environment patterns supporting MCSs at the three regions show similar baroclinic forcing in both spring and fall, but the synoptic forcing is strongest during winter. Large-scale forcing in the Great Plains is weak during summer and MCSs are primarily driven by local forcing, as evidenced by the largest and deepest convective features and smallest stratiform area. Genesis of MCSs occurs most frequently between late afternoon and evening in the Great Plains throughout the year except winter, while a much weaker MCS diurnal cycle is observed in the Southeast except summer. These synthesized MCS statistics and large-scale environments

provide useful metrics for next-generation climate model evaluation and developments as model resolution and physical parameterizations continue to improve.

A Hierarchical Evaluation of Mesoscale Convective Systems Simulated by Variable-Resolution MPAS-CAM in the Central US

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BER Program: RGCM

Project: A Hierarchical Evaluation Framework for Assessing Climate Simulations Relevant to the Energy-Water-Land Nexus (Cooperative Agreement)

Project Website: https://facets.agron.iastate.edu/display/ds/FACETS+Homepage

Project Abstract:

The Framework for Assessing Climate's Energy-Water-Land Nexus using Targeted Simulations (FACETS) project aims to develop a wide range of metrics tailored for the energy-water-land nexus and to understand climate model behavior at local to regional scales. As mesoscale convective systems (MCSs) contribute to over 60% of the total warm-season precipitation and over half of the extreme daily precipitation in the central US, the ability of earth system models to simulate MCSs has important implications for modeling the energy-water-land nexus in the region. We developed a novel observation-guided approach specifically designed to evaluate different characteristics of MCSs in climate simulations at a range of model resolutions against observations. MCS metrics such as lifecycle, volume rain rates, propagation speed, and diurnal cycle are applied to simulations produced by the Model for Prediction Across Scales (MPAS) Atmosphere, coupled with the Community Atmosphere Model (CAM) physics. The MPAS-CAM model is configured for three global variable-resolution simulations: 50-200km, 25-100km, and 12-46km grids with a refinement region centered over the contiguous US. The model simulated MCSs are statistically evaluated against observed MCS climatology at equivalent resolutions obtained from geostationary satellite and a ground-based radar network. In addition, we examine the frequency, intensity and moisture transport associated with the Great Plains low-level jet (GPLLJ), since MCSs in the central US are frequently associated with unstable warm and moist air from the Gulf of Mexico transported inland through the GPLLJ. We focus on the sensitivity of the GPLLJ and MCSs simulated in the warm season (March-August) to model grid-spacing. We will also explore the relationships between the GPLLJ and MCS metrics with metrics of large-scale circulation features such as the North Atlantic subtropical high and the northern hemisphere upper-level jet and metrics of land-atmosphere interactions to develop a hierarchical framework of metrics connecting large-scale circulation features, land surface conditions, and regional precipitation.

The role of water governance and irrigation technologies in the West in water resources resilience and vulnerability

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BER Program: Multi-sector Dynamics

Project: Cooperative Agreement

Project Website: www.pches.psu.edu

Project Abstract:

Western water resources in the US are challenged by the demands of increasing population, ecological needs, drought, and changing values and uses for water. How vulnerable are these resources?

We look at the constraints on water resources by water rights and the role agricultural irrigation technologies play in altering when and where water is used. The questions driving this research are: i) is the current regulatory system exacerbating water shortages and ii) how do water distribution and irrigation technologies affect water availability? The overall goal of this research is to create an integrated view of the social and hydro-ecological systems and to explore future outcomes for the western states in the US.

We focus on a test region: the Upper Snake River Basin located predominantly in southern Idaho. This basin includes extensive impoundments to support a large agricultural sector with a rapidly growing dairy industry.

A method is presented to incorporate water rights allocated under the prior appropriation doctrine into the University of New Hampshire macro-scale Water Balance Model to capture the essential structure of these rights and their impacts on the major water use sectors. Additionally, irrigation technologies alter the efficiency of water use through both the conveyance of water (how water is delivered from the water source to the place of use) and the irrigation method (how water is applied at the place of use).

Our ultimate goal is to scale this work up to the entire US West; however, most states do not have the excellent water law data quality available in Idaho. Therefore, we have devised a method to use information from Idaho to construct a general water rights model that can be applied elsewhere in the US West. To do this, we characterize cumulative water rights and water rights distributions as functions of other data-rich changes over time; for example, cropland area, irrigated area, reservoir capacity and population.

A Hybrid Economic-Engineering Model to Estimate Water-Energy Interactions: IMPLAN-PSM

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BER Program: Multi-sector Dynamics

Project: Cooperative Agreement

Project Website: www.pches.psu.edu

Project Abstract:

We develop a combined economic-engineering model to capture important water-energy interactions that will allow us to answer the following research questions: (1) What infrastructure investments should be made to be resilient to the range of possible future stresses from natural systems? and (2) What are the impacts of potential natural shocks to the coupled systems of land, water, energy, and economic activity? Valid estimates of impacts and valuation of adaptive, resilient system design requires the representation of both the ability to substitute across economic sectors (captured by economy-wide economic models) and physical and engineering constraints of the power system (captured by power system models). Although hybrid economic-power system models currently exist, all face one or more of the following limitations: (a) use of a small number of "representative" demand hours; (b) omission of intertemporal constraints (unit commitment); and (c) omission of transmission constraints (optimal power flow). Omitting these constraints will bias estimates of the impacts of extreme events. Thus, we design a hybrid modeling system that captures both intertemporal and spatial constraints. Our preliminary results show that shutting down selected coal plants in WECC in response to water shortages will lead to higher power generation in California and lower generation in the rest of WECC, and higher electricity prices and lower electricity demand in both regions. Importantly, we find that a non-coupled modeling system generates much larger impacts than a coupled system, proving that the substitution away from electricity in response to higher prices dampens the economic impacts of this shock to the power system.

Global river responses to rising CO_2: separating the effects of physiological and radiative changes on streamflow and flooding

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BER Program: RGCM

Project: Early Career / RGMA

Project Abstract:

River networks are expected to respond to global warming in a variety of ways, ranging from more extreme annual low flows to more frequent and intense flood events. Though understanding the drivers of such shifts can help inform future modeling efforts, little focus has been placed on assessing the relative roles of the atmospheric (radiative) and land-based (plant physiological) responses to climate change in altering streamflow characteristics. Here, we begin to fill this gap through a series of downscaled Earth System Model experiments that isolate the two response pathways to a quadrupling of pre-industrial CO_2 that is applied only to the atmosphere or only to the land. We show here that the physiological response to global warming (i.e., reduced stomatal conductance leading to higher soil moisture) rivals the strength of the radiative response (i.e., intensification of precipitation) in terms of increasing the frequency of the 100-year flood. On shorter timescales, we find that this plant response can also be the primary driver of increased annual mean and maximum flows for a number of basins globally, including the Amazon, Mekong, and Yangtze. These findings not only suggest the importance of including interactive plant responses to CO_2 in future flood projections, but also highlight regions, typically those with high leaf area index and low snowfall amounts, where future observational efforts should be focused to better constrain the strength of the stomatal closure effect.

Increases in freshwater runoff at high latitudes with sustained climate warming disrupts marine ecosystem function in the Arctic Ocean

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BER Program: RGCM

Project: RUBISCO

Project Website: https://climatemodeling.science.energy.gov/projects/reducing-uncertainty-biogeochemical-interactions-through-synthesis-and-computation-rubisco

One of the most robust changes in the hydrological cycle predicted by Earth System Models (ESMs) during the 21st century with "business as usual" climate warming is an increase in precipitation and runoff over the land surface at high northern latitudes. Here we explore the impacts of these changes in land surface hydrology for marine ecosystems in the Arctic Ocean using a simulation from the Community Earth System Model (CESM) for the period from 1850 to 2300. We find that until the year 2100, net primary production in the Arctic Ocean increases as a consequence of climate warming, with loss of sea ice increasing light availability and the length of the ice-free growing season. After 2100, however, sustained increases in freshwater delivery to the Arctic Ocean reduce surface salinity and suppress deep convection in the sub-arctic North Atlantic. As a consequence of enhanced stratification and reduced lateral nutrient influx into the Arctic Ocean, nutrient concentrations in the euphotic zone decline significantly, reducing net export production. Concurrently, the increasing nutrient stress causes a shift in community composition, favoring the growth of small phytoplankton in both spring and autumn blooms, and limiting the abundance of large phytoplankton (which export less efficiently). A reduced complexity model of NPP driven by present-day light, nutrients and temperature is able to predict most of the variability in NPP observed within the CESM through the year 2100, but breaks down in the following centuries as a consequence of the community shifts. Our analysis highlights the critical importance of land-ocean hydrologic coupling at high northern latitudes as a driver of long-term biogeochemical changes in the Arctic Ocean.

Precipitation Extremes Under High Summer Radiative Forcing

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BER Program: RGCM

Project: Paleo-Megadroughts and Abrupt Climate Changes in the Speleothem Records; university grant.

With enhanced radiative forcing, more intense rainfall and prolonged droughts have been predicted. We present a case study of the climate and hydrologic cycle nine thousand years before present (9ka), when northern hemisphere mid-latitudes received greater summer insolation June-August and less winter insolation, compared to today. Speleothem records in China and India reveal a progressive enrichment in calcite $\delta^{18}O$ since 9ka (Cai et al. 2010). The trend is interpreted as a decrease, from 9ka to the present, of summer precipitation associated with the summer East Asian and South Asian monsoons.

We have carried out a series of isotope-enabled climate model simulations for the present day and 9ka. In an experiment with present-day SST but 9ka forcings, 9ka precipitation was enhanced over continental regions compared to present day, due to the low specific heat of land. This finding is consistent with the theory of Boos and Korty (2016). However, the precipitation enhancement is much lower than that expected from speleothem $\delta^{18}O$ records, thus calling into play SST anomalies and other mechanisms. We are aware of little information about 9ka SST changes, except for a reconstruction in the equatorial Pacific (Gill et al. 2016). We are confronted by a quandary: several modeling studies show a cooler North Pacific in the summer despite the higher insolation, while several climate model experiments of 9ka assert success in capturing the precipitation changes despite the wide range of SSTs used.

In this study, we use an isotope-enabled global climate model to explore the suite of 9ka SSTs that could produce an enrichment of precipitation $\delta^{18}O$ in the East Asian and South Asian monsoons. The results may be helpful in identifying paleodata that could resolve the quandary, and may contribute to our understanding of the factors that contribute to precipitation extremes.

References

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Gill, E. C., B. Rajagopalan, P. Molnar, and T. M. Marchitto (2016), Reduced-dimension reconstruction of the equatorial Pacific SST and zonal wind fields over the past 10,000 years using Mg/Ca and alkenone records, *Paleoceanography and Paleoclimatology* 31, 928–952.

Mid-western US Heavy Summer-precipitation in Regional and Global Climate Models: the Impact of Downscaling on Model Skill

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BER Program: IA

Project: Cooperative Agreement

Abstract: Regional climate models (RCMs) can simulate heavy precipitation more accurately than general circulation models (GCMs) through more realistic representation of topography and mesoscale processes. Analogue methods of downscaling, which identify the large-scale atmospheric conditions associated with heavy precipitation, can also produce more accurate and precise heavy precipitation frequency than the simulated precipitation in GCMs. In this study, we examine the performances of the analogue method *versus* direct simulation, when applied to RCM and GCM simulations, in detecting present-day and future changes in summer (JJA) heavy precipitation over the Midwestern United States. We find analogue methods are comparable to MERRA-2 reanalysis in characterizing the occurrence and interannual variations of observed heavy precipitation events. For the late twentieth-century heavy precipitation frequency, RCM precipitation improves upon the corresponding driving GCM with greater accuracy yet comparable inter-model discrepancies, while both RCM- and GCM-based analogue results outperform their model-simulated precipitation counterparts in terms of accuracy and model consensus. For the projected trends in heavy precipitation frequency through the mid twenty-first century, analogue method also manifests its superiority to direct simulation with reduced intermodel disparities, while the RCM-based analogue and simulated precipitation do not demonstrate a salient improvement (in model consensus) over the GCM-based assessment. Given the weaker dependence of the analogue method on resolution, it presents an opportunity to develop a robust assessment of the projected changes in regional-scale heavy precipitation frequency. We have also applied the analogue method to assess the shifts in summertime hot days and the potential impact on the Large Power Transformer (LPT) of the electric grid.

The ocean of circulation change impact on the Arctic and Antarctic sea ice response to CO2 forcing

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BER Program: RGCM
Project: HiLAT
Project Website: http://hilat.org/

Sea ice evolution due to atmospheric radiative changes occurs through the complex interactions between the ocean and atmosphere, their circulation responses, and feedbacks between them. We isolate the impact of ocean circulation change in this complex interaction and its effect on sea ice evolution by using a unique partially-coupled methodology in which the ocean circulation feedback on air-sea fluxes is removed from coupling. We further decompose ocean-driven ice growth and melt fluxes into components driven by surface heat fluxes and ocean circulation changes in both fully- and partially-coupled simulations. By doing so, we isolate the individual roles of the atmosphere and ocean and the coupling between them in sea ice loss in the Arctic and Antarctic.

Ocean circulation changes play a more crucial role than surface heat fluxes in both Antarctic and Arctic sea ice loss, particularly over longer timescales by driving anomalous ocean heat transport into the polar oceans. However, through the ocean circulation change feedback on air-sea fluxes in the Subpolar Atlantic, ocean circulation change eventually stabilizes Arctic Sea ice loss in the fully-coupled simulation. The air-sea interaction with ocean circulation changes causes further circulation weakening and greater cooling of the Atlantic subpolar gyre (SPG), and as a result, reverses the anomalous heat transport into the Arctic. Without this negative circulation feedback on SPG temperature, Arctic sea ice completely disappears in the partially-coupled simulation. In the Antarctic, ocean circulation change feedbacks on air-sea interaction cause no further circulation changes, but rather increase surface heat fluxes by changing atmospheric energy transport into the Antarctic. This interaction, however, has a much weaker impact on Antarctic sea ice evolution.

Title: **The role of Arctic sea ice decline on high-latitude ocean and sea ice ecosystems**

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BER Program: ESM

Project: Cooperative Agreement between UAF and LANL

Project Abstract: Models of the Arctic Ocean ecosystem can provide insights into the mechanistic control of the rapidly changing physical environment on marine productivity. Here we have simulated the impact of reduced sea ice on the regional dynamics of the lower trophic level Arctic ecosystem. We performed hindcast experiments with the ACME-HiLAT global Earth system model, using two approaches to simulate reduced sea ice. Firstly, the baseline air temperature from version 2 of the Coordinated Ocean-ice Reference Experiments was modified by varying degrees using moderate and more extreme predictions of future temperature change from the Intergovernmental Panel on Climate Change atlas of global and regional climate projections. Secondly, model parameters related to snow grain size and thermal conductivity, previously shown to influence sea ice extent, area and volume, were modified to simulate a reduced sea ice environment. The relative control of ice cover and water temperature on water column structure, light and nutrient availability, and the resultant ice and ocean biological productivity is discussed. The heterogeneous response of net primary production, diagnosed for each of the Arctic shelves and basins, to the physical perturbations are compared and contrasted in an effort to better understand feedbacks between Arctic Sea ice and upper ocean, and predict the overall response of the Arctic ecosystem structure and carbon budget to a warming Arctic.

Using the PCMDI Metrics Package to provide objective performance summaries of all CMIP class models

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The PCMDI Metrics Package (PMP) is an open-source Python-based capability used to produce and document objective summaries of Earth System Model (ESM) agreement with observations. This is accomplished via a diverse suite of relatively robust summary statistics across space and time scales. Among other purposes, the PMP helps us address the question – Do targeted model improvements come at the expense of other simulation characteristics?

In this presentation we highlight new metrics that have been incorporated into the PMP. Some of these are based on recent PCMDI research while others result from DOE program collaborations as well as ongoing collaborations with expert international teams. Examples include metrics for extra-tropical modes of variability, ENSO, monsoons and other high frequency simulated precipitation characteristics. Avenues for ongoing research will also be discussed as well as the role of the PMP in the Coordinated Model Evaluation Capabilities (CMEC).

PCMDI curates data from all generations of AMIP and CMIP going back to the early 1990s. The earlier (pre CF conventions) data is gradually and meticulously being brought up to meet community standards that will facilitate future research. This work positions PCMDI to use the PMP to document model improvements over nearly 30 years of model development with attention now turning to CMIP6 as new simulations are being published to the Earth System Grid Federation (ESGF). These multi-model and multi-generation summaries provide valuable context for the use of the PMP in the development cycle of E3SM and other US and international ESMs.

Leveraging over twenty years of DOE supported Python-based analysis software (including the Community Data Analysis Tools; CDAT), an important objective of the PMP is to create end-to-end provenance to ensure the benchmarking of CMIP class models is fully documented, traceable and reproducible across all variants of input data and the tools used to analyse them. The PCMDI Metrics Package v1.2 is available at https://github.com/PCMDI/pcmdi_metrics.

Acknowledgements: This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. We also acknowledge support from the U.S. Department of Energy, Office of Science, Climate and Environmental Sciences Division, Regional and Global Modeling and Analysis Program.

Contribution to: 2018 Modeling Principal Investigator's (PI) Meeting, Bolger Center, Maryland, 5-9 November 2018, https://www.orau.gov/modeling2018/.
LLNL Release Number: IM-946900; LLNL-ABS-758679. Target session: Data, Metrics and Diagnostics

Title: The DOE E3SM Coupled Model Version 1: Overview and Evaluation at Standard Resolution.

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BER Program ESM

Project: E3SM

Project Website: e3sm.org

Project Abstract: E3SMv1 is the first version of DOE's Energy Exascale Earth System Model. E3SMv1 started from CESM1 but has since undergone significant changes. E3SMv1 includes new ocean and sea ice components based on the Model for Prediction Across Scales (MPAS) as well as a new river model, Model for Scale Adaptive River Transport (MOSART). In the atmosphere, the spectral-element (SE) dynamical core replaces the finite volume option and most of the physics has been enhanced or replaced. The number of vertical levels in the atmosphere was also more than doubled from 30 to 72 levels. CMIP6 simulations were run at the standard horizontal resolution of 100km atmosphere and 60-30 km ocean.

We present an overview of the modeled climate at standard resolution. Progress towards reducing systematic climate mode biases (such as improved clouds and precipitation) has been made, but significant challenges remain. E3SMv1 is a high sensitivity model with a strong aerosol-cloud forcing. E3SMv1 exhibits realistic ENSO variability, with long-term modulation in the control simulation. The E3SMv1 simulated AMOC is on the weak end of CMIP5 models (~12 Sv). Consistent with other CMIP5 models, E3SMv1 exhibits excessive sea ice in the Labrador Sea.

Finally, we compare regionally averaged SST from the historical transient ensemble to that from the CESM large ensemble. We find that even with a limited ensemble size, the E3SM ensemble captures much of the CESM large ensemble (40 members) spread. While E3SMv1 compares well with CESM large ensemble and reproduces the amount of warming observed over the 20th Century, the temporal evolution of that warming is unrealistic. We present evidence to suggest that both sensitivity and aerosol forcing are at fault.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. It is supported by the Energy Exascale Earth System Model (E3SM) project, funded by the U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research. IM Release LLNL-ABS-758563. The work has been approved for unlimited release LA-UR-18-28986.

SOM-based Hybrid Downscaling of AR Days

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BER Program: RGCM

Project: A Hierarchical Evaluation Framework for Assessing Climate Simulations Relevant to the Energy-Water-Land Nexus (Cooperative Agreement)

Project Website: https://facets.agron.iastate.edu/display/ds/FACETS+Homepage

Project Abstract: A new hybrid downscaling approach for extreme precipitation days is presented using large-scale meteorological patterns (LSMPs) to group precipitation regimes. The LSMPs are defined using a self-organizing map (SOM) for the western U.S., the nodes of which span the patterns that can occur on atmospheric river (AR) days. AR days are selected (Goldenson et al., 2018) from the ERA-Interim reanalysis (1980-2005), and then total moisture column and 500 mbar heights are used to define the SOM. Observation-informed gridded precipitation data is used to define precipitation probability density functions (PDFs) for days that resemble each LSMP for each high-resolution grid cell. The observational data is downsampled to a high-resolution grid at ~12km, to match downscaled GCM data produced for the DOE-FACETS project with WRF and RegCM. That dynamically downscaled data will be used to derive a change signal for the PDFs at each grid cell for each LSMP to account for thermodynamic changes in downscaling the future period (2075-2100). The procedure to produce the downscaled product consists of sampling randomly from the precipitation PDF for the appropriate time period at each grid cell (as in Hewitson and Crane, 2006), depending on the LSMP that most closely matches a given day. The procedure is repeated multiple times to get a range of possibility and a median projection. This approach enables the examination of biases and changes in the relative frequency of different large-scale meteorological patterns, the production of a downscaled product that is not subject to the distinct precipitation biases in each GCM and RCM, and a partitioning of uncertainty between the global and regional steps of data production for all GCMs. Results can be compared with other downscaling for the FACETS project on the subset of days with landfalling ARs. Preliminary results will be presented.

References:

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Climate Change Impacts on Global and Regional Water across the Shared Socioeconomic Pathways

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BER Program: Multi-sector Dynamics (MSD)
Project: IHESD SFA
Project Website: http://www.globalchange.umd.edu/

Global and regional water use is expected to change over this century due to increases in population, improvements in infrastructure, and water supply changes resulting from climate change-induced precipitation shifts. Changes in water use can be modeled with a combination of a Global Hydrologic Model and an Integrated Assessment Model (IAM) in order to capture both socioeconomic changes as well as the water supply impacts of future precipitation changes as modeled by Global Circulation Models (GCMs). This study explores the impacts on water use produced by a combination of four future climate change scenarios, the Representative Concentration Pathways (RCPs) and five future socioeconomic change scenarios, the Shared Socioeconomic Pathways (SSPs) by using the Global Change Assessment Model (GCAM). Global, regional, and gridded water use for all 15 future SSP-RCP combinations are analyzed while accounting for future climate change driven water supply changes, crop yield effects, hydropower shifts, and building energy requirements. Gridded future water scarcity assessments of the SSP-RCP scenario matrix through the end of the century are derived by disaggregating IAM results into grid-scale land allocations and water demands with the use of the downscaling product Demeter-Tethys. The results of this study show that throughout the century, global water demands are significantly impacted by the changing demand for bio-energy across both climate policy scenarios and SSPs. As the willingness to invest in bio-energy increases, such as in SSP1 and in deep climate policy scenarios, water demands increase. It is found that regional shifts in water demands exist in the climate scenario extremes due to both the availability of water changes and production shifts resulting from increased bio-energy demands. This study acts as a first analysis of water use in the SSP-RCP scenario matrix while accounting for both climate driven water supply changes and SSP driven technological change within the water sector.

Efficient Time-stepping Methods for Ocean Modeling with Highly Nonuniform Grids

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BER Program: ESM
Project: University Award

A central goal of the Florida State University/University of South Carolina research is to develop efficient, parallelizable time-stepping methods for ocean modeling in the presence of highly nonuniform grids such as would be needed to resolve into coastal regions or for accurately resolving specific areas of interest. To achieve our goal, we use several strategies. First, we develop time-stepping schemes that remain stable and accurate even for time steps considerably larger than that those dictated by the CFL condition for standard methods such as Runge-Kutta ones. Specifically, we develop efficient exponential integrators which propagate the fastest linear modes of the model exactly in time. Second, we develop domain decomposition schemes that allow for different time-step sizes. Specifically, we investigate the parallel and local implementation of exponential integrators which is an important step on the path to combining both approaches and to produce the efficiencies needed to meet our goal. A third strategy is to develop a reduced-order modeling capability. By using data-driven instead of a grid-based bases, this allows for simulations with larger time-steps at a substantial lower cost compared to those incurred using large-scale ocean models. This would enable, e.g., relatively inexpensive uncertainty quantification and data assimilation studies. In this presentation, we give a brief overview of our progress up to this date. Details are found in the five posters:

- Exponential integrators with fast and slow mode splitting for multilayer ocean models

- Localized exponential time differencing methods based on domain decomposition

- Conservative explicit local time-stepping schemes for the shallow water equations

- Exponential time differencing for the tracer equations appearing in primitive equation ocean models

- Hamiltonian structure preserving reduced-order model for the shallow water equations.

Title: Framework for Assessing Climate's Energy-Water-Land Nexus Using Targeted Simulations (FACETS)

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BER Program: RGCM

Project: A Hierarchical Evaluation Framework for Assessing Climate Simulations Relevant to the Energy-Water-Land Nexus (Cooperative Agreement)

Project Website: https://facets.agron.iastate.edu/display/ds/FACETS+Homepage

Actionable climate science entails the provision of local-to-regional scale climate information to support decision-making regarding climate impacts, adaptation and mitigation. However, large uncertainties in model projections of climate change remain that challenge our understanding of the controlling processes, and hampers the use and communication of climate information for societal benefits. We have been developing a hierarchical model evaluation framework informed by different uses of climate models and climate model outputs by climate scientists and stakeholders for planning and managing resources. The framework features a cascade of metrics including standard descriptive metrics, new climatological and ingredients-based quality metrics, new phenomena-based metrics for specific event types, and integrated regional metrics that combine the above metrics for specific regions. Metrics specifically tailored for the energy-water-land (E-W-L) nexus help inform strategies for modeling human-Earth system dynamics at regional scales. The metrics take advantage of multiple observational data sources for evaluating model fidelity and exploring mechanisms and sources of model errors and uncertainty. To demonstrate the usefulness of this evaluation framework, we are working with representative approaches from a suite of dynamical, empirical, and hybrid downscaling models and designing structured, hierarchical experiments that feature benchmarking simulations across a range of spatial resolutions and modeling approaches. Some numerical experiments focus on the impacts of future land use and land cover changes associated with food and bioenergy crop production and urbanization, and expansion of wind turbine deployment, which highlight specific challenges for modeling the E-W-L nexus.

The majority of research includes the conterminous U.S. However, some in-depth studies focus on specific regional phenomena, such as the North American Monsoon, the Great Plains Low-Level Jet and West Coast Atmospheric Rivers. Key outcomes of the research will be: (1) A set of methodologies, algorithms, and software functions and scripts for individual and integrated metrics; (2) Differentiation of model skill based on the metrics and hierarchical experiments, and understanding of the spatial scale dependence of the results; (3) Elucidation of local human impacts related to the E-W-L nexus on climate; (4) A rich dataset produced by the hierarchical modeling experiments that are being archived and ultimately made available for use by the broader climate science community and stakeholders; and (5) A rigorously tested model evaluation framework and tools that form the basis for future development of a computationally enabled user-friendly model evaluation system for community use.

First Author Jacob Spender[1], Co/Presenting Author William J. Gutowski[1], Co Authors Raymond W Arritt[1] & Melissa S Bukovsky[2]

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BER Program: RGCM,

Project: A Hierarchical Evaluation Framework for Assessing Climate Simulations Relevant to the Energy-Water-Land Nexus (Cooperative Agreement);

Project Website: https://facets.agron.iastate.edu/display/ds/FACETS+Homepage

Project Abstract:

Extreme Precipitation vs. Model Resolution across the Upper Mississippi River Valley for DJF

As we continue to see an increase in extreme precipitation anomalies during the summer and winter months across the United States, it is important to focus on how to better forecast for these events. For instance, crop yields and fields may be washed away or destroyed due to flash flooding and extreme snowfall events causing revenue loss to many stakeholders. One way to better understand and forecast these extreme precipitation events is to assess the variations of resolutions between regional climate models. The literature has shown that winter months are more ideal for analysis as the dynamics of weather systems are continuous and focus on the synoptic scale.

This study focuses primarily on the Upper Mississippi River Valley during the months of December, January, and February when weather systems are producing heavy snow events across this domain. A reanalysis is done from 2002 through 2012 to evaluate the effectiveness of the RegCM4 and WRF on replicating Stage IV observational precipitation at various resolutions. Sub daily precipitation is used on a 6 hourly basis to observe multiple events that may occur on a given day. Every 6 hours 2m temperature, 500hPa geopotential height, 10m wind, and 2m specific humidity are used to simulate the initial atmospheric conditions to produce each extreme precipitation event. Frequency vs intensity, simultaneity, QQ plots, and composites are used to distinguish which resolution replicates observations in a precise and accurate fashion. Expectations are for the lowest resolution in the WRF and RegCM4 to have the most defined replication of the Stage IV precipitation.

Title: **The origins of sub-seasonal triggers of South Asian Monsoon Onset**

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BER Program: RGCM

Project: Water Cycle and Climate Extremes Modeling (WACCEM) SFA

Project Website: https://climatemodeling.science.energy.gov/projects/water-cycle-and-climate-extremes-modeling

Project Abstract:

While the climatological South Asian Monsoon onset date is in early June, there is significant interannual variability of the onset date that is of societal importance and interest. This study examines the origin of this variability and the implications for potential predictability at sub-seasonal scales. In this work, a method for calculating the contribution of vorticity patterns over a specific region to a circulation pattern over some other regions is developed. Application of the method to global reanalyses shows that much of the circulation variability during monsoon onset is associated with westward propagating 10-20 day equatorial Rossby waves. In this presentation we will discuss the origins and propagation characteristics of these waves and the implications for the interannual variability and potential predictability of the South Asian monsoon onset.

Quantifying the Arctic Local Radiative Feedbacks Based on Observed Short-Term Climate Variations

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BER Program: RGCM

Project: HiLAT

Project Website: https://www.hilat.org

The Arctic has warmed dramatically in recent decades, with temperature increasing at a rate of about twice as fast as the global mean value. This phenomenon, commonly known as Arctic amplification (AA), has been found in the observed and modeled climate changes. Several feedback mechanisms were shown to contribute to AA, but their relative importance is still very uncertain. In this study we use a variety of 35-year reanalysis and 15-year satellite (CERES EBAF) datasets to quantify the Arctic local feedbacks based on short-term climate variations, evaluate the feedbacks simulated in the Community Earth System Model (CESM), diagnose the impact of dataset choices on the feedback estimates, and identify the sources of main uncertainties. All datasets agree that the lapse rate (LR) and surface albedo feedbacks are positive and their magnitudes are comparable. Compared to the tropics, the lapse rate feedback is the largest contributor to AA among all feedbacks, followed by surface albedo feedback and Planck feedback deviation from its global mean. Both shortwave and longwave water vapor (WV) feedbacks are positive, leading to a significant positive net WV feedback over the Arctic. Our best estimates (based on datasets from ERA-Interim, JRA-55 and MERRA-2) for Planck, LR, albedo and net WV feedbacks over the Arctic are 0.54±0.03, 1.34±0.2, 1.33±0.32, and 0.26±0.1 W m^{-2} K^{-1}, respectively. The net cloud feedback has large uncertainties including its sign, which strongly depends on the data used for all-sky and clear-sky radiative fluxes at the top of the atmosphere, the time periods considered, and the methods used to estimate the cloud feedback. Most of the uncertainty in cloud feedback is from its shortwave component. A better understanding of fine-scale Arctic cloud processes and improvement to their representation in climate models would be required to reduce uncertainties in estimating cloud feedback and its contribution to the Arctic warming.

Title: "Emergent Constraints on Climate Change: Recent Progress and Future Prospects"

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BER Program: ESM

Project: Identifying Robust Cloud Feedbacks in Observations and Models

Project Website: NA

Project Abstract: Earth System Models (ESMs) have traditionally been assessed for fitness to simulate future climate by evaluating their simulations of current climate against a suite of observed variables believed to characterize the climate system's basic features. Such a weak filter on model quality has allowed for a large spread in future climate change to persist in ESM ensembles. This large uncertainty makes planning for environmental change difficult, and can lead to the perception that climate science is untrustworthy. In recent years, an alternative model evaluation technique has arisen, targeting those aspects of current climate that supply information about future changes. "Emergent constraints" (ECs) rely on strong simulated relationships, across an ensemble of different ESMs, between an observable aspect of current climate and future changes. Combining these relationships with contemporary measurements can constrain predictions of those future changes. We review and discuss the credibility and meaning of ECs that have been proposed. We argue that ECs offer uncertainty reduction when the statistical relationships between current and future climate are underpinned by credible mechanisms. As many ECs involve aspects of future climate critical to society, we believe that policy-relevant predictions should consider these constraints, even when mechanisms underpinning the ECs are merely plausible rather than proven. Looking forward, the EC technique may be useful to focus ESM improvement efforts on aspects of climate that matter most for simulation of climate change. We also believe there are undiscovered ECs relating to climate extremes and teleconnections. Finally, we discuss the possibility that ECs may be used for the critical task of identifying tipping points in the climate system.

Assessing the Suitability of NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) Dataset for Coupled Human-Environment Analysis

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BER Program: PCHES
Project: Program on Coupled Human and Earth Systems (PCHES) under DOE Cooperative Agreement
Project Website: https://www.pches.psu.edu

Almost all coupled human-environment models require some information from climate datasets. To make the climate data useable in other models, they are usually converted to different types of summary measures. Most of the measures are constructed based on daily temperature and precipitation information. There are several categories of climate indicators which may represent normal or extreme conditions.

In this study, the authors evaluate the performance of NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset in reproducing extreme heat indicators to be used in coupled climate-human systems. We focus on degree days above various thresholds – a critical metric for determining climate impacts. We are interested in replicating historical temporal standard deviations, interannual changes, annual averages, temporal persistence, and interannual persistence.

The results of this study suggest that the climatological patterns of average annual temperature from NEX-GDDP models are close to the benchmark. We generate the error range of the dataset in reproducing the spatial patterns of short-term extreme atmospheric conditions with respect to the benchmarks. We also find the bias range of NEX-GDDP datasets in replicating interannual variation and the interannual variability of extreme heat. In summary, careful evaluation of climate datasets is a critical component of coupled human-environment analyses.

Climate, Soil Moisture, and Yield: A Fine-Scale Analysis of Climate and Land Interactions

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BER Program: PCHES
Project: Program on Coupled Human and Earth Systems (PCHES) under DOE Cooperative Agreement
Project Website: https://www.pches.psu.edu

Natural systems interact with the human systems in many complex ways. One major channel of interaction is through the changes in agricultural crop yields due to climate variations which may affect crop yields, farmers, agribusiness, food markets, and final consumers. A predictive understanding of the interaction between climate and agriculture is critical for achieving food security as well as environmental sustainability.

Numerous empirical studies have attempted to predict crop yields by summarizing daily climate information in different indices including average temperature, growing degree days, harmful degree days, and average precipitation through the growing season. This study seeks to improve current estimates of the interaction between climate, soil moisture, and crop yields by introducing a more accurate and computationally advanced approach. We introduce a new dataset and suggest using new indicators of soil moisture and its daily interaction with temperature. We pair a fine-scale daily dataset of precipitation and temperature from PRISM (Parameter-elevation Regressions on Independent Slopes Model) with new time series on predicted daily root-zone soil moisture from WBM (Water Balance Model), then we estimate determinants of the county-level yield of maize and soybeans as reported by USDA-NASS (United States Department of Agriculture-National Agricultural Statistics Service). We estimate the model assuming a non-linear climate effect following Schlenker and Roberts (2009).

Our estimation results suggest that a) average soil moisture performs better in explaining yields compared to the conventional metric of average precipitation; b) including the daily interaction of soil moisture and temperature improves the parameter estimates; c) the soil moisture coefficient is higher for the first and the second (two-month) periods of plant growth.

Title: Sub-cloud moist entropy curvature as a predictor for changes in the seasonal cycle of tropical precipitation

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BER Program: RGCM

Project: WACCEM (Pacific Northwest National Laboratory)

Project Website: https://climatemodeling.science.energy.gov/projects/water-cycle-and-climate-extremes-modeling

Project Abstract: Convective Quasi-Equilibrium (CQE) may be a useful framework for understanding the precipitation minus evaporation (P-E) response to CO2-induced warming. To explore this proposition, a suite of aquaplanet simulations with a slab ocean from the Tropical Rain belts with an Annual cycle and a Continent Model Intercomparison Project (TRACMIP) is analyzed. A linear relationship between P-E and the curvature of sub-cloud moist entropy, a criterion for the onset of a tropical direct overturning circulation under CQE conditions, is shown to exist across many of the TRACMIP simulations. Furthermore, this linear relationship is a skillful predictor of changes in P-E in response to CO2-induced warming. The curvature metric also shows improvement in predicting P-E changes compared to the simpler method of relating P-E directly to the sub-cloud moist entropy field or a simple ‘wet-get-wetter’ type null hypothesis, especially on seasonal and shorter timescales. Using fixed relative humidity in the curvature metric and sub-cloud moist entropy degrades their ability to predict P-E changes, implying that both temperature and relative humidity changes in the boundary layer are important for characterizing future precipitation changes. To understand why the curvature metric is a skillful predictor of hydrological changes, a moist static energy (MSE) budget analysis is performed for a subset of the TRACMIP models. MSE divergence by transient eddies, which is well parameterized as a downgradient diffusive process, has a similar spatiotemporal structure to the curvature term, suggesting transient eddies are an important component to understanding the linear relationship between the curvature term and P-E.

Title: E3SMv0-HiLAT: A Climate System Model Targeted for the Study of High Latitude Processes

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BER Program: RGCM

Project: HiLAT

Project Website: https://www.hilat.org

Project Abstract:

We document the configuration, tuning and evaluation of the initial version of a climate system model specifically intended for the study of high latitude processes, establishing a context from which to improve the representation of such processes.

Starting from the E3SMv0 version of CESM.1, our updated version of the model includes changes to the atmospheric model to improve aerosol transport to high northern latitudes and to reduce shortwave cloud bias over the Southern Ocean. Marine biogeochemistry has been extended, with changes to ocean BGC and inclusion of sea ice BGC supporting the capability of having cloud nucleation dependent on marine emissions of aerosol precursors, and providing an improved context in which to study the rapidly changing climate of the high latitudes.

Global groundwater depletion: Future outlooks using a multisector approach

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BER Program: Multi-sector Dynamics (MSD)
Project: IHESD SFA
Project Website: http://www.globalchange.umd.edu/

Many of the major aquifers underlying dry regions are experiencing rapid rates of depletion, which is unsustainable. The situation is expected to worsen with increasing water demands—especially in regions supplying irrigation water for crop production. In this study, we explore the coevolution of energy-water-land systems affected by groundwater depletion across the globe. We use the Global Change Assessment Model (GCAM), which represents interactions between population, economic growth, energy, land, water, and climate systems within a consistent economic modeling framework. The model is run under 900 scenarios and with climate impacts on hydrology, hydropower, and crop yields embedded. The scenarios include combinations of five Shared Socioeconomic Scenarios (SSPs), four Representative Concentration Pathway limits on climate forcing (2.6, 4.5, 6.0, 8.0 Wm^{-2}), five climate models (ISI-MIP GCMs), six water availability scenarios, and two observational groundwater depletion datasets that we calibrate against. The results suggest that groundwater pumping as a backstop technology for mitigating water scarcity is likely to diminish toward the end of the century, and that basins that are now heavily dependent on groundwater resources to meet their domestic and irrigation demands would likely be subjected to increasing costs of groundwater and food production. New investments in water resources and policies targeted at reducing groundwater abstraction will be required in many regions to prevent aquifer exhaustion and associated environmental degradation.

Title: **The Interannual Variation of Oxygen Isotopes of Precipitation in the East Asian Monsoon Region**

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BER Program: RGCM

Project: University

Project Abstract:

An isotope-enabled general circulation model (iGCM) nudged to atmospheric temperature and winds from the NCEP2 reanalysis is analyzed in the context of the East Asian summer monsoon (EASM) with an eye toward understanding the large-scale climate controls of isotopic variations in East Asian speleothems, e. g., cave stalagmite records. We partition the model output into two regimes based on the domain mean of the rainfall-weighted isotope of rainfall in East Asia, which is closely related to an Asia-wide empirical orthogonal function of the same quantity. From this partitioning scheme, we find that years with anomalously depleted rainfall exhibit northward-shifted westerly jets over Asia during June through October that occur with increased southerly winds that act to advect both moisture and depleted oxygen isotopes from the South. The result of this kinematic forcing across stark North-South gradients in these quantities is to increase the statistical probability of summer rainfall in East Asia, while depleting the isotopic ratio of the ambient moisture. Likewise, the rainfall that occurs within such a regime therefore becomes isotopically depleted. The kinematic forcing mechanism described here is also evident when independent months are partitioned, suggesting that both seasonal and inter-annual variability can be driven in this way. This finding supports the hypothesis that isotopic changes during the EASM are primarily due to the anomalous advection of moisture into the region via circulation changes and is thus related to the EASM "Jet transition hypothesis" put forth by Chiang et al. (2015) whereby the state of the East Asian summer monsoon is dynamically linked to the northward migration of westerlies across the

Tibetan Plateau. Our results contribute to the interpretation of speleothems in the region and give insight into past and future changes in extreme drought and rainfall during the EASM.

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Nonlinear Interactions between Climate and Atmospheric Carbon Dioxide Drivers of Terrestrial and Marine Carbon Cycle Changes from 1850 to 2300

Forrest M. Hoffman[1], James T. Randerson[2], J. Keith Moore[2], Michael L. Goulden[2], Weiwei Fu[2], Charles D. Koven[3], Abigail L. S. Swann[4], Natalie Mahowald[5], Keith Lindsay[6], Ernesto Muñoz[6], Gordon B. Bonan[6]

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BER Program: RGMA
Project: RUBISCO SFA
Project Website: `https://www.bgc-feedbacks.org/`

Quantifying feedbacks between the global carbon cycle and Earth's climate system is important for predicting future atmospheric CO_2 levels and informing carbon management and energy policies. We applied a feedback analysis framework to three sets of Historical (1850–2005), Representative Concentration Pathway 8.5 (2006–2100), and its extension (2101–2300) simulations from the Community Earth System Model version 1.0 (CESM1(BGC)) to quantify drivers of terrestrial and ocean responses of carbon uptake. In the biogeochemically coupled simulation (BGC), the effects of CO_2 fertilization and nitrogen deposition influenced marine and terrestrial carbon cycling. In the radiatively coupled simulation (RAD), the effects of rising temperature and circulation changes due to radiative forcing from CO_2, other greenhouse gases, and aerosols were the sole drivers of carbon cycle changes. In the third, fully coupled simulation (FC), both the biogeochemical and radiative coupling effects acted simultaneously. We found that climate–carbon sensitivities derived from RAD simulations produced a net ocean carbon storage climate sensitivity that was weaker and a net land carbon storage climate sensitivity that was stronger than those diagnosed from the FC and BGC simulations. For the ocean, this nonlinearity was associated with warming-induced weakening of ocean circulation and mixing that limited exchange of dissolved inorganic carbon between surface and deeper water masses. For the land, this nonlinearity was associated with strong gains in gross primary production in the FC simulation, driven by enhancements in the hydrological cycle and increased nutrient availability. We developed and applied a nonlinearity metric to rank model responses and driver variables. The climate–carbon cycle feedback gain at 2300 was 42% higher when estimated from climate–carbon sensitivities derived from the difference between FC and BGC than when derived from RAD. These differences are important to quantify and understand because different model intercomparison efforts have used different approaches to compute feedbacks, complicating intercomparison of ESMs over time. Underestimating the climate–carbon cycle feedback gain would result in allowable emissions estimates that would be too low to meet climate change targets.

Effects of Ocean and Ice Shelf Basal Melt Variability on Sea Level Rise Contribution from Thwaites Glacier, Antarctica

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BER Program: ESM
Project: Energy Exascale Earth System Model, Probabilistic Sea Level Projections from Ice Sheet and Earth System Models
Project Website: https://e3sm.org/, https://doe-prospect.github.io/

Theory, modeling, and observations indicate that marine ice sheets on a retrograde bed, including Thwaites Glacier, Antarctica, are only conditionally stable. Previous modeling studies have shown that rapid, unstable retreat can occur when ice-shelf basal melting causes the grounding line to retreat past restraining bedrock bumps. Here we explore the initiation and evolution of unstable retreat of Thwaites Glacier when the ocean-induced ice-shelf basal melt forcing includes temporal variability mimicking realistic climate variability. We use an ice sheet model (MALI) forced with an ice shelf basal melt parameterization derived from previous coupled ocean/ice sheet simulations. We add sinusoidal temporal variability to the melt parameterization that represents shoaling and deepening of Circumpolar Deep Water within the subshelf cavity. We perform an ensemble of 250 year duration simulations with different values for the amplitude, period, and phase of the variability. Preliminary results suggest that, overall, variability leads to slower grounding line retreat and less contribution to sea level rise than steady simulations. Short period (2 yr) variability leads to similar results as steady forcing, whereas decadal variability can result in up to one-third less sea level rise contribution. Differences in phase lead to a large range in ice mass loss/grounding line retreat, but it is always less than the steady forcing. The timing of ungrounding from each restraining bedrock bump, which is strongly affected by the ocean variability, is the rate limiting factor, and variability-driven delays in ungrounding at each bump accumulate. Grounding line retreat in the regions between bedrock bumps is relatively unaffected by ocean variability. While the results are sensitive to the form of the melt parameterization and its variability, we conclude that decadal period ocean variability could potentially delay marine ice sheet instability by up to many decades. However, it does not alter the eventual mass loss and sea level rise at centennial scales. The potential differences are significant enough to highlight the need for further observations to constrain the amplitude and period of the modes of climate and ocean variability relevant to Antarctic ice shelf melting. The complex and uncertain ice sheet model behavior demonstrated here should be expected when running dynamic ice sheets within an Earth system model, such as E3SM.

2018 E3SM Modeling PI Meeting Abstract

Title: **Using dynamic vegetation modeling to explore shifts in boreal forest canopy cover under changing climates**

Jennifer Holm[1], Bill Riley[1], Ryan Knox[1], Gautam Bisht[1], Zelalem Mekonnen[1]

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Changes in high-latitude forests have strong implications to regional and global climate, and water and carbon cycling. Shifts in canopy cover (i.e., abundance and shifts between evergreen and deciduous species) will alter albedo, carbon, and water fluxes. For example, many studies suggest that increasing fire frequency will shift conifer-dominated forests to deciduous forests. Deciduous trees transpire 21–25% of available snowmelt water, while coniferous trees transpire <1%. A shift to deciduous trees therefore reduces groundwater recharge, and potentially leads to more storms and lightning-induced fires. All these climate-related interactions will affect plant competition, survival, and ultimately community distribution and carbon storage. To be able to accurately predict and model these complex ecological processes we are using a new dynamic vegetation model (FATES; Functionally-Assembled Terrestrial Ecosystem Simulator) that is coupled to ELMv1, the land surface model in E3SM. We use FATES to quantify the impacts on water cycling (e.g., water use efficiency, latent heat, soil water storage) and carbon fluxes (NEE) under transitions between boreal evergreen and deciduous trees.

To evaluate changes in high-latitude water and carbon cycling as a result of climate-vegetation interactions, we performed a parameter sensitivity analysis using a Latin hypercube approach to sample the parameter space of 15 main vegetation parameters, over a 100-member ensemble run. In addition, leaf and wood allometry parameters for boreal plants have been updated based on observational data from the BAAD Database. Initial tests of FATES at a boreal Alaska site found strong biomass sensitivity to soil moisture stress. Therefore, we will apply the newly developed plant hydraulic scheme (FATES-Hydro) which will allow us to simulate the impacts of precipitation and soil moisture changes on shifting boreal evergreen and deciduous tree cover.

Is the AMOC and PMOC a nature seesaw pattern of modern climate?

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BER Program: RGCM

Project: CATALYST – DOE and UCAR cooperative agreement

Project Website: http://www.cgd.ucar.edu/projects/catalyst/

Mechanisms governing the setup of modern Atlantic Meridional Overturning Circulation (AMOC) are still not well understood. Commonly it was thought that the much saltier Atlantic provides the chance for the deep convection to occur in subpolar North Atlantic and the fresher Pacific prevents the occurrence of deep convection. Here we use the Community Earth System Model version 1 (CESM1) to explore whether a collapsed AMOC would change the salinity contrast between North Atlantic and North Pacific, and whether the deep convection or Pacific MOC (PMOC) could develop through adding additional freshwater into the subpolar North Atlantic. This added freshwater is compensated either by global oceans other than subpolar North Atlantic or just compensated by the subpolar North Pacific. Results show that AMOC collapses in all experiments, but the PMOC only sets up in the experiments with the added freshwater compensated by subpolar North Pacific. Further analysis indicates that with a collapsed AMOC, Bering Strait throughflow severely weakens or even reverses its direction in these experiments, keeping more freshwater or bringing in additional freshwater to the subpolar North Pacific, preventing the deep convection to occur in the global compensation experiments. With the subpolar North Pacific compensation, the deep convection develops in the subpolar North Pacific and PMOC forms in a similar fashion as the active AMOC due to the additional salt input there. With a collapsed AMOC, the Antarctic circumpolar current (ACC) strengthens by about 30% in all experiments relative to the control run, suggesting that the upper branch of the return flow for AMOC may have impeded the ACC. At the same time, the Indonesia Throughflow weakens by about 20% in the experiment without an active PMOC, 50 to 80% in the experiments with an active PMOC, which suggests that part of the Indonesia Throughflow is driven by AMOC. With an active PMOC, the west Pacific warm pool significantly weakens, possibly associated to the weaker easterlies, leading to the dramatic reduction of the Indonesia Throughflow. In summary, the AMOC and PMOC are not a nature seesaw pattern under modern climate with an open Bering Strait unless significant salt is added into the subpolar North Pacific.

Title: **Quantifying the Mitigation Potential of Bioenergy Crops over the Conterminous United States**

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BER Program: MSD

Project: Integrated Multisector, Multiscale Modeling Scientific Focus Area

Project Website: https://im3.pnnl.gov

Project Abstract:

In scenarios of future emissions and land use changes designed to mitigate climate change, plantation areas of bioenergy crops are projected to expand. While traditional row crops, such as corn and soybean, can be used as bioenergy feedstocks, they are less favored due to unintended consequences for food security and environmental sustainability. Perennial grasses such as switchgrass and miscanthus therefore have become a better alternative to traditional crops because of their higher productivity and water use efficiency, and less demands for nutrients and water. To date, however, representations of these key bioenergy crops are largely missing from Earth system models (ESMs) such as the Community Earth System Model (CESM) or the Energy Exascale Earth system model (E3SM). To effectively quantify the biogeophysical and biogeochemical effects of alternative scenarios projected by multi-sector dynamics models on the climate system, it is therefore imperative to develop parametrizations to better represent the key bioenergy crops in such ESMs.

In this study, we implement two new perennial bioenergy crop types (i.e., switchgrass and miscanthus) into the community land model version 5 (CLM5) by modifying parameters associated with photosynthesis capacity, phenology, and allocation, and validate the model simulated fluxes and biometric variables (e.g., leaf area index, aboveground biomass) against observed fluxes and biometric data from flux tower sites located in central Illinois. The model will then be configured to run over the conterminous U.S. at 1/8th degree resolution, driven by future climate and land use change (LUC) scenarios. The LUC scenarios are downscaled from the Global Change Assessment Model (GCAM) using Demeter, a land use and land cover

change disaggregation model designed for multi-sector dynamics models. We expect that the explicit representations and simulations of bioenergy crops will have significant impacts on simulated water and biogeochemical cycles, and consequently project alternative mitigation potentials compared to simulations accounting for traditional crops only over the conterminous United States.

Title: **Modeling the Effects of Land Use and Land Cover Change on Climate Extremes and Land-Atmosphere Coupling at the Regional Scale using Variable Resolution CESM2**

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BER Program: MSD and RGCM

Project: Integrated Multisector, Multiscale Modeling (IM3) Scientific Focus Area

Reducing Uncertainties in Biogeochemical Interactions through Synthesis and Computation (RUBISCO) Scientific Focus Area

Project Website: https://im3.pnnl.gov and https://www.bgc-feedbacks.org

Project Abstract:

Regional and local climate change, including changes in variability and extremes, will directly affect the nation's water, energy and food security, and indirectly affect human health, national security and many other sectors. Climate impacts are typically felt through extreme weather, including extremes of precipitation and its subsequent impact on the water cycle, including flooding and drought. We hypothesize that in order to improve our capability to understand, model, and predict climate variability, and assess impacts of human-Earth system interactions on regional climate, accurate treatment of processes with spatial scales 10-30 km is required because many relevant phenomena have intrinsic scales in the sub-grid range (e.g., convection, urban centers, irrigation, topographic variations, and land use patterns), and processes at the smallest scales of the Earth system can potentially alter behaviors at the larger scales.

Here we perform a suite of unique Community Earth System Model version 2 simulations with the spectral element dynamical core in a uniform low-resolution (~1°) and in variable resolution with a regionally refined mesh at 0.125° resolution over the Contiguous United States. In these simulations, prognostic plant and irrigation modules in Community Land Model version 5 with land use inputs representative of preindustrial and present-day conditions were activated so that complex interactions between regional climate and land use and land cover change (LULCC) and land management practices, in addition to interactive plant phenology and physiology can be captured. Moreover, the Model for Scale Adaptive River Transport (MOSART) river transport model is configured to run at 0.125° resolution so that changes in

streamflow regimes in response to climate, vegetation dynamics, and LULCC can be evaluated. The simulations follow the Atmospheric Model Intercomparison Project protocols to allow for dynamic land and atmosphere model coupling with prescribed ocean temperatures and sea ice. We expect that these simulations will be valuable not only for evaluating the scale dependence of climate and weather extremes, LULCC, and regional circulation regimes, but also for assessing the skill of Earth System Models for capturing critical interactions between human and Earth system processes at global and regional scales, and the role of multi-sector interactions with the physical-human system.

Title: Improved Representation of Surface-Atmosphere Longwave Coupling and Its Impact on the Simulated Polar Climate

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BER Program: ESM

Project: Incorporate more realistic surface-atmosphere radiative coupling in E3SM

Project Website: N/A

Project Abstract: Surface longwave emissivity can be less than unity and vary significantly with frequency. However, most ESMs still assume a blackbody surface in the longwave (LW) radiation scheme of their atmosphere models. Moreover, ice cloud in the far-IR can have a single scattering albedo as large as 0.8, while most ESMs still assume non-scattering clouds in the LW. The two issues can manifest in the high latitudes where atmospheric column water vapor is much less than in the mid-latitudes and tropics. The study is motived by such issues and aimed at improving the representation of surface-atmosphere radiative coupling in the models.

This first part of the study describes our work of incorporating realistic surface spectral emissivity into the atmospheric component of the CESM 1.1.1 and evaluates its impact on simulated climate. By ensuring consistency of the broadband surface longwave flux across different components of the models, the top of atmosphere (TOA) energy balance in the modified model can be attained without re-tuning the model. The inclusion of surface spectral emissivity, however, leads to a decrease of net upward longwave flux at the surface and a comparable increase of latent heat flux. The global-mean surface temperature difference between the modified and standard CESM simulation is 0.20 K for the fully coupled run and 0.45 K for the slab-ocean run. Noticeable surface temperature differences between the modified and standard CESM simulations are seen over the Sahara desert and polar regions. Accordingly, the climatological mean sea ice fraction in the modified model simulation can be less than that in the standard simulation by as much as 0.1 in some regions. Therefore, the inclusion of surface emissivity partly addressed the cold biases in polar surface air temperature and the excessive freezing bias in sea ice coverage of both polar regions. The second part of the study describes our implementation of surface spectral emissivity and longwave cloud scattering into the E3SM, and the assessment of its impact on the simulated climate mean state in high latitudes, as well as comparisons with the simulation results from the first part.

Title: **Characterizing the Changes of the Top Atmospheric River Events over the California in the Future**

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BER Program: RGCM, IAR

Project: An Integrated Evaluation of the Simulated Hydroclimate System of the Continental [HYPERION]

Project Website: https://climate.ucdavis.edu/hyperion/participants.php

Project Abstract: A majority of annual precipitation along the U.S. West Coast including California originates from a few intense atmospheric river (AR) events each year characterized by narrow and filamentary corridors of enhanced water vapor flux. ARs are typically associated with extratropical cyclones over ocean basins and are responsible for a large majority of poleward moisture transport in the mid-latitudes. Severe flooding can occur when ARs make landfall and interact with complex coastal topography, sometimes yielding extraordinarily intense orographic precipitation rivaling that of landfalling tropical cyclones [Ralph et al., 2006; Leung and Qian, 2009; Neiman et al., 2011]. One recent example of a highly consequential extreme AR occurred in the Feather River watershed of Northern California during the February 2017 storm sequence, which escalated an engineering failure on the Oroville Dam to a crisis of national significance [Huang et al., 2018].

This projected increase is primarily due to thermodynamic increases in atmospheric water vapor, but an additional contributor may be a local eastward shift of the subtropical jet stream exit region over the far eastern Pacific (which would primarily affect California ARs [Langenbrunner et al., 2015; Neelin et al., 2013; Swain et al., 2018]. As a result of this shift in projected AR intensity, correspondingly large increases in the occurrence of extreme subseasonal storm sequences are anticipated in this region [Swain et al., 2018], along with a substantially elevated risk of major flood events.

While GCMs studies can yield useful information regarding coarse-scale changes in ARs and their associated environments, more detailed insights into links between changes in these large-scale conditions and regional precipitation extremes require a different approach. In order to bridge the gap between the GCM scale and the scale on which extreme precipitation occurs, this work targets the top twenty AR events over California under high-resolution downscaling from the recent past (year 1996-2005) to the end of 21st century (year 2071-2080). This study aims to

capture not only the large-scale patterns of intense water vapor transport but also the extreme precipitation that occurs when these events make landfall over complex terrain. Our goals are to investigate the dynamical and physical mechanisms under the changes of the top AR events locally, including both explicitly represented and parameterized processes, involving vapor transport, precipitation, and vertical motion. We aim to better understand the response of AR-related regional precipitation extremes to a warming climate.

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Impacts of climate variability and extremes on US power sector investments

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BER Program: Multi-sector Dynamics

Project: Integrated Human-Earth System Dynamics (IHESD) SFA, Pacific Northwest National Laboratory

Project Website: http://www.globalchange.umd.edu/

Electricity demand is expected to grow over the coming decades creating a need for long-term power sector planning (EPRI, 2018; Mai et al., 2018). Planning will require two considerations. First, maintaining reliability requires enough capacity to supply electricity during hours of peak demand. This requires an understanding of the character of load profiles and the availability of dispatchable electricity. Second, understanding the resilience of the power sector to future stressors will require an assessment of the interactions of the power sector with co-evolving natural and human systems within a multi-sectoral context. For example, future temperature increases could lead to an increase in the demand for air conditioning resulting in increased peak demands and consequently the need for additional capacity.

Many analytical tools are used for long-term power sector planning. Power sector focused models capture the complexities of electricity supply and demand but are limited in capturing the interactions of the sector with the broader system (Electric Power Research Institute, 2017; Eurek et al., 2016; Paul et al., 2009). In contrast, multi-sector human-Earth system models capture complex relationships across sectors and systems but represent power sector dynamics at fairly aggregate levels (Pietzcker et al., 2016). We study the evolution of the electricity system by simultaneously accounting for power sector focused process dynamics and the interactions of the power sector with the broader system under a consistent integrated framework.

To do so, we make improvements to GCAM-USA, a long-term multi-sector human-Earth system model with state-level detail in the U.S.(Iyer et al., 2017a; Iyer et al., 2017b). We incorporate i.) information about sub-annual demand profiles combined with the ability to separate investment and operation decisions to track capacity requirements in response to changes in peak demands and ii.) relationships between temperature change and peak electricity demands in the building sector. Using the improved model, we study investments and operations in the US power sector under plausible scenarios of future temperature variability and extremes.

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Title: **The E3SM Code Development Process**

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BER Program: ESM

Project: Energy Exascale Earth System Model

Project Website: http://www.e3sm.org

Project Abstract:

The E3SM phase 1 Software Engineering group established processes and tools for code development of our new Earth system model. Our goals were to establish a process that allows for high productivity of model development across a large dispersed team while maintaining a trusted, working code base, all with an eye to long-term agility and sustainability. We established a distributed version control workflow through a set of "integrators" that provides a scalable way to do code development, ensure code quality, and triage problems. Our procedure includes a multi-layered testing strategy to balance frequent commits of new features while also keeping confidence that the model is running correctly on all of the targeted computational resources. The testing framework is based on the Case Control System from CIME, the Common Infrastructure for Modeling the Earth, which was rewritten in python by E3SM and CESM developers during phase 1. Where possible, we looked to adopt common Open Source software tools to minimize the software maintenance burden and decrease the learning curve for future E3SM software engineers, including: git, Github Issues, Jenkins, CDash, slack, and Python. In this talk we will present our set of tools and processes, discuss improvements that are in the works, and solicit suggestions for future.

Title: **Investigating the Role of Sea Ice Biogeochemistry in the Marine-DMS-Climate Feedback using E3SMv0-HiLAT**

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BER Program: RGCM

Project: HiLAT – High-Latitude Application and Testing of Earth System Models

Project Website: https://www.hilat.org

Project Abstract:
One of the important ways polar marine biogeochemistry modifies climate is through the production of dimethyl sulfide (DMS) pre-cursor. In clean-air regions, such as the Southern Ocean, the marine DMS flux is a significant contributor to the production of non-sea salt sulfate aerosol, which influences cloud albedo through the indirect affect. Recent work by Wang et al. (2018) suggests a weak positive phytoplankton-DMS-climate feedback on global scales. However, the authors also find that surface DMS production is strongly dependent on planktonic ecosystem structure and individual autotrophic responses to warming climate, and that estimates of climate feedbacks are also dependent upon representation of this structure and response. Notably absent from these and previous analyses, particularly given the importance of polar regions, is sea ice algal production of DMS pre-cursor, a known cryoprotectant. To investigate the role of sea ice biogeochemistry in the marine DMS-climate feedback, we conduct several simulations using the fully coupled E3SMv0-HiLAT model with active ocean and sea ice biogeochemistry. Phytoplankton and ice algal sub-modules contain explicit representations of *Phaeocystis* sp., an efficient organosulfur producer adapted to polar regions, as well as the ubiquitous diatom. In addition, sulfur cycling is modelled in sea ice, ocean, and atmosphere with dynamic cloud response. Simulations contrast a pre-industrial (PI) control with climate conditions under four times present day CO_2 concentrations. In the PI control, potential contributions of ice algal chlorophyll to the upper ocean layer are twice the modelled values poleward of 75^{o}N and 65^{o}S. However, DMS contributions from ice algal production are less than half the surface values in the same regions. Marine surface DMS concentrations in a warming climate show marked overall decreases, with some regional increases in the sea ice zone. Notably, surface chlorophyll remains fairly stable throughout the Southern hemisphere, a further indication of the importance of phytoplankton community structure in sulfur cycling. Results indicate that sea ice biogeochemistry modifies the DMS-climate feedback through direct production of DMS pre-cursor and indirectly through biochemical enhancement of diatom production in the upper ocean.

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Impacts on water-mass transformation from ice shelf melting over the Southern Ocean in E3SM v1 simulations

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BER Program: ESM

Project: E3SM

Project Website: https://e3sm.org

The Southern Ocean is an important driver for the meridional overturning circulation and it plays a major role in the transport of heat, the uptake of carbon and the global climate system. The strength of the global abyssal overturning circulation is proportional to the rate at which Antarctic bottom water (AABW) is produced and this production rate is determined by net surface buoyancy loss. Due to the low thermal expansion of seawater at low temperatures, buoyancy loss in polar waters is strongly dominated by the surface freshwater flux rather than heat flux. Data-assimilating models show that sea-ice formation and melting are the most important processes for water-mass formation over the Southern Ocean, followed by precipitation. Even though glacial melt is relatively small in magnitude, it is located spatially very close to convection areas, where it may also have an influence on dense water formation. Furthermore, ice shelves can contribute to the freshwater flux both directly by meltwater input, and indirectly by impacting stratification and circulation in ways that feedback on sea-ice formation and melt. Recently, the Department of Energy (DOE) has developed a new global coupled climate model, the Energy Exascale Earth System Model (E3SM) version 1. Using coupled and ocean/sea-ice stand-alone simulations from E3SM, we analyze the impacts of glacial melt over the Southern Ocean on water-mass transformation/formation. Both simulations show that the freshwater flux from land ice to the ocean increase upwelling water as a direct impact and that it can also affect water-mass transformation caused by sea-ice formation as an indirect impact.

Hailstone Temporal and Spatial Trend and Variabilities over the Central United States

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BER Program: DOE Early Career Research Program

Project: Understanding Severe Convective Storms in the Central United States ("SCS" project)

Hailstones pose a significant threat to property and economy. Therefore, a detailed knowledge of their occurrence and characteristics is essential. Further understanding the dynamic and physical factors contributing to hail formation and hailstone size is of a great importance to the weather and climate prediction and policy makers. In this study we analyze the temporal and spatial variabilities for hail occurrence over the Southern Great Plain (SGP) and Northern Great Plain (NGP) in the recent decade over 2004-2016 with two datasets: NOAA Storm Prediction Center (SPC) and the newly-developed radar-retrieved the maximum expected size of hail (MESH) data. We found that in spring, the occurrence of the significant severe hail has a trend of moving toward southern Texas. However, in summer, the hail zone has a northwest expansion over NGP. The increasing trend of hail occurrence over NGP and the southeast part of SGP is statistically significant. The hail occurrence frequency over SGP has a large year-to-year variability. This inter-annual variability correlates with sea surface temperature (SST) anomalies over Gulf of Mexico (GoM): with more (less) hail occurrence under warm (cold) SST anomaly. This is because warmer SST increases specific humidity and convective available potential energy over SGP through low-level jet, leading to stronger convective storms. Moreover, the hail occurrence frequency over SGP correlates with satellite retrieved aerosol optical depth (AOD) to some extent. The increase of AOD in Spring over SGP is mainly due to the transport of smoke aerosols from the Central America. Therefore, both dynamic and physical factors contribute to the magnitude of the hail annual variability.

Title: **Understanding the Dynamics and Thermodynamics of ENSO and Its Complexity Simulated in Climate Models: Progress and Plans**

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BER Program: RGCM

Project: **Understanding the Dynamics and Thermodynamics of ENSO and Its Complexity Simulated by E3SM and Other Climate Models**

Abstract

Despite the seeming success of most state-of-the-art climate models in simulating the El Niño-Southern Oscillation (ENSO), there is strong evidence that models may often achieve realistic levels of ENSO activity for the wrong reasons. This occurs due to a near-cancellation of large errors in the relative contribution of coupled dynamic and thermodynamic feedback processes to the growth of ENSO anomalies. Climate models remain deficient in simulating the observed ENSO spatial and temporal complexity that involves interplays of coupled dynamic and thermodynamic feedbacks, interactions across multiple scales, nonlinear processes in the tropical atmosphere and ocean system, biases in mean sate and physical processes, and influences external to the equatorial Pacific coupled ENSO dynamics. We aims at advancing predictive and process-level understandings of ENSO simulated in climate models under current and future climate conditions, using a hierarchy of coupled dynamical frameworks to analyze, diagnostics and explore pathways towards improving GCM's capability of simulating ENSO and its complexity. Some preliminary results will be present on examining ENSO's dynamic and thermodynamic feedbacks; the across-scale interactions of ENSO and MJO/WWB/TIW activity; and nonlinear ocean dynamic heating on simulated ENSO. Plans for further investigations of fundamental properties of ENSO in E3SM and CMIP6 outputs will be discussed.

How to Drive Your New Hybrid Computer

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BER Program: ESM

Project(s): Coupling Approaches for Next-Generation Architectures (CANGA), E3SM

Project Website: http://canga-scidac.org

Exascale and next-generation computer architectures feature hybrid elements and enhanced parallelism throughout the node, requiring new approaches to achieve high performance. The past few decades of wasteful, gas-guzzling CPUs have encouraged some poor driving practices. We will describe a number of approaches to getting the best performance out of your new hybrid vehicle and present some early experiences with alternative driving styles. Your mileage may vary.

Conservative Explicit Local Time-Stepping Schemes for the Shallow Water Equations

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BER Program: ESM

Project: University Award

We develop explicit local time-stepping (LTS) schemes with second and third order accuracy for the shallow water equations. The system is discretized in space by a C-grid staggering method, namely the TRiSK scheme adopted in MPAS-Ocean, a global ocean model with the capability of resolving multiple resolutions within a single simulation. The time integration is designed based on the strong stability preserving Runge-Kutta (SSP-RK) methods, but different time step sizes can be used in different regions of the domain through the coupling of coarse-fine time discretizations on the interface and are only restricted by respective local CFL conditions. The proposed LTS schemes are of predictor-corrector type in which the predictors are constructed based on Taylor series expansions and SSP-RK stepping algorithms. The schemes preserve some important physical quantities in the discrete sense, such as exact conservation of the mass and potential vorticity and conservation of the total energy within time-truncation errors. Moreover, they inherit the natural parallelism of the original explicit global time-stepping schemes. Extensive numerical tests including are presented to illustrate the performance of the proposed algorithms in accuracy, conservation ability and parallel scalability.

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Title: Greening of the Land Surface in the World's Cold Regions Consistent with Recent Warming

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BER Program: Regional and Global Climate Modeling

Project: RUBISCO

Project Website: https://www.bgc-feedbacks.org/

Project Abstract:

Global ecosystem function is highly dependent on climate and atmospheric composition, yet ecosystem responses to environmental changes remain uncertain. Cold, high-latitude ecosystems in particular have experienced rapid warming, with poorly understood consequences. Here, we use a satellite observed proxy for vegetation cover – the fraction of absorbed photosynthetically active radiation – to identify a decline in the temperature limitation of vegetation in global ecosystems between 1982 and 2012. We quantify the spatial functional response of maximum annual vegetation cover to temperature and show that the observed temporal decline in temperature limitation is consistent with expectations based on observed recent warming. An ensemble of Earth system models from the Coupled Model Intercomparison Project (CMIP5) mischaracterized the functional response to temperature, leading to a large overestimation of vegetation cover in cold regions. We identify a 16.4% decline in the area of vegetated land that is limited by temperature over the past three decades, and suggest an expected large decline in temperature limitation under future warming scenarios. This rapid observed and expected decline in temperature limitation highlights the need for an improved understanding of other limitations to vegetation growth in cold regions, such as soil characteristics, species migration, recruitment, establishment, competition, and community dynamics.

Shifting Flood Risk Perceptions and Housing Market Outcomes; A Multi Regional Analysis, Houston, Texas and Tampa Bay, FL

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Project: PCHES

Global costs associated with coastal flooding are high and rising, but results from hedonic property studies in the economics literature suggest that housing markets may not fully capitalize flood risk. Some, but not all, studies suggest that at-risk properties sell at a discount, but published estimates range from steep discounts to (counterintuitively) small premiums. The reasons for this variation are poorly understood, and the consequences are significant; coastal cities' resilience to increasing flood frequency and magnitude, as well as the fiscal solvency of federal disaster relief programs, depend on the ability of property buyers and sellers to accurately assess risk. This paper examines two potential reasons for variation in the responsiveness of housing prices to flood risk: inadequate representation of risk in prior studies, and variation in household characteristics that may affect risk perception and valuation. We focus on two housing markets with significant flood risk: Houston, TX and Tampa Bay, FL, from 2000-2016. Using the standard reduced-form hedonic approach in the economics literature, preliminary results are consistent with the wide variation observed in the literature -- housing prices in Houston do not reflect flood risk, and prices in Tampa do. To test whether these inconsistent results are due in part to misspecification, we develop a spatially-refined measure of prior flood exposure that reflects flood presence in a property's sub-watershed, rather than coarser measures at the whole metropolitan area or the county (typical of prior work). Preliminary results suggest that property prices may respond more to a local flood measured using this new method than a regional one. To test whether household characteristics may drive the degree to which housing prices reflect flood risk, we will match our housing data with homeowner demographic data for both cities, allowing us to follow homeowners across multiple transactions. We will then estimate reduced-form hedonic property models for each of the two markets by income quantile, to see if flood risk responsiveness varies with characteristics such as income and education. Results will inform efforts to reform federal and state flood risk disclosure policies and other efforts to educate property owners about flood risk.

The FLOod Probability Interpolation Tool (FLOPIT)

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BER Program: IA

Project: Program on Coupled Human and Earth Systems (PCHES) under Cooperative Agreement No. DE-SC0016162

Project Website: https://www.pches.psu.edu/

Project Abstract

Understanding flood hazards is essential to managing flood risks. Flood hazard information is used, for example, to inform decisions about insurance rates, development plans, and choices to buy, sell, or flood-proof homes. Current hazard assessments typically rely on flood zones (i.e. the 100- and 500-year flood zone) for communication. However, binning hazards into such coarse categories can lead to biased estimates and poor decisions. Here we develop and test the FLOod Probability Interpolation Tool (FLOPIT) to help to address this issue. FLOPIT uses flood zones as delineated by published hydraulic and hydrologic models of water surface elevation for a given probability flood event. FLOPIT interpolates the published flood hazards between water surface elevation maps to produce continuous maps. This continuous flood hazard mapping is relatively simple and easily applied to already existing datasets used to create flood zones. Using openly available data (e.g., FEMA and state datasets), we demonstrated the use of this tool for three cities; Houston, TX., Muncy, PA., and Selinsgrove, PA. We use the example of Houston, TX, to demonstrated and quantify how moving from the coarse flood zones to the interpolated hazard maps can improve accuracy and bias.

Effects of Mixed Distribution Statistical Flood Frequency Models on Dam Safety Assessments: A Case Study of the Pueblo Dam

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BER Program: IA

Project: Program on Coupled Human and Earth Systems (PCHES) under Cooperative Agreement No. DE-SC0016162

Project Website: https://www.pches.psu.edu/

PI: John Weyant

Project Abstract

Statistical flood frequency analysis, coupled with hydrograph scaling, is commonly used for dam safety assessment. These safety assessments can be highly sensitive to the choice of the statistical flood frequency model. Past studies typically use a single distribution model, often the Log Pearson Type III or Generalized Extreme Value distributions. Floods, however, may result from multiple physical processes such as snowmelt or rainstorms. This can result in a mixed distribution of annual peak flows. Engineering design choices based on a single distribution statistical model are vulnerable to the effects of this potential structural model error. We analyze observations from Pueblo, Colorado, for model testing, where summer snowmelt and intense summer rainstorms are key drivers of annual peak flows. We analyze the potential implications for the annual probability of overtopping induced failure of the Pueblo Dam as a didactic example. We address the temporal and physical cause separation problems by building on previous work with mixed distributions. We first use hydrograph scaling and a flood routing model to determine the smallest flood to cause overtopping. We then analyze annual peak flows, historical floods, and paleoflood records through single and mixed distribution statistical models to estimate overtopping flood return periods. We first identify mixed distributions of peak flows using statistical flood frequency models and robust model choice criteria. We then identify the Mixed Generalized Extreme Value distribution as the best model for mixed distribution flood frequency analysis in this case. Finally, we show that accounting for mixed distributions can greatly increase predicted flood risk.

We find a significant enhancement of the North Atlantic subtropical high (NASH) on interannual timescales (1970-2016) concurrently linked to an anomalously strong Indian monsoon in September. Consistent with a stronger NASH, enhanced anticyclonic flow and subtropical easterlies in the eastern Atlantic basin are found during strong monsoon years. Observational regression analysis combined with a statistical track model are used to assess the influence of these monsoon-linked wind variations on Atlantic TC tracks originating in the main development region (MDR). When controlling for effects of El Niño Southern Oscillation (ENSO), a westward shift of TC tracks is shown to be robustly correlated to internal monsoon variability in September. This work highlights variability of the Indian monsoon as an additional constraint on Atlantic TCs, with increased landfall probability during a strong monsoon. Previous attribution of similar steering effects to ENSO need to be reconsidered to account for ENSO’s correlation with the monsoon.

Title: **Using LIVVkit to Evaluate Ice Sheet Surface Mass Balance in E3SM**

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BER Program: Earth System Modeling (ESM)
Project: ProSPect
Project Website: https://doe-prospect.github.io/

Making robust real-world predictions of ice flow behavior requires an accurate representation of ice sheets and glaciers within Earth system models. Verification and validation (V&V) is a set of techniques used to quantify model confidence and can be used to enhance the credibility of models. LIVVkit is a land ice V&V toolkit being developed within the ProSPect project and available in the e3sm_unified conda environment. It includes a new surface mass balance (SMB) validation extension that analyses E3SM's modeled SMB to observed SMB, both visually and analytically. As part of the analysis, a wide variety of detailed visualizations are generated covering both Greenland and Antarctica. These include, for example, map-view pseudocolor representations of the modeled and observed SMB for the whole ice sheet, as well as for individual drainage basins. Observations used for comparison include multiple core and stake SMB datasets, in both the ablation and accumulation zones, and SMB estimates from NASA's Operation IceBridge airborne radar data.

LIVVkit compiles all the produced visualizations, statistics, and comparison information into a dynamic and portable website, which can be easily hosted or shared with colleagues. This allows model developers and users to build confidence in their model and credibility throughout the Earth system modeling community.

Title: **Moving Beyond Bit-for-bit: Reproducibility Testing in E3SM**

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BER Program: Earth System Modeling (ESM)
Project: CMDV-SM
Project Website:
https://climatemodeling.science.energy.gov/projects/cmdv-sm-global-climate-model-software-modernization-surge

Continuous testing of model changes is critical to developing a credible Earth system model. Code modification can impact a model's results in three ways:

1. Changes continue to produce bit-for-bit identical solutions
2. Changes that cause numerical differences, yet produce a statistically identical climate
3. Changes that cause numerical differences and produce a different climate

Only in the third case must changes undergo an extensive review before being accepted into the model. However, E3SM does not yet have a robust way to distinguish between type 2 and type 3 changes. This results in a large development burden as all non-bit-for-bit changes must be treated as climate changing and undergo a time-intensive review process, often relying on subjective expert opinion.

Through the CMDV-SM project, a series of statistical climate reproducibility tests have been developed and are being evaluated for use in regular integration testing. These tests use a variety of approaches for testing whether numerical differences are also climate changing. The multivariate tests evaluate climate statistics of a ~1 year test ensemble against that of a baseline ensemble, by using several modern nonparametric (distribution-free) two-sample statistical tests for multivariate data to determine the equality of distributions. Alternatively, the perturbation growth test is a deterministic test method that determines if the divergence of atmospheric state between a baseline and a test ensemble within a single time step is larger than the growth of rounding-level initial perturbations. A large deviation after any parameterization update indicates both test failure and the specific parameterization causing the failure. Likewise, the time-step convergence test is another deterministic test method that determines if the test ensemble convergences to the baseline's reference ensemble after ~10 minutes of simulation and hence can be considered equivalent to the baseline within numerical uncertainty.

These tests are being integrated into E3SM's case control system CIME in order to provide a consistent workflow to developers and use EVV (Extended Verification and Validation for Earth System Models), a python based analysis package, to perform the statistical analyses. In addition to providing a pass-fail test result, EVV produces a portable website that details the test analysis, the obtained results, and any relevant figures (e.g., P-P plots). This allows clear and contextualized testing results to be quickly shared among developers when evaluating changes and will accelerate model development by allowing type 2 changes to be integrated rapidly.

Title: The Madden-Julian Oscillation, Tropical Cyclones, and Precipitation Extremes in E3SMv1

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BER Program: RGCM

Project: Process-oriented diagnosis of the Madden-Julian oscillation, tropical cyclones, and precipitation extremes in E3SMv1

Project Website:

Project Abstract: Despite recent improvements, many Earth system models (ESMs) still show strong biases in the representation of the Madden-Julian oscillation (MJO), tropical cyclones (TC), and mid-latitude extreme precipitation events. These biases limit the reliability of model predictions and projections for informing societally-relevant decisions. Strong connections among the MJO, TCs, and precipitation extremes motivate the needs to understand these processes and errors in their representations synergistically.

We will present preliminary results of our process-level diagnosis of the MJO, TCs, and precipitation extremes in DOE's Energy Exascale Earth System Model version 1 (E3SMv1). Both low- and high-resolution simulations will be examined. Our diagnostic will include key processes associated with MJO propagation and maintenance, TC genesis and intensification, and frequency and location of mid-latitude precipitation extremes in simulations made with E3SMv1. Biases in the representations of the MJO, TCs, and precipitation extremes will be identified by comparing the model diagnostics to corresponding observations. Possible causes, especially those that are rooted in the errors in the parameterization schemes, of the biases will be discussed.

Can NAO-Related Buoyancy Fluxes in the Labrador Sea Alone Produce Atlantic Multidecadal Variability and Its Associated Climate Impacts?

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BER Program: RGCM
Project: HiLAT, NOAA/CPO/CVP, NSF/EaSM2
Project Website: https://www.hilat.org

Multidecadal variability in the North Atlantic sea surface temperatures, often referred to as the Atlantic multidecadal variability (AMV), is a key source of low-frequency climate variability, particularly in the Northern Hemisphere. Atlantic meridional overturning circulation (AMOC) variability on multidecadal timescales and its associated heat transport are often invoked as the driving mechanism of AMV, but such a prominent role for AMOC is still under debate. Additionally, how multidecadal AMOC variability comes about remains an active research area with numerous proposed mechanisms. Here, we test the hypothesis that buoyancy fluxes associated with the North Atlantic Oscillation (NAO) over the Labrador Sea alone can produce AMV-like patterns and associated climate impacts through thermohaline circulation changes in a coupled model framework. In our ensemble simulations, surface heat flux perturbations associated with the NAO are added to / subtracted from surface heat fluxes of the ocean component of the Community Earth System Model, using a similar approach as in Delworth et al. (2015), but only over the Labrador Sea. These NAO-related perturbations are applied during the first 10 winters of 20-year simulations with 10 ensemble members for each positive and negative heat flux perturbations. We find an increase in deep water formation in the Labrador Sea along with strengthening in basin-scale AMOC and buoyancy-driven subpolar gyre, but heat convergence occurs in a relatively small area in the subpolar North Atlantic. The atmospheric response to this localized subpolar warming resembles the negative phase of the NAO, which drives the subtropical–tropical extension of AMV and reinforces the subpolar component of AMV through surface heat fluxes, eventually evolving into a conventional AMV pattern. We also identify most of the climate impacts associated with AMV reported previously. Our study not only underpins the importance of NAO-related buoyancy forcing over the Labrador Sea and response of ocean dynamics to this forcing, but also shows the critical role of the atmospheric response to the ocean-driven heat anomalies in creating the full structure of AMV and its associated climate impacts.

Observed Tropical Low Cloud Feedbacks and Their Dependence on Environmental Changes

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BER Program: RGCM

Project: LLNL Climate SFA/Cloud Feedbacks

Project Website: https://pcmdi.llnl.gov/projects/cloud_feedbacks/

Project Abstract: Observational evidence that the tropical low cloud feedback is positive is summarized according to Klein et al. 2017 (10.1007/s10712-017-9433-3). This study reviews a number of different studies including our earlier work in Qu et al. 2015 (10.1002/2015GL065627) and Qu et al. 2014 (10.1007/s00382-013-1945-z). The magnitude of positive feedback magnitude is in agreement with that predicted by large-eddy simulations. Both the observational and modeling evidence rely upon knowing the changes in the environmental conditions, most notably the inversion strength, which are taken from future simulations by CMIP models. Given model predicted changes in inversion strength (Qu et al. 2015, 10.1007/s00382-014-2441-9), the tropical low cloud feedback is clearly positive. However, if the warming of sea-surface temperature (SST) in the tropical deep convection regions exceeds that of the tropical low-cloud regions then the inversion strength will markedly increase causing the tropical low cloud feedback to go to zero or even become negative. Observational evidence from Zhou et al. 2016 (10.1038/ngeo2828) is presented that a dramatically increased SST gradient occurred over the period 1979 to present causing the low-clouds to increase, even as the planet warmed. Our idealized modeling experiments with regionally specified SST warming patches supports this conclusion (Zhou et al. 2017, 10.1002/ 2017MS001096). As a result, how the SST gradients between warm and cold regions in the tropics changes with climate warming is a crucial question determining the ultimate magnitude of low cloud feedbacks. Work at LLNL was performed under the auspices of the United States Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. LLNL-ABS-758429.

Title: **A Framework for Testing Plant Allocation and Reactive Transport Hypotheses**

Ryan Knox*[1], Charles Koven[1], William Riley[1], Gautam Bisht[1], Jeff Chambers[1], Bradley Christoffersen[2], Jennifer Holm[1], Rosie Fisher[3], Lara Kueppers[1], David Medvigy[4], Jacquelyn Shuman[5], Anthony Walker[6], Liang Wei[7] and Chonggang Xu[7]

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BER Program: TES, ESM

Project: NGEE-Tropics, CMDV-Land,

Project Website: https://ngee-tropics.lbl.gov/

Project Abstract:The land-surface components of several Earth System Models have the capacity to represent the size and compositional structure of terrestrial plants (FATES, ED, SEIB-DGVM, LPJ-GUESS, Ent, etc). Subsequently, these models can represent dynamic processes that operate on single plants, plant cohorts or other similar scaling structures closely tied to plant biology and physiology, that were previously intractable. While the model framework exists to simulate the allocation and reactive transport of nutrients and carbon isotopes in terrestrial vegetation, these processes are not as well understood as other aspects like leaf physiology and chemistry.

Here we present a software framework designed to enable the testing and intercomparison of different hypotheses for nutrient and carbon isotope allocation and reactive transport in plants. This framework, called the Plant Allocation and Reactive Transport Extensible Hypotheses (PARTEH) is designed with an emphasis on modularity and extensibility, and makes use of modern Fortran programming standards such as inheritance to facilitate the addition of new hypotheses. These hypotheses are evaluated both as a single plant simulation environment, and as coupled with the Functionally Assembled Terrestrial Ecosystem Simulator (FATES). An evaluation of at least two different schemes is presented, a carbon-only allometry based allocation model, and a nitrogen-phosphorous model based on stoichiometric targets with allometrically based carbon. The testing and inclusion of this framework within an ESM highlights the importance of size-structured vegetation and the associated allometric relationships implemented in nutrient transport, as well as areas in need of more research.

Assessing rainfall intensity from resolved and parameterized processes in the Community Atmosphere Model with high-resolution and superparameterization

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BER Program: RGMA

Project: University

Abstract:

Deficiencies in the parameterizations of convection used in global climate models often lead to a distorted representation of the simulated rainfall intensity distribution (i.e., too much rainfall from weak rain rates). While encouraging improvements in high percentile rainfall intensity have been found as the horizontal resolution of the Community Atmosphere Model is increased to ~25 km, we demonstrate no corresponding improvement in the moderate rain rates that generate the majority of accumulated rainfall. Using a statistical framework designed to emphasize links between precipitation intensity and accumulated rainfall beyond just the frequency distribution, we show that the Community Atmosphere Model (CAM) cannot realistically simulate moderate rain rates, and cannot capture their intensification with climate change, even as resolution is increased. However, by separating the parameterized convective and large-scale resolved contributions to total rainfall, we find that the intensity, geographic pattern, and climate change response of CAM's large-scale rain rates are more consistent with observations (TRMM 3B42), superparameterization, and theoretical expectations, despite issues with parameterized convection. Increasing CAM's horizontal resolution does improve the representation of total rainfall intensity, but not due to changes in the intensity of large-scale rain rates, which are surprisingly insensitive to horizontal resolution. Rather, improvements occur through an increase in the relative contribution of the large-scale component to the total amount of accumulated rainfall. Analysis of sensitivities to convective timescale and entrainment rate confirm the importance of these parameters in the possible development of scale-aware parameterizations, but also reveal unrecognized trade-offs from the entanglement of precipitation frequency and total amount.

Publication:

Kooperman, G. J., M. S. Pritchard, T. A. O'Brien, and B. W. Timmermans (2018), Rainfall from resolved rather than parameterized processes better represents the present-day and climate change response of moderate rates in the Community Atmosphere Model, *Journal of Advances in Modeling Earth Systems*, **10**, 971-988. https://doi.org/10.1002/2017MS001188

Title: **Exploring Vegetation Responses to Climate Extremes Using the FATES Model**

Charles Koven[1]*, Ryan Knox[1], Rosie Fisher[2], Lara Kueppers[1], Jeff Chambers[1], Jennifer Holm[1], Brad Christoffersen[3], Chonggang Xu[4], Tom Powell[1]

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BER Program: RGCM, ESM, TES

Project: Early Career Research Program, LBNL; and NGEE-Tropics

Project Website: n/a

Project Abstract:

Vegetation responses to climate extremes include both short-term direct responses to the climate extremes, as well as longer-term responses that are mediated by ecological shifts in response to the extreme. These include both shifts in the functional composition of the ecological community and in the structure of individuals within the environment. A major rationale for developing structured ecosystem models such as FATES is to represent these responses, and their role in the coupled Earth system. Here we will discuss recent work using the FATES model, in both tropical forests and the western US, to begin to explore these dynamics.

Evaluating Atmospheric River Detection Algorithms using state-of-the-art heuristics and machine learning techniques.

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BER Program: [RGCM]
Project: Calibrated & Systematic Characterization, Attribution, & Detection of Extremes (CASCADE)
Project Website: http://cascade.lbl.gov

As part of CASCADE's effort to comprehensively understand uncertainty in detection and characterization of atmospheric rivers (ARs), our group will present results and highlights on two active approaches in development. First, by comparing and evaluating uncertainty between algorithms proposed by the Atmospheric River Tracking Method Intercomparison Project (ARTMIP) within a single analysis infrastructure, namely TECA. Second, by using a state-of-the-art convolution neural network trained on ARTMIP detection results producing a novel machine learning (M.L.) based AR detector.

ARTMIP defines ARs as dynamically driven, filamentary structures. They are often associated with extreme winter storms and heavy precipitation along the western coasts of mid-latitude continents and have the ability to produce major flooding events and/or relieve droughts. One of the major results from ARTMIP is a comprehensive survey of major AR detection algorithms as well a well defined standardized output of results applied to MERRA-2 data.

We will highlight several analytical tools aimed at evaluating uncertainty in the current AR detection and analysis approaches. Current highlight results on CASCADE's effort includes improving accuracy using a 16-layer model pre-trained on ImageNet attaining 92% accuracy of detections.

Finally, our diagnostic tools are designed to be scalable to address current and future data results produced from the latest versions of E3SM and CESM as well as evaluated on CMIP6 . This is exemplified by our use case being one of the finalists at 2018 Gordon Bell Prize as Super Computing for reaching ~1 Exascale-ops sustained performance on the Summit supercomputer.

Exploration and Quantification of Uncertainty in integrated Energy-Water-Land Systems

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Water resources management largely occurs at regional scales, yet water systems are shaped by global change through the interdependent evolution of climate, energy, agriculture, and industrial systems. Therefore, it is important for regional actors to account for the impacts of global changes on their systems in a globally consistent but regionally relevant way. This can be challenging because emerging global reference scenarios may not reflect regional sources of challenge; likewise, regional scenarios may miss important global/national feedbacks. In this collaborative work between the Joint Global Change Research Institute (JGCRI) and Tufts University, we contribute a scenario discovery framework to identify regionally-specific, decision relevant scenarios from an ensemble of global change scenarios. To this end, we generate a large ensemble of time evolving regional, multi-sector global change scenarios by sampling the underlying assumptions of the shared socio-economic pathways (SSPs), using the Global Change Assessment Model (GCAM). We create corresponding hydrologic scenarios using the Xanthos model, and downscale each scenario's land and water use to a basin level using Tethys and Demeter, to enable sub-regional analyses of sustainability under uncertainty. Statistical and visual analytics are used to discover which SSP/hydrologic assumptions are particularly consequential for various regions, considering a broad range of time-evolving metrics that encompass multiple spatial scales and sectors. We identify the most important global change narratives to inform water resource planning scenarios for several geographic regions using the proposed scenario discovery framework. Our results highlight the relative importance of demographic and agricultural evolution compared to technical improvements in the energy sector. We show that relying solely on a few canonical reference scenarios provides a narrow view of the consequence space, increasing the risk of tacitly ignoring major impacts. Formulating consequential scenarios of deeply and broadly uncertain futures requires a better exploration of which quantitative measures of consequences are important, for whom they are important, where, and when. To this end, we will contribute a large database of climate futures that can support 'backwards' scenario generation techniques, and that capture a broader array of consequences than those that emerge from limited sampling of a few reference scenarios.

Title: Applying ILAMB to data from several generations of the Community Land Model to assess the relative contribution of model improvements and forcing uncertainty to model-data agreement

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BER Program: RGCM

Project: RUBISCO

Project Website:

Project Abstract:

The International Land Model Benchmarking (ILAMB) project is a model-data intercomparison and integration project designed to assess and help improve land models. The current package includes assessment of more than 25 land variables across more than 60 global, regional, and site-level (e.g., FLUXNET) datasets. ILAMB employs a broad range of metrics including RMSE, mean error, spatial distributions, interannual variability, and functional relationships. Here, we apply ILAMB for the purpose of assessment of several generations of the Community Land Model (CLM4, CLM4.5, and CLM5). Encouragingly, CLM5, which is the result of model development over the last several years by more than 50 researchers from 15 different institutions, shows broad improvements across many ILAMB metrics including LAI, GPP, vegetation carbon stocks, and the historical net ecosystem carbon balance among others. We will also show that considerable uncertainty arises from the historical climate forcing data used (GSWP3v1 and CRUNCEPv7). ILAMB score variations due to forcing data can be as large for many variables as that due to model structural differences. Strengths and weaknesses and persistent biases across model generations will also be presented.

Quantifying the Agreement Between Observed and Simulated Extratropical Modes of Interannual Variability

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BER Program: RGCM
Project: PCMDI
Project Website: https://pcmdi.llnl.gov/

Using Historical simulations of the Coupled Model Intercomparison Project-5 (CMIP5) models and multiple observationally-based datasets, we employ skill metrics to analyze the fidelity of the simulated Northern Annular Mode (NAM), the North Atlantic Oscillation (NAO), the Pacific North America pattern (PNA), the Southern Annular Mode (SAM), the Pacific Decadal Oscillation (PDO), the North Pacific Oscillation (NPO), and the North Pacific Gyre Oscillation (NPGO). We assess the benefits of a unified approach to evaluate these modes of variability, which we call the common basis function (CBF) approach, based on projecting model anomalies onto the observed empirical orthogonal function (EOF). The CBF approach circumvents issues with conventional EOF analysis, including the need to correct for arbitrary signs of EOF's/PC's, and the need to test if higher-order model modes better compare with the observed modes. Compared to conventional EOF analysis of models, the CBF approach indicates that models compare significantly better with observations in terms of pattern correlation and root-mean-squared-error (RMSE) than heretofore suggested. In many cases, models are doing a credible job at capturing the observationally-based estimates of patterns; however, errors in simulated amplitudes can be large and more egregious than pattern errors. Sensitivity tests demonstrate that the results from our objective tests are relatively insensitive to methodological considerations (CBF vs. conventional approach), observational uncertainties in pattern (as determined by using multiple datasets), and internal variability (when multiple realizations from the same model are compared). The skill metrics proposed in this study can provide a useful summary of the ability of models to reproduce the observed EOF patterns and amplitudes. Additionally, the skill metrics can be used as a tool to objectively highlight where potential model improvements might be made. We advocate more systematic and objective testing of simulated extratropical variability, especially during the non-dominant seasons of each mode, when many models are performing relatively poorly.

Investigation of the Latent Heat Polynya to the North of Greenland in February 2018

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BER Program: RGCM
Project: Advancing Arctic Climate Projection Capability at Seasonal to Decadal
Project Website: http://www.oc.nps.edu/NAME/RASM_PhaseIII.html

As the Arctic has been experiencing an unprecedented warming, sea-ice loss has been accelerated and linked to shifts in the atmospheric and oceanic circulations. It has been observed that the frequency and duration of Arctic winter warming has increased. There is an evidence that the primary changes of the Arctic sea ice cover relate to thinning and the decline of multi-year ice cover. At the same time, sea ice drift speed and deformation has increased, implying stronger fracturing and more lead opening, as the younger and thinner Arctic sea ice becomes more vulnerable to wind forcing. In the late February 2018, satellite measurements captured images illustrating the development of a polynya north of Greenland, between the Lincoln and Wandel Seas, where polynyas have not been previously active. It was reported that the emergence of this polynya event was strongly associated with the significantly warm air-temperature over the northeastern Greenland.

Using a fully-coupled sea ice-ocean-atmospheric model known as Regional Arctic System Model (RASM), we diagnosed that a similar polynya event north of Greenland has been simulated by RASM between 15 and 25 February, 2018. We have further determined the processes involved in the formation of the polynya by linking atmospheric forcing based on retrospective observational data and model results. The RASM simulation demonstrated that change of sea-ice in this region was not influenced by thermodynamic ice melt but was predominantly due to dynamic ice transport and redistribution. We have associated this polynya with the specific wind pattern over the northern Greenland region, i.e. southeasterly winds, and demonstrated that similar yet smaller polynya events developed in winters of earlier years, such as in 2001, 2011, and 2017. The sudden warming of Arctic exhibited little impact on melting of sea-ice to the north of Greenland, while counterintuitively the rate of thermodynamic ice growth was almost doubled up in the region during and after the polynya opening. Furthermore, sea-ice was not fully replenished there before the following melt season, as relatively thinner, i.e. less than 2-m sea ice persisted through the end of March. This in turn might have preconditioned the sea-ice in this region for 2018 summer melt and re-occurrence of polynya in the similar location.

Title: **Observation and Modeling of Mesoscale Convective Systems and Their Large-Scale Environment**

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BER Program: RGCM

Project: Water Cycle and Climate Extremes Modeling (WACCEM) SFA

Project Website: https://climatemodeling.science.energy.gov/projects/water-cycle-and-climate-extremes-modeling

Project Abstract:

Organized mesoscale convective systems (MCSs) are responsible for ~60% of summer rainfall in the U.S. Great Plains and 50-60% of tropical rainfall globally. MCSs also account for over 50% of extreme precipitation in the U.S. east of the Rocky Mountains. Deficiency in representing MCSs contributes importantly to climate model biases in simulating the precipitation and its diurnal variability over the central U.S. and tropical circulation, with important implications to modeling the regional and global water cycles. In the past decades, observed increases in springtime total and extreme rainfall in the central U.S. have been dominated by increased frequency and intensity of long-lasting MCSs. Understanding the environmental conditions producing long-lived MCSs is therefore a priority in determining how the characteristics of precipitation may change in the future. Regional and global variable resolution models are being used to perform convection permitting simulations of MCSs and their interactions with the large-scale environment. The large-scale and mesoscale ingredients identified from the simulations and analysis of CMIP5 models provide a framework for understanding and modeling the potential changes in MCSs and hydrometeorological extremes in the future.

Title: **Future Changes in Seasonality of Subtropical Highs and Tropical Rainfall**

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BER Program: RGCM

Project: Water Cycle and Climate Extremes Modeling (WACCEM) SFA

Project Website: https://climatemodeling.science.energy.gov/projects/water-cycle-and-climate-extremes-modeling

Project Abstract:

The subtropical highs are semi-permanent atmospheric features that strengthen during April-September, exerting a large influence on regional precipitation. Previous studies focused on the changes of subtropical highs during their peak season (June-August), but little is known about their seasonality changes. Here, a suite of multi-model simulations are used to demonstrate the robust seasonally-dependent responses of the zonal mean subtropical highs and tropical rainfall to global warming. The zonal-mean subtropical highs in the Northern Hemisphere are shown to strengthen more during April-June than July-September, with opposite responses for the Southern Hemisphere counterparts. These responses are closely related to a southward shift of tropical precipitation in April-June relative to July-September, manifesting in a seasonal delay of tropical precipitation and monsoon onset in the Northern Hemisphere. Such seasonality changes are found to occur in response to elevated latent energy demand in the hemisphere warming up seasonally, as dictated by the Clausius-Clapeyron relation. The interhemispheric energy contrast drives a southward shift of tropical precipitation that strengthens the Hadley cell and zonal-mean subtropical highs in the Northern Hemisphere in April-June relative to July-September. These changes scale linearly with warming, with increasing implications for projecting climate changes in the tropics and subtropics as warming continues.

Representing Reservoir Effects on Riverine Sediment Processes

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BER Program: ESM

Project: E3SM

Abstract:

Suspended sediment plays a vital role in regional or global cycling of carbon and nutrients by transporting particulate carbon and nutrients from headwaters into large rivers then the ocean. Human activities like reservoir management could fundamentally modify the sediment transportation processes. However, effective representation of sediment is missing in most existing land surface or earth system models, leaving alone the effects of reservoirs on sediment processes. We introduce a physically based river sediment module within an earth system modeling framework, which includes process-based parameterizations of: 1) hillslope soil erosion and discharge into streams; 2) sediment erosion, suspension and transportation through river networks; 3) reservoir regulation based on the inflows from upstream areas and water demand from downstream areas; and 4) sediment trapping by reservoirs. This new sediment module is developed within an earth system modeling framework and to be applied to the river networks at the regional or global scales. Model application and validation will be carried out at the contiguous U.S. using historical streamflow and sediment observations from USGS. The relative contribution of reservoir trapping mechanism and flow regulation on riverine suspended sediment processes will be isolated and quantified through customized numerical experiments. This new sediment module lays the foundation for modeling transportation and transform of particulate C, N and P through rivers into the ocean to close the global C, N and P cycles.

Evaluation of E3SMv1 Atmospheric Simulations Over the Southern Polar Region

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This work aims to evaluate E3SMv1 simulations over the Southern polar region to provide an assessment of the simulated atmospheric forcings that exert a strong influence on the cryosphere system around the Antarctica and the dynamical connection between Southern Polar regions and lower latitudes. The atmosphere model simulations used are part of the E3SMv1 DECK (Diagnostic, Evaluation and Characterization of Klima) experiments, with prescribed observational sea surface temperature and ice coverage. The analysis of the forcings focuses on the simulated atmospheric climatology. The Southern Annular Mode (SAM) and its variability are analyzed to evaluate the simulated dynamical connection between high and low latitudes in the model. Preliminary analysis shows that the simulated cloud, precipitation, and radiation fields, in comparison with limited available observations, exhibits large discrepancies that are with strong seasonality and sharp contrast over ice sheets, on the periphery of the ice sheets and over the circumpolar southern oceans. These are clear indications that issues in cloud physics, surface-air interactions and the ability to reproduce synoptic scale weather systems over the region may all have a large influence on the model results. For this consideration, the synoptic regimes are classified and evaluated to characterize the model behavior in simulating large-scale circulations and separate the influence of dynamics from model physics on simulated precipitation, cloud and radiation. The outcome of this work will be used to guide the improvement of the simulations of the atmospheric forcings important to modeling the cryosphere system.

Bayesian parameter estimation and uncertainty assessment in the Hector simple climate model

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BER Program: Multi-Sector Dynamics Program

Project: iHESD SFA PNNL

Project Website:

https://climatemodeling.science.energy.gov/projects/integrating-human-and-earth-system-dynamics-ihesd-scientific-focus-area

https://github.com/jgcri/hector

Simple climate models (SCMs) are climate models with low computational complexity that can provide estimates of large-scale climate variables for future scenarios. Because of their low computational cost, these models are ideal for situations where rapid turnaround is needed, such as when coupling to a human systems model (e.g., Hartin, et al. 2017; Clarke, et al. 2018). As with most scientific models, SCMs have a collection of input parameters that influence the output of the model, and these parameters are subject to uncertainty.

This paper describes a series of parameter estimation exercises using the Hector SCM (Hartin, et al., 2015). The constraints derived for the model parameters depend on the data the model output is being compared to. Therefore, we perform several variants of the exercise using different comparison data, including comparison to earth system model (ESM) output, comparison to historical measurements, and comparison to both ESM and historical data. For the comparisons to future runs, we include a new formulation of the likelihood function that reflects our deep uncertainty about the future trajectory of climate variables, and we argue that the methods for comparing to ESM projections commonly used in previous studies produce parameter estimates that are overconfident (i.e., their credible intervals underestimate our true uncertainty about these parameters).

We present results of all of these exercises, including summary statistics for the model parameters, marginal probability distributions, and credible intervals. We compare these results for the different variants of the exercise and offer interpretations about how they relate to the true uncertainty of the model parameters.

References:

Clarke, L, et al.: Effects of long-term climate change on global building energy expenditures, Energy Economics, 2018.

Hartin, C. A., Patel, P., Schwarber, A., Link, R. P., and Bond-Lamberty, B. P.: A simple object-oriented and open-source model for scientific and policy analyses of the global climate system – Hector v1.0, Geosci. Model Dev., 8, 939-955, https://doi.org/10.5194/gmd-8-939-2015, 2015.

Hartin, C, et al.: Building sector feedbacks lead to increased energy demands, AGU Fall Abstracts, 2017.

Assessing Extratropical Impact on the Tropical Bias in a Coupled Climate Model

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BER Program: ESM
Project: Collaborative Project: Developing Coupled Data Assimilation Strategy for Understanding Model Bias and Extreme Climate Events in E3SM (University)

The tropical bias of double-Intertropical Convergence Zone (ITCZ) has been a persistent feature in global climate models. It remains unclear how much of it is attributed to local and remote processes, respectively. Here we assess the extratropical influence on the tropical bias in a coupled general circulation model dynamically, systematically, and quantitatively using the Regional Coupled Data Assimilation (RCDA) method. RCDA experiments show that the model's double-ITCZ bias is improved systematically when sea surface temperature, air temperature, and wind are corrected toward real-world data from the extratropics into the tropics progressively. Quantitatively, the tropical asymmetry bias in precipitation and surface temperature is reduced by 40% due to extratropical impact from outside of ~25°. Coupled dynamics, as well as atmospheric and oceanic processes, play important roles in this extratropical-to-tropical teleconnection. Energetic analysis of cross-equatorial atmospheric energy transport and equatorial net energy input are used to explain the changes in the precipitation bias.

Title: Sensitivity of the ITCZ Location to Ocean Forcing via q-flux Green's Function Experiments

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BER Program: RGCM

Project: WACCEM/SFA (PNNL)

Project Abstract:

The sensitivity of the Intertropical Convergence Zone (ITCZ) position to forcing patterns is important for understanding changes in tropical rainfall. A set of Green's function experiments reveals that this sensitivity is asymmetric depending on which hemisphere (northern or southern) the forcing is applied. Northern hemisphere forcings produce a much larger response than southern hemisphere forcings of similar magnitude. The response of the ITCZ position to forcing can be broken into linear and nonlinear components, and it is shown that the asymmetry arises from the nonlinear component. The linear and nonlinear response components have similar magnitudes, but the nonlinear component is insensitive to the location of the forcing, such that it amplifies the response to northern hemisphere forcings and dampens the response to southern hemisphere forcings. This asymmetry hints at an intrinsic mode of the climate system such as the ITCZ response to forcing depends on the current climate state.

Title: Sea Ice-Originated Global Cooling as a Nonlinear Mode Response to Heat Perturbations

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BER Program: RGCM

Project: Compensation between Poleward Energy Transport in the Ocean and Atmosphere (University: WHOI, PNNL)

High-order nonlinear terms are often assumed to be small and neglected in climate change and feedback studies. However, through examining the nonlinear surface temperature (TS) response in a set of q-flux Green's function experiments with an AGCM coupled to a slab, we found a significant nonlinear component of TS response with comparable magnitude to the linear component. Further, the nonlinear pattern is characteristic of a polar-amplified global cooling, irrespective of the latitudinal location of the q-flux forcing, indicative strongly of an internal mode behavior to the climate system simulated by the AGCM.

The origin of the large nonlinearity appears to arise from the regime shift between a two-way coupling of an ocean-atmosphere system and a three-way coupled system involving ocean, sea ice, and atmosphere. Disabling sea ice formation and seasonal cycle in a series of purposefully designed experiments can eliminate the nonlinearity. The epitomizes the importance of the sea ice component of the polar system in shaping the global climate response to external perturbations. Moreover, since there are larger areas characterized by sea ice-open water interface in the Southern Hemisphere than the Northern Hemisphere in winter season, the ice-induced nonlinear feedback processes tend to produce more cooling in the former than the latter hemispheres, driving a southward atmospheric energy transport across the equator.

Title: **Enhanced Hydrological Extremes in the Western United States under Global Warming through the Lens of Water Vapor Wave Activity**

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BER Program: RGCM

Project: WACCEM/SFA (PNNL)

Project Abstract:

A novel diagnostic framework based on the wave activity of column integrated water vapor (CWV) is used to probe into the higher moments of the hydrological cycle with bearings on the extremes. Applying the CWV wave activity analysis to the historical and RCP8.5 scenario simulations by the CMIP5 models reveals a super Clausius-Clapeyron rate of increase in the wet-versus-dry disparity of daily net precipitation due to the enhanced stirring length of wave activity at the poleward flank of the storm track, despite a decrease in the hydrological cycling rate (HCR) measured by the reciprocal of wave activity residence time. The local variant of CWV wave activity unravels the unique characteristics of atmospheric rivers (ARs) in terms of their transport function and locally enhanced mixing efficiency. Under RCP8.5, the local moist wave activity increases by ~40% over the northeastern Pacific and western United States by the end of the 21st century, indicating lengthening and more frequent landfalling ARs with a consequence of a ~20% increase in the related hydrological extremes $(\widetilde{P-E})^+$ in the west coast, despite a robust weakening of the local HCR. These results imply that the unusually wet winter the west coast just experienced in 2016/17 might be a harbinger of more frequent wet extremes in a warmer climate.

Title: **What are the causes of a warm bias in surface air temperature over land?**

Hsi-Yen Ma,[1*] Stephen A. Klein[1], Shaocheng Xie[1], Chengzhu Zhang[1], Shuaiqi Tang[1], Qi Tang[1], Cyril J. Morcrette[2], Kwinten Van Weverberg[2], Jon Petch[2], Maike Ahlgrimm[3], Larry K. Berg[4], Frederique Cheruy[5], Jason Cole[6], Richard Forbes[3], William I. Gustafson Jr.[4], Maoyi Huang[4], Ying Liu[4], William Merryfield[6], Yun Qian[4], Romain Roehrig[7], Yi-Chi Wang[8] and Ian Williams[9]

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BER Program: RGMA

Project: LLNL Climate Change Research SFA

Project Website: https://pcmdi.llnl.gov/projects/capt/

Project Abstract:

Many weather forecast and climate models simulate warm surface air temperature (T2m) biases over mid-latitude continents during the summertime, especially over the Great Plains. We present here a summary of a series of papers from a multi-model intercomparison project (CAUSES: Cloud Above the United States and Errors at the Surface), which aims to evaluate the role of cloud, radiation, and precipitation biases in contributing to the T2m bias using a short-term hindcast approach during the spring and summer of 2011. Observations are mainly from the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) sites. The present study examines the contributions of surface energy budget errors. All participating models simulate too much net shortwave and longwave fluxes at the surface but with no consistent mean bias sign in turbulent fluxes over the Central U.S. and SGP. Nevertheless, biases in the net shortwave and downward longwave fluxes, as well as surface evaporative fraction (EF) are contributors to T2m bias. Radiation biases are largely affected by cloud simulations, while EF bias is largely affected by soil moisture modulated by seasonal accumulated precipitation and evaporation. An approximate equation based upon the surface energy budget is derived to further quantify the magnitudes of radiation and EF contributions to T2m bias. Our analysis ascribes that a large EF underestimate is the dominant source of error in all models with a large positive temperature bias, whereas an EF overestimate compensates for an excess of absorbed shortwave

radiation in nearly all the models with the smallest temperature bias. From a follow-up study, we will also demonstrate in the presentation the impact of land surface parameterizations, specifically the bare-ground resistance, stomatal conductance and leaf optical properties, on the simulated surface heat fluxes and T2m. (This study is funded by the RGMA and ASR Programs of the U.S. Department of Energy as part of the Cloud-Associated Parameterizations Testbed. This work is performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344)

Title: **Observational Constraint on Cloud Susceptibility Weakened by Aerosol Retrieval Limitations**

Po-Lun Ma[1*], Philip Rasch[1], Hélène Chepfer[2,3], David Winker[4], Steven Ghan[1]

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BER Program: ESM and RGMA

Project: Energy Exascale Earth System Model

Project Website: https://climatemodeling.science.energy.gov/projects/energy-exascale-earth-system-model

Project Abstract:

Aerosol-cloud interactions remain a major uncertainty in climate research. Studies have indicated that model estimates of cloud susceptibility to aerosols frequently exceed satellite estimates, motivating model reformulations to increase agreement. Here we show that conventional ways of using satellite information to estimate susceptibility can serve as only a weak constraint on models because the estimation is sensitive to errors in the retrieval procedures. Using instrument simulators to investigate differences between model and satellite estimates of susceptibilities, we find that low aerosol loading conditions are not well characterized by satellites, but model clouds are sensitive to aerosol perturbations in these conditions. We quantify the observational requirements needed to constrain models, and find that the nighttime lidar measurements of aerosols provide a better characterization of tenuous aerosols. We conclude that observational uncertainties and limitations need to be accounted for when assessing the role of aerosols in the climate system.

Publication

Ma, P.-L., P. J. Rasch, H. Chepfer, D. M. Winker, and S. J. Ghan (2018), Observational constraint on cloud susceptibility weakened by aerosol retrieval limitations. *Nat. Commun*., 9, 2640, https://doi.org/10.1038/s41467-018-05028-4

High-Resolution Integration of Water, Energy, and Climate Models at the Watershed and Regional Scale to Assess Local and Regional Electricity Grid Dynamics from Changes in Water Resources

Jordan Macknick,[1*] Measrainsey Meng,[2] Vincent Tidwell,[3] Katrina Bennett,[4] Kelly Sanders[2], Matthew O'Connell[1].

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BER Program: Multi-Sector Dynamics
Project: Integrated Multi-sector, Multi-scale Modeling (IM3) project
Project Website: https://im3.pnnl.gov/

The U.S. power sector is dependent on water resources for generating hydroelectricity and cooling thermoelectric power plants. Insufficient access to water or increases in cooling water temperatures can have negative consequences on the efficiency and reliability of the electricity grid. Although previous studies have assessed the water usage of power plants, most do not incorporate physical water constraints or the dynamic nature of power plant dispatching. This lack of linkages between grid operations with physical water constraints and/or climate-induced changes in water resources leads to deficiencies in estimations of power systems flexibility and adequacy. In addition, many hydrologic and hydropower models have a limited representation of power sector water demands and grid interaction opportunities of demand response and ancillary services. A multi-sector modeling framework was developed, coupling a power model, a reservoir operations model, a surface hydrology model, and a climate model. The San Juan River basin, located in the Southwestern U.S., was chosen as a case study. Simulations reflect downscaled data from global climate models and predicted changes in regional water demand changes. An electricity production cost model developed in PLEXOS simulated the impacts of climate variability on electric grid operations and cooling water usage. This model was integrated with a Variable Infiltration Capacity (VIC) hydrologic model, which was used to project inflows, ambient air temperature, and humidity, while a RiverWare model was used to simulate river operations, hydroelectricity generation, water deliveries, and new water demands. Results indicate that during intense drought scenarios, reductions in water availability could require thermoelectric generators to decrease power production as much as 50% in some years. This novel framework can be applied in other regions to model the impacts of climate and hydrologic variability on the dispatch, operational behaviors, and reliability of the power sector, at both the generating unit level and systems level, in high spatio-temporal resolution. Modeling efforts are currently being expanded to include additional representations of water resource availability through the Water Management model, an exploration of how agent-based modeling

dynamics can affect water availability for the power sector, an expansion of the future climate scenarios considered, and lastly integration with electric sector capacity expansion models.

Title: **Reducing uncertainty of polar to midlatitude linkages using DOE's E3SM in a coordinated model-experiment setting**

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BER Program: RGCM

Project: University

Project Website: sites.uci.edu/PAMIP (not live yet)

Project Abstract:

The dramatic warming of the Arctic (a process referred to as Arctic Amplification) and associated reduction in sea-ice extent/thickness may have a profound impact on the climate system in the 21st century. Despite extensive research, the impact of observed and projected Arctic change on climate and weather (including extreme weather) in the densely populated mid-latitude Northern Hemispheric region is still uncertain. The variety of observational and modeling studies that have tackled the problem find contradictory results, especially concerning the remote atmospheric circulation response to Arctic sea-ice anomalies. This uncertainty is in large part due to inconsistency in the experimental design of model simulations, that can only be addressed through coordinated efforts such as the so-called Polar Amplification Model Intercomparison Project (PAMIP) that will be part of CMIP6. The proposed work will contribute to the hierarchy of coordinated model experiments represented in PAMIP using E3SM. Output from the numerical experiments will be diagnosed in tandem with analysis of model output from other participants in PAMIP that run different models.

The proposed work addresses the following questions: What are the causes of polar amplification? How do changes in Arctic and Antarctic sea-ice cover affect the local and remote atmospheric circulation? Do polar changes impact the frequency, intensity and duration of extreme weather events in mid-latitudes? What is the role of the stratosphere and forcing of anomalous planetary waves in communicating the response to mid-latitudes? How do polar changes combine with the general response to greenhouse gas forcing at the end of the 21st century, and what is the resulting response in mid-latitude flow and extreme weather events? What is the oceanic response to changes in sea ice, and how does it feedback onto the atmosphere? How can the contribution of sea-ice loss to the change in mid-latitude circulation be separated from tropical influences in the real world and in climate simulations?

The model simulations will be analyzed using diagnostic tools that have been tried and tested in the investigators' previous work. Additional diagnostics will be derived and applied. A hierarchy of model simulations, based on the E3SM, is planned to answer specific questions that may be hard to address in the most sophisticated model setting. The project will contribute to a deeper understanding of extreme events, modes of variability, high-latitude feedbacks, the cycling of water, and interactions in the earth system especially between atmospheric and ocean dynamical and thermodynamic processes.

Title: **Space-time Adaptivity for Climate Models**

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BER Program: SciDAC

Project: N/A

Project Website: Chombo.lbl.gov

Project Abstract:

Many problems in climate exhibit large variations in spatial and temporal scale which can be addressed by local refinement in space and time. Adaptive Mesh Refinement (AMR) has already shown promise in climate-related applications such as ice sheet modeling and atmospheric dynamics. As progress toward higher resolution and exascale computing continues, algorithmic innovations such as higher-order discretizations coupled with framework-driven software improvements promise to make AMR more mainstream for computational climate science. We present four case studies of AMR in climate applications.

In the climate community, perhaps the biggest AMR success to date is in ice sheet modeling. Ice sheets are particularly well-suited for AMR because they demand extremely high (sub-kilometer) resolution near rapidly-evolving grounding lines and ice streams, while remaining relatively quiescent over much of the remaining continental-scale domains. The DOE-funded BISICLES ice sheet model, based on the SciDAC FASTMath-supported Chombo AMR framework, can fully resolve the dynamics of the Antarctic ice sheet at a computationally-tractable cost. Adaptive mesh refinement has been applied to moist non-hydrostatic global atmospheric dynamics as well. We use horizontal, vertical, and time-adaptive refinement to allocate computational effort only where greater accuracy is needed for dynamic features, like tropical cyclones, that occur below hydrostatic scales. At the cost of some software complexity, the accuracy of solutions can be greatly improved, but with 10-100x fewer grid points and greatly reduced computational expense. The Chombo-based Stratified Ocean Model with Adaptive Refinement (SOMAR) has been developed to apply dynamic mesh adaptivity to ocean modeling, solving the non-hydrostatic, baroclinic flows encountered in regional and coastal ocean simulations. Finally, the process of sea ice formation results in the formation of narrow brine

rejection channels which control the transport of salt and nutrients between the porous ice and the ocean. These channels are dynamically complex, require fine mesh resolution and exhibit strong transient behavior as they form and evolve, which makes them also excellent candidates for block-structured AMR; we are developing an AMR model of this process in collaboration with Oxford University in the UK.

In the Chombo framework, we have also developed high-order finite volume methods on mapped grids, with ongoing development of applications to gyrokinetic modeling in tokamaks and atmospheric fluid dynamics. We expect the use of high-order methods, with their increased arithmetic intensity, to be particularly useful as we bring AMR applications forward to new and emergent architectures in the exascale era.

Title: Drivers of Future Arctic Sea Ice Regimes

Authors:
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Abstract

We use the Regional Arctic System Model (RASM) to investigate and quantify some of the key uncertainties of the Arctic surface energy budget, including the oceanic forcing of the Arctic sea ice and the potential role of its ongoing decline in the regional and global energy imbalance. RASM is a fully coupled limited-domain ice-ocean-atmosphere-land model developed to better understand the linkages and coupling channels within the Arctic System at a process scale and to improve prediction of its change at a spectrum of timescales. Its domain is pan-Arctic, with the atmosphere and land components configured on a 50-km grid. The ocean and sea ice components are configured on rotated sphere meshes with four configuration options: 1/12^{o} (~9.3km) or 1/48^{o} (~2.4km) in the horizontal space and with 45 or 60 vertical layers.

The main objective of this study is to quantify the oceanic fluxes in and out from the Arctic Ocean in order to understand their sensitivity to model spatial configurations and varying parameter space as well as their impacts on the sea ice cover and regional surface energy budget. Our results imply significant variability of the total oceanic heat convergence into the central Arctic Ocean subject to different model configurations. We find that the range of uncertainty in the net oceanic heat transport is comparable to the amount of extra energy required to melt almost all the Arctic sea ice in summer. We argue that basin-wide changes in the sea ice cover contribute substantially to the regional energy imbalance, via the dramatic reduction of surface albedo and accumulation of heat in the upper ocean due to insolation.

Evaluation of under-ice phytoplankton blooms in the fully-coupled, high-resolution Regional Arctic System Model (RASM)

M. Frants, R. Osinski, W. Maslowski, A. Roberts, N. Jeffery, M. Jin

Recent studies suggest that satellite-based assessments of Arctic primary production might be significantly underestimated, as they do not include contributions of under-ice blooms. For example, a massive under-ice phytoplankton bloom was observed in the Chukchi Sea in July 2011, with depth-integrated under-ice biomass about fourfold greater than in open water. Subsequent model studies have suggested that such blooms could be more widespread than previously thought, and that they are becoming more common as a result of increasing light availability due to thinning ice and increasing prevalence of melt ponds in the Arctic Ocean.

We present results from the fully-coupled, high-resolution Regional Arctic System Model (RASM), including marine biogeochemistry (mBGC) in its ocean and sea ice components. Our analysis of results from two RASM simulations, employing different parameterizations of sea ice mBGC, focuses on the spatial and temporal evolution of under-ice Arctic blooms from 1990 (?why not 1980?) through 2017. We will discuss the influence of melt pond proliferation and nutrient availability, as well as the effect of the different parameterizations of sea ice mBGC on the extent and duration of these blooms. Finally, we will present estimates of Arctic Ocean primary production that incorporate the contributions of under-ice blooms.

Antarctic and Southeast Greenland Continental Shelf Circulations from Forced Global Eddy-Resolving and Eddying POP/CICE Simulations.

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BER Program: RGCM
Project: University Award

Melting ice releases freshwater into the ocean, changes water properties, modifies stratification, and impacts ocean circulation both locally and remotely. Basal melt rates at land ice/ocean interfaces in Antarctic ice cavities and at the termini of tidewater glaciers in Greenland fjords have accelerated over past decades. In both cases, warm salty waters from adjacent deep basins are hypothesized to be responsible for this increased basal melt. The goal of this project is to enhance understanding of the dynamics governing the delivery of these warm waters to the land ice/ocean interfaces. Very small-scale mesoscale eddies (several kilometers in size) are implicated in both regions, while changing ocean circulation and climate mode variability are also considered to play roles. To address this dichotomy of scales, we are carrying out a multi-decadal (1975-2009) global coupled ocean and sea-ice simulation using the Parallel Ocean Program 2 (POP2) and CICE5, using a new global grid that is of sufficiently high horizontal resolution to replicate mesoscale eddy processes at high latitudes. The grid size is 2-3 km around southern Greenland, and 1-3 km around the Antarctic shelf. It is configured in the "HiLat" framework and is forced with interannually varying Coordinated Ocean-ice Reference Experiment-II (CORE-II) atmospheric fluxes. Early results distinguish this simulation from an earlier lower resolution eddying (0.1°) global POP/CICE simulation by, among others, simulating well-resolved fine-scale mesoscale eddies emanating from the Labrador Sea boundary currents, frontal mixing between warm Irminger Sea and cold East Greenland Current waters over the southeastern Greenland shelf, and a realistic North Atlantic Current that forms a robust "northwest corner".

Representations of land ice based on observations from both hemispheres are being tested in a less computationally expensive counterpart global 0.1° POP2/CICE5 simulation prior to adding them to the "ultra-high" simulation. The impacts of freshwater releases on the continental shelf ocean circulation and sea ice as well as the realism of sea ice thickness, concentration, and drift from CICE5 will be discussed. Results from a full vorticity budget around Antarctica constructed from an earlier global 0.1° POP/CICE4 simulation are used in the first instance to understand the importance of eddy forcing on the Antarctic continental shelf. Maps of budget terms from 200-500m show eddy forcing to be of leading order importance in West Antarctica where the Antarctic Slope Front (ASF) is absent, whereas it is unimportant in the Atlantic Ocean sector of the Southern Ocean where the ASF is present.

Title: **Urban Systems as Hubs of Interdependent Land-Energy-Water Networks**

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BER Program: IA

Project: Energy-Water Nexus Knowledge Discovery (DOE, BER, IA)

Project Website: https://ewnkdf-dev.ornl.gov/

Project Abstract: Cities are hubs of major infrastructural and social networks across the globe. While dense populations of humans foster sociopolitical power and economic growth, cities are also dense regions of resource consumption inducing impacts and stresses on distal ecosystems. Indeed, urban areas have disproportionate impacts on surrounding land-energy-water resources given their size. For instance, urban areas constitute only 5% of the US landscape, yet consume as much as 95% of electricity production and produce a fraction of their own energy. Cities are also prime architects of landscape transformation. The conversion of agricultural lands to urban uses places additional stress on remaining agricultural lands to increase production to meet growing population demands. Elevated stress on land and energy systems ultimately impact hydrologic cycles, compounding stress on water availability for cities and their neighboring cities. Cities rely on expansive infrastructure to meet their demands, and as such, serve to govern those same networks well outside metropolitan boundaries. As cities grow and compete with other cities, their choices regrading resource uses, morphologies, energy porfolios, and infrastructural adaptations can influence distal land-energy-water systems. We present work on examining the direct, indirect, and distal impacts of city infrastructures, specifically their land footprint, EnergySheds, and WaterSupply Sheds, on surrounding regions and water cycle impacts. We also present frameworks that provide alterative scenarios of city growth under future land-energy-water networks and emphasize the importance of translating scenarios into physical on-the-ground relevance for measuring land and hydrologic impacts.

Title: **Determining the Differential Credibility of Future Climate Projections Based on Multiple Downscaling Methods: An Overview Approach from the FACETS Project**

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BER Program: RGCM

Project: A Hierarchical Evaluation Framework for Assessing Climate Simulations Relevant to the Energy-Water-Land Nexus (Cooperative Agreement)

Project Website: https://facets.agron.iastate.edu/display/ds/FACETS+Homepage

Project Abstract:

Differential Credibility Analysis (DCA) refers to analyses (using both metrics and model process- -level investigations) used to determine whether some downscaling methods are more robust and provide stronger evidence for believable projections of climate change than others. One of the strengths of our project is the variety of downscaling methods being employed. This includes multiple dynamical downscaling approaches, statistical downscaling methods, and a hybrid method.

Credibility of current conditions can be ~~at least~~ partially based on the collection of metrics being developed and/or applied in FACETS. However, most fundamentally for the future, it must be based on detailed process- -level analysis of how controlling processes evolve and change under future conditions. Are these changes 'credible' given our understanding of the processes and the errors in the models (Barsugli et al. 2013)?

Can we 'rate' the different simulations and statistical downscaling methods based on the credibility analyses?

C~~The c~~redibility analyses will be performed over different sub-regions of the U.S. domain dominated by different atmospheric processes (e.g., ~~SW~~ Southwest Monsoon, southern Great Plains) and across different spatial resolutions (for the dynamical methods) to answer the question:~~-~~ Does credibility evolve across different spatial scales in different regions?

All methods will use at least two different CMIP5 GCMs ~~(GFDL and MPI)~~ to ~~serve as driving~~drive ~~conditions for the~~ current and future projections. For the RCMs, these GCMs provide the initial and ~~lateral~~ boundary conditions (ICBC) for current and future simulations. For these simulations both the ~~driving conditions from the GCMs~~ICBC and the ~~quality of the~~ final simulations ~~determined via process level analysis~~ will be investigated. Bukovsky et al. (~~2017~~2015) provides a good example for the Southwest Monsoon region based on the NARCCAP simulations. For the ~~stretched grid~~variable resolution approach using MPAS, ~~the~~ sea surface temperature and ice ~~temperature boundary conditions~~ from the GCMs are used as lower boundary conditions (LBC). In this case, the ~~quality of the SSTs from the GCMs~~LBC as well as the MPAS current and future simulations will be analyzed. ~~process level analysis of the MPAS current and future simulations will be performed.~~ For the various statistical downscaling methods, in most cases, large-scale upper level predictors from the GCMs are used to formulate the statistical models, and the quality of these predictor variables will be carefully evaluated (both in the current and future conditions). Therefore, different aspects of the driving models are involved in the various downscaling methods.

This presentation will provide the conceptual framework for this work, since detailed analyses of the different approaches have not yet been performed.

References:

Barsugli et al., 2013. The practitioner's dilemma. *EOS* 94:424.

Bukovsky et al., 2015 Toward assessing NARCCAP regional climate model credibility for the North American Monsoon. *J. Climate* 28:6707.

Title: **Radiative Forcing Associated with Regional Aerosol Emissions**

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BER Program: RGCM

Project: CATALYST / UCAR Cooperative Agreement

Project Website: http://www.cgd.ucar.edu/projects/catalyst/

Project Abstract: Aerosol forcing remains highly uncertain, mostly because of large uncertainties surrounding cloud-aerosol interactions. Empirical results suggest that historical aerosol forcing is proportional to global emissions. During CESM development, a subtle change in aerosol emissions lead to a surprisingly large climate response, at odds with the picture drawn from the empirical results. The CESM climate response appeared related to a dramatic low cloud response in the Pacific. This study takes a step back to ask some simple questions about the role of aerosols in the climate system. We focus on the top-of-atmosphere radiative balance in idealized simulations. Results show that aerosols have a profound influence of the global energy budget, and that assumptions about the aerosol emissions play a large role in the aerosol forcing. In particular, a set of experiments shows how the spatial distribution of aerosol emissions impacts the effective radiative forcing. Contrary to the empirical results based on observations, we show that aerosol forcing depends on the distribution of emissions and not on the total global emissions. Further, it is shown that the aerosol forcing depends on what atmospheric regimes are impacted by the aerosols, and not just the areal extent of emissions. Although the experiments are idealized, they illustrate how changes in the patterns of aerosol emissions could lead to different impacts on the climate system.

Sudden Antarctic sea ice retreat, connections to the tropics, and ocean regime change around Antarctica

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BER Program: RGCM
Project: CATALYST

In September-October-November (SON) 2016, there was a dramatic *decrease* of Antarctic sea ice extent. This followed nearly three decades of observed *increasin*g trends of Antarctic sea ice extent that accelerated after the Interdecadal Pacific Oscillation (IPO) transitioned from positive to negative around 2000. Here we perform a sensitivity experiment using an atmosphere-only model with a specified positive convective heating anomaly in the eastern Indian/western Pacific Ocean to represent the record (for the 2000s) positive precipitation anomaly there in SON 2016. An anomalous atmospheric Rossby wave response, forced by that tropical heating, produces a teleconnection pattern around Antarctica with surface wind anomalies that contributes to the decrease of Antarctic sea ice extent. The sustained decreases of Antarctic sea ice extent after late 2016 are associated with a warmer upper Southern Ocean regime. This is the culmination of a negative decadal trend of wind stress curl with positive SAM and negative IPO, Ekman suction that brought warmer water closer to the surface, a transition to positive IPO around 2014-2016, and negative Southern Annular Mode (SAM) in SON 2016.

A global gridded biogeophysical, biogeochemical and hydrological land system model for multi-sectoral dynamics and energy-water-land interactions research

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BER Program: Multi-sector Dynamics

Project: An Integrated Framework for Climate Change Assessment (DOE-MIT Cooperative Agreement)

In order to represent multi-sectoral dynamics and Energy-Water-Land interactions in a coupled human-Earth system (CHES) modeling framework, a new global gridded biogeophysical, biogeochemical and hydrological land system model is built by integrating the National Center for Atmospheric Research (NCAR) Community Land Model (CLM), the Marine Biological Laboratory (MBL) Terrestrial Ecosystem Model (TEM) and the Food and Agriculture Organization of the United Nations (FAO) AquaCrop model. The resulting model will represent the coupled biogeophysical, biogeochemical and hydrological processes of natural and managed terrestrial ecosystems, including various crops and managed forest. It will be used to simulate the impact of changes in climate, atmospheric chemistry (ozone, carbon dioxide and nitrogen) and land use on the land system and the modification of the global and regional cycles of energy, water, carbon and nutrients by human activity. This model is intended to be linked to the MIT Water Resource System (WRS) model that represents the multi-sectoral dynamics between the geophysical water resources (water storage and runoff) and anthropogenic water requirements (municipal, energy, industry and irrigation) for basin-scale assessment of water availability. It is also intended to be linked to the MIT Economic Projection & Policy Analysis (EPPA) model, a multi-sector, multi-region, computable general equilibrium (CGE) model of the world economy to simulate the impact of climate change on land productivity and the subsequent land-use change decisions. This poster describes the structure of the model, its linkages to the coupled human-Earth system model and examples of future applications to global change studies.

Toward a Consistent Modeling Framework to Assess Multi-sectoral Climate Impacts

Erwan Monier[1*], Sergey Paltsev[1], Andrei Sokolov[1], Y.-H. Henry Chen[1], Xiang Gao[1], Qudsia Ejaz[1], Evan Couzo[1,3], C. Adam Schlosser[1], Stephanie Dutkiewicz[1], Charles Fant[1], Jeffery Scott[1], David Kicklighter[2], Jennifer Morris[1], Henry Jacoby[1], and Ronald Prinn[1]

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BER Program: Multi-sector Dynamics

Project: An Integrated Framework for Climate Change Assessment (DOE-MIT Cooperative Agreement)

Efforts to estimate the physical and economic impacts of future climate change face substantial challenges. To enrich the currently popular approaches to impact analysis—which involve evaluation of a damage function or multi-model comparisons based on a limited number of standardized scenarios—we propose integrating a geospatially resolved physical representation of impacts into a coupled human-Earth system modeling framework. Large internationally coordinated exercises cannot easily respond to new policy targets and the implementation of standard scenarios across models, institutions and research communities can yield inconsistent estimates. Here, we argue for a shift toward the use of a self-consistent integrated modeling framework to assess climate impacts, and discuss ways the integrated assessment modeling community can move in this direction. We then demonstrate the capabilities of such a modeling framework by conducting a multi-sectoral assessment of climate impacts under a range of consistent and integrated economic and climate scenarios that are responsive to new policies and business expectations.

Mechanisms of Southern Ocean Nutrient Trapping and Potential Climate Impacts

Recent Earth System Model projections suggest unchecked, multicentury climate warming could initiate a massive transfer of nutrients to the deep ocean, leading to long term declines in the biological productivity of marine ecosystems globally. The transfer of nutrients to the deep ocean is primarily driven by dynamics in the Southern Ocean around Antarctica, where changes in the prevailing winds, sea surface temperature, and sea ice cover drive a localized increase in biological production. The increasing production above the Antarctic Divergence upwelling zone traps nutrients in the Southern Ocean, decreasing the northward nutrient transport in surface waters that eventually supports much of the lower latitude productivity. With the main pathway for deep nutrients to return to surface waters weakened, over time upper ocean nutrients are depleted and concentrations increase throughout the deep ocean, aided by increasing stratification globally, and the collapse of deep winter mixing in the North Atlantic. Simulations with the ocean component of the Community Earth System Model (CESM) are used to examine the role and impacts of these distinct, climate-driven forcings (winds, temperature, and sea ice cover) in initiating nutrient trapping in the Southern Ocean. The global-scale impacts of Southern Ocean nutrient trapping on air-sea CO_2 flux will be examined.

The Madden Julian Oscillation: Sensitivities to Resolution and a Warmer World

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BER Program:

Project: DOE-NCAR Cooperative Agreement (CATALYST)

Project Website: http://www.cgd.ucar.edu/projects/

Project Abstract: RGCM

The Madden Julian Oscillation (MJO) is an important mode of sub-seasonal variability not just directly in the tropics reflected in convective organization time and space scales, but also in the remote influences effecting seasonal meteorology features such as Atmospheric Rivers and tropical. Changes in the local and remote influence of the MJO in a future warmer world could manifest in many ways including amplitude, frequency and phase modifications.

MJOs produced by the CESM1 large-ensemble have a number of deficiencies, but it does produce intra-seasonal large-scale coupled variability that explains a significant portion of the total variability. To detect a real change in this metric in the future, we examine its spread from all large-ensemble members in 1° historical and RCP8.5 experiments. It is clear that to discount similar ensemble members from the separate population, and reject the influence of internal variability, warming has to be at the level of the end of this century. Is it a non-linear change?

Address the robustness of this result to resolution we examine a similar, but smaller, subset of simulations at a much higher 0.25° resolution. Increased resolution gives rise to a stronger and more realistic MJO and equivalently a future MJO that is stronger, more so that for the future MJO at low-resolution.

We will also show preliminary results from most recent releases CESM2 and E3SMv1. Many characteristics of the MJO are much improved in these models, in particular the mean propagation strength of events out into the Pacific. These models also re-ignite the question regarding intra-seasonal surface coupling and its role in at least sustaining (and maybe initiating?) MJO events.

Title: Severe Convection Driving Amazon Functioning

Robinson Negron-Juarez[1*], Daniel Marra[2], Gautam Bisht[1], Hillary Jenkins[3], Alessandro Araujo[4], Damien Bonal[5], Niro Higuchi[6], William Riley[1], Jeffrey Chambers[1]

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BER Program: Regional & Global Climate Modeling (RGCM)

Project: RUBISCO

Project Website: https://climatemodeling.science.energy.gov/projects/reducing-uncertainty-biogeochemical-interactions-through-synthesis-and-computation-rubisco

The lack of mechanistic explanation for tree mortality across the Amazon has limited the community's understanding of drivers of ecosystem functioning in these forests. Mesoscale Convective Systems (MCS) are responsible for heavy rainfall in the Amazon. Associated with this rainfall are strong descending winds that can uproot or break trees, producing the dominant modes of tree mortality in the Amazon. We show here that heavy rainfall explains a large fraction of observed tree mortality across the Amazon. This insight was parameterized in the Energy Exascale Earth System Model (E3SM) Land Model (ELM) to study the impact of heavy rainfall in the regional carbon, hydrological, and surface energy budgets and their spatial patterns across the Amazon.

Title: Diagnosing Externally-forced Changes in ENSO Dynamics and Predictability within a CGCM Large Ensemble

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BER Program: **RGCM**

Project: University Award entitled: "*Mechanisms of Pacific decadal variability in ESMs: the roles of stochastic forcing, feedbacks & external forcing*"

Project Website: http://www.podx.org

Project Abstract:

We constructed Linear Inverse Models (LIMs) from oceanic and atmospheric data from the NCAR-CESM1 large ensemble (CESM-LE) to diagnose potential anthropogenically-forced changes in tropical climate dynamics and ENSO predictability. Separate LIMs were constructed from sea surface temperature (SST) and height (SSH) anomalies drawn from the 40-member ensemble of each 20-yr period from 1950-2069, where first the anomalies were determined from the time-evolving base state (i.e., including effects from changing radiative forcing).

It can be shown that for any unbiased model, forecast skill is related to the "signal-to-noise" ratio of the predictable signal to unpredictable noise. In the LIM these terms are easily determined. Additionally, the "maximum amplification" curve determined from the LIM shows the maximum possible predictable anomaly growth (under a norm of interest) as a function of the forecast lead time, where the initial condition or "optimal perturbation" leading to maximum anomaly growth (and therefore maximum potential predictability) for a time interval is determined from an SVD of the system propagator. This calculation was made from the LIMs from each 20-yr period.

One clear result is that, as the external forcing drives a long-term base state change (including global SST warming), maximum potential ENSO growth both significantly increases and peaks at slightly shorter lead times. This is related to optimal initial conditions where the SSH portion of the anomaly becomes increasingly important for ENSO development, suggesting a pronounced change in the balance of processes responsible for ENSO in the model. This change in the dynamics is evident in tropical SST variability, which increases over this period. That is, using LIMs constructed from CESM-LE output shows that the model projects ENSO itself will become more predictable.

Challenges and Opportunities for the Use of Weather and Climate Data in Multi-Sector Dynamics Research

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Research endeavors that seek to examine the dynamics of coupled natural and multi-sectoral human systems face unique challenges in terms of their selection, provisioning, and use of weather and climate data. This necessarily interdisciplinary work requires careful choices with regard to dataset characteristics, spatial and temporal scale, and treatment of uncertainty. At the same time, the selection of computational and data sharing platforms becomes more complex, as the the unique needs and scholarly traditions of each discipline must be taken into account, sometimes indicating a need for new translational tools to facilitate collaboration. Here we discuss some of the data-related challenges and point a way toward a few potential solutions.

Title: “Using the Community Earth System Model Large Ensemble to investigate changes in frequency of major precipitation accumulations in a warming climate”

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BER Program: ESM

Project: Identifying Robust Cloud Feedbacks in Observations and Models

Project Website: NA

Major precipitation accumulations associated with severe flooding (100s of mm) appear to be becoming more frequent in various locations around the world, and observations indicate that through the late-21st Century the magnitude of major accumulations increased. The Community Earth System Model (CESM) Large Ensemble is used to predict and understand future changes in frequency of these devastating events. The unique ability of a large ensemble is to aggregate the members to form a time series of several hundred years, so that exceptionally rare events, e.g., the 100-year accumulation, can be calculated, along with the future increase in their occurrence. Accumulation sizes are binned by the local average recurrence interval (ARI), ranging from 0.1—100 years, for the current and projected late-21st Century climates separately. For all ARIs, the frequency of exceedance of the given accumulation size increases in the future climate almost everywhere, in particular for the greatest accumulations, with the 100-year accumulations becoming about 3 times more frequent, averaged over the global land area, and about 10 times more frequent in parts of the tropics. Precipitation accumulation is approximately equal to the product of moisture, mass convergence, and duration, so that increases in frequency of a given accumulation size can be broken down into the increases due to each factor individually. For relatively small accumulation sizes (<1-year ARI), increases are almost precisely predicted by moisture increases, but for greater accumulation sizes (>10-year ARI), moisture is insufficient to explain the projected increase in frequency. In parts of the midlatitudes, duration increases are important for >10-year events, responsible for making events almost 1.5 times more frequent, but moisture is the most important factor. In the tropics and monsoon regions, increasing mass convergence also impacts the >10-year events, responsible by itself for an approximate doubling of frequency, comparable to that of moisture increase. These projections represent a serious threat to flood risk around the world, so that the changes to duration and mass-convergence should be better understood in order to more accurately predict the future frequency of these major accumulations

Evaluation of the Representation of Land-Atmosphere Interactions Across Sub-Saharan Africa in the Coupled Model Intercomparison Project Phase Five

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BER Program: RGCM

Project: Evaluation of the Large-Scale and Regional Climatic Response Across North Africa to Natural Variability in Oceanic Modes and Terrestrial Vegetation Among the CMIP5 Models (University Award)

This study aims to evaluate the representation of terrestrial feedbacks across sub-Saharan Africa among the Coupled Model Intercomparison Project Phase Five (CMIP5) Earth System Models (ESMs). It is motivated by (1) the large socio-economic and ecological vulnerability to hydrological variability across sub-Saharan Africa, (2) vast uncertainty in future rainfall projections across the study region, and (3) lack of analyses of vegetation feedbacks in the CMIP5 ESMs, which generally include interactive vegetation phenology and sometimes include dynamic vegetation types. The study is made possible by the development of the multivariate statistical method, Stepwise Generalized Equilibrium Feedback Assessment (SGEFA), which was successfully validated using the Community Earth System Model. The observed individual impacts of variability in sea-surface temperatures, leaf area, and soil moisture on sub-Saharan regional climate are extracted in observational, remote sensing, and reanalysis data using SGEFA. This observational benchmark is then used to assess the reliability of the representation of the sub-Saharan regional climate responses to oceanic versus terrestrial forcings among the CMIP5 ESMs.

Metrics for Understanding Large-scale Controls of Multivariate Temperature and Precipitation Variability

Two or more meteorological/climatological extremes spatio-temporally co-located (co-occurring extremes) place far greater stress on human and ecological systems than any single extreme could. This was observed during the California drought of 2011-2015 where multiple years of negative precipitation anomalies occurred simultaneously with positive temperature anomalies resulting in California's worst drought on observational record. The large-scale drivers which modulate the occurrence of extremes in two or more variables remains largely unexplored. Using California wintertime (November-April) temperature and precipitation as a case study, we apply a novel, nonparametric conditional probability distribution method that allows for evaluation of complex, multivariate, and nonlinear relationships that exist among temperature, precipitation, and various indicators of large-scale climate variability and change. We find that multivariate variability and statistics of temperature and precipitation exhibit strong spatial variation across spatial scales that are often treated as having homogenous. Further, we demonstrate that the multivariate statistics of temperature and precipitation are highly non-stationary and therefore require more robust and sophisticated statistical techniques for accurate characterization. Of all the indicators of the large-scale climate conditions we studied, the dipole index explains the greatest fraction of multivariate variability in the co-occurence of California wintertime extremes in temperature and precipitation.

Probabilistic AR Detection for Understanding Western Coastal Hydroclimate

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BER Program: RGCM
Project: CASCADE SFA, LBNL
Project Website: https://cascade.lbl.gov

Precipitation from atmospheric rivers (ARs) presents both opportunity and challenge to human and natural systems near midlatitude western coasts: opportunity in that AR-related precipitation often satisfies a large portion of local water budgets in these coastal regions, and challenge in that the associated precipitation is often more extreme than that from other types of storm systems. Despite this importance, and a reasonably well-understood qualitative definition of ARs, the quantitative detection of ARs has remained surprisingly challenging. Results from the Atmospheric River Tracking Method Intercomparison Project (ARTMIP) indicate that there are a broad range of plausible AR detectors, and that scientific results can depend on the algorithm used. It is therefore imperative that AR-related science explicitly account for this uncertainty in the quantitative definition of ARs. We present results from novel statistical and machine learning approaches that detect ARs in atmospheric data and explicitly account for uncertainty in the detection. The first method utilizes convolutional neural networks to estimate the probability that each location in a global dataset is associated with an AR. The second method utilizes a Bayesian approach to sample the posterior distribution of parameters in a simple, heuristic AR detector; the essential goal of the method is to probabilistically select heuristic AR detectors that get the 'right' counts for ARs relative to a dataset of synoptic fields in which experts counted ARs. We compare our results to other detection methods within ARTMIP, and we apply our probabilistic AR detection methods to a variety of climate model scenarios to explore the interactions among AR detection uncertainty, natural variability, and external forcing.

International Ocean Model Benchmarking (IOMB): An Improved Package to Evaluate Model Performance and Skill

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The ocean remains an important carbon sink - taking up more than a quarter of annual anthropogenic CO_2 emission. However, uncertainty abound as to how the ocean will continue to respond to increasing atmospheric CO_2. Additionally, possible influence of this increase on marine ecosystem dynamics and biogeochemical processes are also open for discussion. Challenges with appropriate representation of physical and biological processes in Earth System Models (ESM) undermines the effort to quantify seasonal to multidecadal variability in ocean uptake of atmospheric CO_2. In a bid to improve analyses of marine biogeochemical contributions to climate–carbon cycle feedbacks, we have developed new analysis methods and biogeochemistry metrics as part of the International Ocean Model Benchmarking (IOMB) effort to meet the growing diagnostic and benchmarking needs of ocean models. These methods aim to use high quality observations to constrain model predictions and inform model developments. The generated package was employed to validate DOE ocean models and other international ocean models that contributed results to the fifth phase of Coupled Model Intercomparison Project (CMIP5). Our analyses show considerable limitations in ESMs representation of some biogeochemical processes that might influence marine uptake of atmospheric CO_2. Polar regions continue to show notable biases in biogeochemical and physical variables. Some of these disparities could have first order impacts on the conversion of atmospheric CO_2 to organic carbon. Combined effects of two or more of these forcings on ocean biogeochemical cycles and ecosystems are challenging to predict as additive and antagonistic effects may occur. A benchmarking tool for accurate assessment and validation of marine biogeochemical outputs is indispensable as we continue to improve ESM developments and understand the role of the global ocean under conditions of increasing atmospheric carbon dioxide. To improve our understanding of the implications of multiple stressors on marine contribution to climate–carbon cycle feedbacks, the International Ocean Model Benchmarking team continues to develop metrics and encode available datasets to analyze contemporary ocean model performance. This

effort will help to quantify uncertainties in ESMs, enhance future model development and further explicate marine contributions to global carbon cycle. To this end, IOMB offers a strategic platform to engage the ocean science community in assessing marine biogeochemistry and general circulation models in support of sixth Coupled Model Intercomparison Project (CMIP6).

Title: Coordinated Long-Term Spatially-Explicit Modeling of Urban and Agricultural Land Use for Investigating Regional Climate-Land-Use Interactions

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BER Program: RGCM

Project: A Hierarchical Evaluation Framework for Assessing Climate Simulations Relevant to the Energy-Water-Land Nexus (Cooperative Agreement)

Project Website: https://facets.agron.iastate.edu/display/ds/FACETS+Homepage

Project Abstract: To examine the size of potential two way influences between climate and land use, the FACETS project developed a new long-term spatial urban land model, and linked it with NCAR's existing agricultural land model, to produce plausible long-term spatial scenarios of coordinated urban and agricultural land use that are consistent with the Shared Socioeconomic Pathways (SSPs) and can serve as inputs to regional climate modeling. The urban model is a new capacity. It took a data-science approach, drawing on newly available time series of fine-spatial-resolution urban land change data spanning the past 30 years, as well as best available spatial population and environmental variables. The model functions at two spatial scales: (1) At national level, existing data indicate that contemporary urbanization presents three distinct development styles reflecting different socioeconomic trajectories (i.e. developed, steadily developing, and rapidly developing). Using models of these trajectories and Monte Carlo experiments, our model estimates decadal change in total amount of urban land throughout the 21st century, in relation to existing quantitative projections (e.g. population and economic growths) and qualitative narratives of the SSPs. (2) At 1/8-degree grid cell level, we capture subnational variations in the spatiotemporal dynamics of contemporary urbanization with a spatial model mapping land development potentials for each 1/8-degree grid cell using spatially-explicit drivers of urban land change and time series of historical urban land expansion maps. Our urban land model is unique and improves existing large-scale spatial urban land change models in at least four ways: (a) it is closely calibrated to historical time series data in contrast to the common approach relying heavily on stylized assumptions about spatiotemporal interactions, (b) it embodies multiple design features to capture subnational, local variations in the urban land expansion process, in contrast to existing models that operate at regional scale (e.g. one model setup per continent), (c) our spatial model is designed to extrapolate well over long time horizons where currently rural or undeveloped landscapes may evolve into potentially densely urban ones in high-development scenarios, and (d) it complies with both quantitative modeling results and qualitative narratives from existing SSP components. Besides the novel methodology, our

presentation will showcase the resulting set of coordinated urban and agricultural land use projections, and highlight prominent trends and patterns.

High-Resolution Ocean-Sea Ice Modeling: Progress in the Understanding of Large-Scale Onshore Heat Transport Pathways and Dynamics around Antarctica

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BER Program: RGCM

Project: University Award

Onshore penetration of oceanic water across the Antarctic continental slope (ACS) plays a major role in global sea level rise by delivering heat to the Antarctic marginal seas, thus contributing to the basal melting of ice shelves. The global societal impacts of this process and the observed rates of mass loss of the Antarctic Ice Sheet emphasize the need for better understanding and prediction of the ocean-atmosphere-cryosphere feedbacks driving the ocean heat transports at decadal time scales. In this project, we pursue two overarching goals: **(I)** Investigate the time-mean ($\boldsymbol{\varphi}^{mean}$) and eddy ($\boldsymbol{\varphi}^{eddy}$) components of the total heat transport ($\boldsymbol{\varphi}$) across the 1000 m isobath along the ACS using a 0.1° global coupled ocean/sea ice simulation based on the Los Alamos Parallel Ocean Program (POP) and sea ice (CICE) models, forced with the interannually-varying Coordinated Ocean-ice Reference Experiment version 2 (CORE-II) dataset and **(II)** Using the model vorticity budget to understand the large-scale dynamics of these cross-slope heat transports. The primary findings from our work on goal **(I)** are as follows: 1) Available *in situ* hydrography shows that the model successfully represents the basic water mass structure over the ACS, with a warm bias in the Circumpolar Deep Water layer; 2) The circumpolar integral of the annually-averaged $\boldsymbol{\varphi}$ is O(20 TW), distributed over along-slope segments of O(100-1000 km). 3) The seasonal and interannual variability of the circumpolarly-integrated $\boldsymbol{\varphi}^{mean}$ is controlled by convergence of Ekman transport, but also has some correlation with the surface buoyancy forcing (which is driven mostly by the freshwater fluxes associated with seasonal sea ice formation and melt); and 4) Prominent warming features at the bottom of the continental shelf (consistent with observed temperature trends) are found both during high-SAM and high-Niño 3.4 periods, suggesting that climate modes can modulate the heat transfer from the Southern Ocean to the ACS across the entire Antarctic margin. Preliminary results on goal **(II)** show that a balance between bottom vortex stretching (BVS), wind stress curl (WSC) and advection of planetary vorticity (APV) may explain the leading-order low-frequency dynamics of cross-slope transports in some segments of the ACS, *e.g.*, the central Weddell and west Amundsen Seas. Small lags in the phase spectrum between WSC + BVS and APV at all frequencies support this interpretation. This suggests that some regions of Antarctica may be more susceptible to changes in climate modes such as SAM and ENSO.

Anthropogenic Influences on Major Tropical Cyclone Events: Dynamical and Statistical Methods for Extreme Event Attribution

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BER Program: RGCM
Project: CASCADE SFA, LBNL
Project Website: https://cascade.lbl.gov/

Attribution of anthropogenic influences on extreme weather events has become an advanced science over the past decade. However, only recently have we developed the capability to quantify changes in the magnitude and probability of occurrence of intense storms such as tropical cyclones (TCs), owing in part to advancements in supercomputing and statistical methods. Here, we present results from two classes of attribution studies for impactful TC events: an extreme-value statistical analysis of observations, and climate change experiments using a convection-permitting dynamical climate model.

The first is an analysis of the record rainfall amounts during Hurricane Harvey in the Houston, Texas area. We analyzed observed precipitation from the Global Historical Climatology Network with a covariate-based extreme value statistical analysis, accounting for both the external influence of global warming and the internal influence of ENSO. We found that human-induced climate change *likely* increased Hurricane Harvey's total rainfall by at least 19%, and *likely* increased the chances of the observed rainfall by a factor of at least 3.5. This suggests that changes exceeded Clausius-Clapeyron (C-C) scaling.

The second analysis investigated how historically destructive TCs could change if similar events occurred in pre-industrial and future climates, using convection-permitting regional climate model simulations. We found that climate change to date enhanced average and extreme rainfall of Hurricanes Katrina, Irma, and Maria, but did not change TC intensity. In addition, future anthropogenic warming robustly increases wind speed and rainfall of intense TCs among 15 events sampled globally. In some cases, rainfall increases exceeded C-C scaling, as in the observational analysis of Hurricane Harvey. Additional simulations suggest convective parameterization introduces minimal uncertainty into the sign of projected TC intensity and rainfall changes, supporting confidence in projections from models with parameterized convection and TC-permitting resolution.

Diversity of ENSO Events Unified by Convective Threshold Sea Surface Temperature: A Nonlinear ENSO Index

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BER Program: RGCM and ASR
Project: CASCADE SFA, LBNL; Land-Atmosphere Coupling and Convection in the Water Cycle, LBNL
Project Website: https://cascade.lbl.gov/

The El Niño-Southern Oscillation (ENSO) is a major driver of variability in extreme climate events globally, and is characterized by a diversity of spatial patterns that have important implications for teleconnections. However, it is well-known that no single ENSO index can uniquely capture the diversity and extremes of ENSO. We show that this deficiency results from the inability of existing indices to characterize zonal shifts in deep convection associated with the Walker Circulation. To address this problem, we present a simple SST-based index of the average longitude of deep convection that uniquely characterizes the diversity of observed and simulated ENSO events. It recovers the familiar global responses of temperature, precipitation, and tropical cyclones to ENSO, and identifies historical extreme El Niño events. Despite its simplicity, the new ENSO longitude index (ELI) describes the nonlinear relationship between the first two principal components of SST. Unlike previous indices, ELI accounts for background SST changes associated with the seasonal cycle and climate change, as well as the nonlinear response of convection to SST. Analysis of ELI in simulations from the Community Earth System Model Large Ensemble Project reveals that extreme El Niño, El Niño Modoki, and La Niña events are projected to become more frequent in the future at the expense of neutral ENSO conditions, which is not apparent in conventional ENSO indices based on fixed-location SST anomalies. In addition, ELI highlights the extreme nature of the 1982-1983 and 1997-1998 El Niño events commonly called “canonical.” Finally, the ENSO longitude index provides a continuous time series for analyses of ENSO dynamics and a physically-based, yet practical way to evaluate climate models.

Title: **The Uneven Nature of Daily Precipitation and its Change**

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BER Program: RGMA

Project: CATALYST

Project Website: http://www.cgd.ucar.edu/projects/catalyst/

Project Abstract: A few days with heavy rain contribute disproportionately to total precipitation, while many days with light drizzle contribute much less. What is not appreciated is just how asymmetric this distribution is, and the even more asymmetric nature of trends due to anthropogenic climate change. We diagnose this asymmetry in models and observations. Half of annual precipitation observed at stations falls in the wettest 12 days each year in the median across stations. Climate models project changes in precipitation that are even more uneven than present-day precipitation. In a high emissions scenario, one-fifth of the projected increase in rain falls in just the wettest two days of the year, and seventy percent in the wettest two weeks. Mapping model projections back to stations, half of the precipitation change occurs in the wettest 6 days each year.

Exponential Integrators with Fast and Slow Mode Splitting for Multilayer Ocean Models

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BER Program: ESM

Project: University Award

We develop a time discretization framework based on exponential integrators for a stacked rotating shallow-water ocean model. The methods are based on a splitting of the forcing term into a linear rotating multi-layer wave-operator and a non-linear residual, corresponding to the advective forces. We discuss different solution strategies for the linear part by an approximation of the matrix exponential with skew-adjoint Krylov methods. The resulting integrator can take large time steps up to the advective time scale, independent of the speed of internal and external gravity waves. Additionally, the vertically coherent structure of the fastest waves can be used to compress the wave operator into a few vertical modes. In a special case, employing a reduction only to the barotropic component, we obtain a new class of methods with similar features to the well-known split-explicit method. Numerical experiments in the context of the SOMA testcase show that the methods are stable over decade-long simulation horizons and accurately reproduce solution statistics.

Effects of Ice and Permafrost on Delta Channel Dynamics

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BER Program: RGCM

Project: HiLAT

Project Website: hilat.org

Deltas are dynamic interfaces that connect rivers to the ocean. Deltas convey water, sediment, and nutrients through complicated networks of channels and lakes, and often control the temporal and spatial distributions of land-ocean fluxes based on water transport pathways and residence times. In the Arctic, permafrost and ice cover strongly influence deltas, yet we lack a fundamental understanding of how permafrost and ice control flow and sediment transport through these coastal landscapes. We conducted a series of numerical experiments using a reduced complexity model of delta dynamics (DeltaRCM) to investigate the influence of permafrost erodibility, ice thickness, and ice extent on delta and channel dynamics. Initial experiments were conducted with either permafrost or ice to examine the individual effects of these variables. Both ice and permafrost increase channel stability, and the presence of either ice or permafrost creates a less mobile channel network. Thick ice cover also plays a strong role in controlling depositional patterns, increasing deposition both overbank and offshore. Ice thickness appeared to be a more important variable than ice extent. Further experiments with both ice and permafrost indicated that both variables greatly reduce channel mobility by equivalent amounts, but that there is an upper limit to how much channel mobility can be reduced by ice and permafrost. Decreasing erodibility of sediments affected by permafrost has a strong impact on sediment distribution on land, while ice cover has a stronger influence on subaqueous and off-shore deposition. Attempts to relocate channels (avulsions) are often unsuccessful on deltas with permafrost, as it is hard to incise into the permafrost-laden deposit. Therefore, less erodible permafrost results in higher maximum elevations on the delta surface and a broader distribution of elevations, as the unsuccessful avulsions deposit sediment overbank. This behavior is enhanced by the presence of ice that increases water surface elevations upstream of the ice boundary and favors more frequent flooding. These results indicate that ice and permafrost reduce channel mobility and alter depositional patterns in coastal systems. As the effects of ice and permafrost diminish in a warming Arctic, we may therefore expect increased channel mobility that results in a more frequent reworking of coastal sediments, as well as decreased overbank deposition that limits the rate of vertical accretion and deltaic ability to keep up with sea level rise.

Title: **Prediction and Projection of the weakly-forced yet high-impact convective storms throughout the Ohio River Valley and Mid-Atlantic United States**

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BER Program: RGCM

Project: HYPERION

Project Website: http://climate.ucdavis.edu/hyperion/

Project Abstract: The 1-in-1000-year precipitation event in late June 2016 over West Virginia caused tremendous flooding damage. Like the 2012 mid-Atlantic derecho that blacked out much of the D.C. area, similar events can be traced to small, mid-tropospheric perturbations (MPs) embedded in the large-scale ridge pattern. Under this "weakly-forced" pattern, severe weather outbreaks commonly occur alongside eastward propagating MPs acting as a triggering mechanism for progressive mesoscale convective systems (MCSs), which move across the central and eastern U.S.. Forecasting of such weakly-forced yet severe weather events is difficult in both weather and climate timescales. The present diagnostic analysis of the MP climatology is the first step toward developing metrics that can identify and evaluate weakly-forced severe weather outbreaks in multi-model projections and is also the objective of the HYPERION project. The developed metrics can be applied for the extreme weather prediction and future climate projection throughout the Ohio River Valley and Mid-Atlantic States including the Susquehanna river basin, which is one of the focused case study regions of the project. We report a discernable, potentially pronounced subseasonal change in the MP climatology associated with the changing climate of North America. Both sea surface temperatures within the Gulf of Mexico

and mid-level high pressure over the central U.S. were found to exhibit strong correlations with MPs. Analysis of regional climate downscaling indicates a projected increase in MP frequency and the associated convective precipitation through the mid 21st century.

MPAS-Analysis: a Package for Evaluating MPAS Simulations with a Focus on the Ocean-ice Dynamics in the Southern Ocean

The MPAS-Analysis package is the first diagnostics package that evaluates MPAS simulations by direct comparison with available observations. It is almost entirely python based and features a shared code structure, so that main tasks such as interpolation from unstructured to regular grid, computation of climatologies, etc., are part of shared routines used by different diagnostic tasks. At the moment, MPAS-Analysis provides two types of diagnostics: 1) large scale metrics important for the evaluation of the coupled climate system, such as climatologies and trends of Sea Surface Temperature (SST), trends of Ocean Heat Content (OHC), Meridional Overturning Circulation (MOC), and climatologies and trends of sea-ice coverage for both hemispheres; 2) metrics important for the evaluation of the Southern Ocean and cryosphere around Antarctica, such as Mixed Layer Depth (MLD) maps and T, S distribution both in the horizontal and vertical direction compared with Southern Ocean State Estimate (SOSE) and World Ocean Circulation Experiment (WOCE) oceanic transect data, as well as melt rates underneath ice shelves compared with recent observations. The resulting diagnostic figures are viewable through an easy-to-browse web interface. Recent development has also provided interfacing with the Cinema software (cinemascience.org), which allows for a more dynamic platform for scientists to explore MPAS simulations in depth.

Probabilistic Sea Level Projections from Ice Sheet and Earth System Models (ProSPect)

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BER Program: SciDAC

Project: Probabilistic Sea Level Projections from Ice Sheet and Earth System Models (ProSPect)

Project Website: https://doe-prospect.github.io/

Changes to the Greenland and Antarctic ice sheet over recent decades have contributed to sea-level rise at an accelerating rate and present the largest potential for future changes in sea level. Accurate sea-level projections require simulations of ice sheet evolution using next-generation ice sheet models coupled to Earth-System Models (ESMs), but current limitations prohibit such projections. The U.S. Department of Energy has invested in the development of advanced ice sheet models that place increased resolution in regions experiencing the largest and most rapid changes. Building from these investments, the Probabilistic Sea Level Projections from Ice Sheet and Earth System Models (ProSPect) project aims to remove current deficiencies in order to allow for probabilistic projections of sea-level change using DOE ice sheet models coupled to the new Energy Exascale Earth System Model (E3SM). ProSPect was launched in 2017 under DOE's Scientific Discovery through Advanced Computing (SciDAC) program, a partnership between DOE's Advanced Scientific Computing Research (ASCR) and Biological and Environmental Research (BER) Offices. ProSPect has three major foci: ice-sheet model physics and ESM coupling, ice-sheet model initialization and uncertainty analysis, and ice-sheet model performance on next-generation, high-performance computing (HPC) architectures. Here, we present a project overview, highlight recent results, and summarize future efforts and interactions with E3SM.

Title: Deep learning to represent subgrid cloud and radiation processes in climate models.

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BER Program: ESM, RGCM

Project: University / Early Career / SciDac

Project Website: sites.uci.edu/pritchard

Project Abstract: Imperfections in climate model parameterizations, especially for clouds, have impeded progress toward more accurate climate predictions for decades. Cloud-resolving models alleviate many of the gravest issues of their coarse counterparts but remain impractically computationally demanding. Here we use deep learning to leverage the power of short-term cloud-resolving simulations for climate modeling. Our data-driven model is fast and accurate, thereby showing the potential of machine-learning–based approaches to climate model development in general. Results are shown for an aquaplanet proof of concept wherein limitations of out-of-sample generalization are explored (Rasp et al. 2018). Then, pilot tests exploring one-way coupling of neural network emulated atmosphere with a full land surface model are shown to discuss potential for use of this method in realistic settings.

Publications:

- Rasp, S., M. S. Pritchard, and P. Gentine. Deep learning to represent sub-grid processes in climate models, *PNAS*, 2018, https://doi.org/10.1073/pnas.1810286115

Title: **A new approach to reliable projections of extreme heat days**

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BER Program: RGCM

Project: FACETS: A Hierarchical Evaluation Framework for Assessing Climate Simulations Relevant to the Energy-Water-Land Nexus (Cooperative Agreement)

Project Website:
http://www.geo.cornell.edu/eas/PeoplePlaces/Faculty/spryor/DoE_FACETS/index.html and https://facets.agron.iastate.edu/display/ds/FACETS+Homepage

Project Abstract: Extreme heat is both a critical aspect of human vulnerability to climate variability and change, and a metric at the very core of the land-water-energy nexus. Most previous research designed to project possible changes in extreme heat has focused solely on the occurrence of extreme air temperatures. However, the human-health impacts of extreme heat are critically dependent on the co-occurrence of high air temperatures (T) and near-surface humidity (Q), while vegetation drought stress and wildfires tend to occur under conditions of high T but low Q. Thus, the historical trajectories of 'wet heat' (i.e. high T and Q) and 'dry heat' (high T and low Q) events differ greatly in space and time (Schoof et al. 2017), and the vulnerabilities to these types of events also differ. Making robust projections of these 'wet heat' and 'dry heat' events and their associated impacts is critically dependent on development and application of methodological approaches that can maintain relationships among variables (i.e. the co-variability of T and Q). Here we present a new approach to development of robust projections of both 'wet heat' (i.e. high equivalent temperature (Te) and T) and 'dry heat' (high T, moderate Te) events and apply it to output from seven models from the 5th Coupled Model Intercomparison Project (CMIP5) to make projections of the frequency and intensity of extreme heat events at the end of the C21st. The approach we have developed is based on a piecewise multivariate quantile mapping approach to temperature and humidity projections, which has the advantage that is preserves the association between T and Q while bias-correcting model output. Results for U.S. regions used in the National Climate Assessment and individual cities are characterized by increases in the frequency of both extreme 'wet heat' and 'dry heat' days as well as increases in the intensity of temperature and humidity conditions on those days. For many regions and individual cities, there is no overlap between the historical and future GCM ensembles, indicating that increases in extreme heat events of both kinds are robust.

Publications:

Schoof J.T., Pryor S.C., and Ford T. (2018): Projected changes in United States regional extreme heat days derived from bivariate quantile mapping of CMIP5 simulations (*in review*).

Schoof J.T., Ford T. and Pryor S.C. (2017): Recent changes in United States heat wave characteristics derived from multiple reanalyses. *Journal of Applied Meteorology and Climatology* **56** 2621-2636.

Title: A hierarchical analysis of the impact of methodological decisions in statistical downscaling

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BER Program: RGCM

Project: FACETS: A Hierarchical Evaluation Framework for Assessing Climate Simulations Relevant to the Energy-Water-Land Nexus (Cooperative Agreement)

Project Website:
http://www.geo.cornell.edu/eas/PeoplePlaces/Faculty/spryor/DoE_FACETS/index.html and https://facets.agron.iastate.edu/display/ds/FACETS+Homepage

Project Abstract: Despite the widespread application of statistical downscaling tools, uncertainty remains regarding (1) variations in downscaling model skill with model formulation (i.e. key decision points) and (2) the requirement of limitations of these approaches when applied to output from Global Climate Models (GCMs).
Specific to item 1) While a large number of downscaling inter-comparisons have been undertaken, variations in, for example threshold to define a wet da, or the use of methods resistant to over-fitting, mean that drawing out of robust generalizations regarding relative skill has proved very challenging. In this presentation we start by using a hierarchical framework resistant to model over-specification and developed within the context of perfect predictors to quantify the impacts of several key aspects of statistical transfer function form on model skill for daily maximum and minimum temperature (Tmax and Tmin), and precipitation occurrence and intensity are evaluated. We focus on; a) Model structure: Simple (generalized linear models, GLM) versus complex (artificial neural networks, ANN) models. b) Predictor selection: Fixed number of predictors chosen *a priori* versus stepwise selection of predictors and inclusion of grid point values versus predictors derived from application of principal components analysis (PCA) to spatial fields. We also examine the influence of domain size used in the 'weather typing' on model performance. For precipitation downscaling, we consider the role of the threshold used to characterize a wet day and apply three approaches (Poisson and Gamma distributions in GLM, and ANN) to downscale wet day precipitation amounts.
Specific to item 2) Two frameworks are typically used for statistical downscaling of GCMs; Model Output Statistics (MOS) and Perfect Prognosis (PP). Use of the former is challenged by the fact that GCMs reproduce a plausible sequence of upper air (and near surface) variables rather than reproducing in historical runs the actual time sequence of conditions. This lack of time-wise coupling to the values of the predictands (e.g. Tmax and Tmin) means this framework is essentially a bias correction approach. Use of a PP framework is possible only if GCM output for the predictors match the probability distributions in the reanalysis data set used to condition the transfer functions. We adopt a PP framework and evaluate measures of distributional similarity for predictors, assess 'how good is good enough?' and then provide illustrative

examples of climate projections using a robust PP approach developed using ERA-Interim reanalysis and applied to output from the MPI and GFDL GCMs.

Publications:

Pryor S.C. and Schoof J.T. (2018): A hierarchical analysis of the impact of methodological decisions on statistical downscaling of daily precipitation and air temperatures. *In review*.

Parametric sensitivity and uncertainty quantification in the version 1 of E3SM Atmosphere Model based on short Perturbed Parameters Ensemble simulations

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BER Program: ESM
Project: E3SM
Project Website: https://e3sm.org/

The atmospheric component of Energy Exascale Earth System Model (E3SM) version 1 (EAMv1) has included many new features in the physics parameterizations compared to its predecessors. Potential complex nonlinear interactions among the new features create a significant challenge for understanding the model behaviors and parameter tuning. Using the one-at-a-time method, the benefit of tuning one parameter may offset the benefit of tuning another parameter, or improvement in one target variable may lead to degradation in another target variable. To better understand the EAMv1 model behaviors and physics, we conducted a large number of short simulations (3 days) in which 18 parameters carefully selected from parameterizations of deep convection, shallow convection and cloud macrophysics and microphysics were perturbed simultaneously using the Latin Hypercube sampling method. From the Perturbed Parameters Ensemble (PPE) simulations and use of different skill score functions, we identified the most sensitive parameters, quantified how the model responds to changes of the parameters for both global mean and spatial distribution, and estimated the maximum likelihood of model parameter space for a number of important fidelity metrics. Comparison of the parametric sensitivity using simulations of two different lengths suggests that PPE using short simulations has some bearing on understanding parametric sensitivity of longer simulations. Results from this analysis provide a more comprehensive picture of the EAMv1 behavior. The difficulty in reducing biases in multiple variables simultaneously highlights the need of characterizing model structural uncertainty (so-called embedded errors) to inform future development efforts.

Impact of urbanization and irrigation on boundary layer and extreme weather events in Eastern US: Long-term WRF simulations at cloud resolving scale

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BER Program: RGCM and IA
Project: FACETS
Project Website: https://facets.agron.iastate.edu/display/ds/FACETS+Homepage

Urbanization affects climate and hydrological cycle by changing land cover and surface albedo, in which the most discernible impact is known as the urban heat island (UHI) effect. In response, to mitigate the heat-stress due to UHI effect, the residents of urban areas consume more energy and emit more air pollution. This eventually add-up to the UHI magnitude of these cities in the form of released anthropogenic heat (AH). Urban areas are most vulnerable to extreme weather conditions like heatwaves and severe storms and the need for robust understanding of urbanization effect on regional heat-stress, cloud formation and rainfall during summer cannot be overemphasized. Meanwhile, irrigation affects the local surface energy and water budgets by enhancing evapotranspiration and reducing surface temperature, and therefore Planetary Boundary Layer (PBL) evolution. However, its effects on regional climate are complicated and uncertain, due to the complex multi-scale interactions between soil moisture, land-surface heterogeneity, plant phenology and physiology, large scale as well as local secondary circulations.

In this study, the impact of irrigation and urbanization including UHI and AH effect, respectively, in Eastern USA is investigated using the Weather Research and Forecasting (WRF) model simulations at cloud resolving scale (4 km). High-resolution nightlight and AH data are used for accurate representation of urban surface and anthropogenic forcing in urban effect simulations. Results show that the daily mean UHI effects are in the range of 2-5 ^{O}C over Eastern USA. Interestingly, ~30 % of the UHI magnitude of these cities is contributed from released AH, suggesting the significant influence of AH fluxes on urban micrometeorology. Although, UHI values are higher during nighttime, contribution from AH is higher during daytime. In addition, daytime UHI effects synergistically increase during Heat wave conditions over Eastern USA, enhancing the heat-stress. We also find that including irrigation reduces model dry bias in warm season precipitation contributed by the mesoscale convective systems (MCS) and improves the precipitation diurnal cycle associated with the MCS propagation over Southern Great Plains. The results demonstrate the importance of irrigation and urbanization effects for Earth system modeling and improve the process-level understanding on the role of human activity in modulating Land–Air–Cloud Interactions and extreme weather events.

Amazonian Rainfall Biases of Andean Origin: Equatorial Wave Mediated Teleconnection over Tropical South America

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BER Program: RGCM

Project: Early Career / RGMA

Regional rainfall simulation in climate models is especially important over tropical rainforests regarding terrestrial carbon exchange and global carbon cycle. However, CMIP5 models still suffer from a Wet Andes–Dry Amazon (WADA) bias in the vicinity of the world's largest rainforest. In complement to other views that have attempted to understand this dipole structure by scrutinizing sea surface temperature over the Atlantic and the Pacific, or by focusing on local atmospheric and terrestrial processes over the Amazon forest, we try to understand the WADA bias from an Andean perspective, by examining the Andean convection – regional circulation feedbacks. Using a wide (180-member) ensemble approach, we conduct sensitivity experiments in the Community Earth System Model (CESM) v1.1 that shed light on the associated mechanisms by revealing an equatorial wave mediated response to artificially muting condensational heating over Andean orography. Comparing to the control group, the experiment group exhibits rainfall reduction over the Andes and eastward expanding rainfall enhancement over the Amazon. The teleconnection bearing signatures of equatorial wave activity is modified by the Andean topography, leading to the pronounced asymmetry of low-level wind response on eastern/western side of the Andes. The strong response of integrated vapor transport on the eastern side of Andes help set up the moisture flux convergence over the forested region, contributing to increased Amazonian rainfall. These findings help reveal a previously underappreciated Andean control pathway on Amazonian rainfall biases and help advance understanding of the root causes of the WADA bias feature in the CMIP multi-model mean.

Title: **Economic carbon cycle feedbacks may offset additional warming from natural feedbacks**

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BER Program: [RGCM, ESM]

Project: [RUBISCO SFA, University ESM project led by Natalie Mahowald, JK Moore]

Project Website: https://www.bgc-feedbacks.org/

Project Abstract:

As the Earth warms, carbon sinks on land and in the ocean will weaken, thereby increasing the rate of warming. Although natural mechanisms contributing to this positive climate-carbon feedback have been evaluated using Earth system models, analogous feedbacks involving human activities have not been systematically quantified. Here, we conceptualize and estimate the magnitude of several economic mechanisms that generate a carbon-climate feedback, using the Kaya Identity to separate a net economic feedback into components associated with population, GDP, heating and cooling, and the carbon intensity of energy production and transportation. We find that climate-driven decreases in economic activity (GDP) may in turn decrease human energy use and thus fossil fuel CO_2 emissions. In a high radiative forcing scenario, such decreases in economic activity reduced fossil fuel emissions by 13% this century, lowering atmospheric CO_2 by over 100 ppm in 2100. The natural carbon-climate feedback, in contrast, increased atmospheric CO_2 over this period by a similar amount, and thus the net effect including both feedbacks was nearly zero. Our work highlights the importance of improving the representation of climate-economic feedbacks in scenarios of future change. Although the impacts of climate warming on the economy may offset weakening land and ocean carbon sinks, a loss of economic productivity will have high societal costs, potentially increasing wealth inequity and limiting resources available for effective adaptation.

The Role of the Ocean in Modulating Radiative Feedbacks over the High Latitudes

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BER Program RGCM
Project: HiLAT
Project Website (http://hilat.org)

We isolate the role of the ocean in polar climate change by directly evaluating how changes in ocean dynamics with CO_2-doubling impact high-latitude climate. With CO_2-doubling, the ocean heat flux convergence (OHFC) shifts poleward in winter in both hemispheres in fully-coupled global climate model (GCM) simulations. Imposing this pattern of perturbed OHFC in a GCM with a slab ocean results in a poleward shift in ocean-to-atmosphere turbulent heat fluxes (both sensible and latent) and sea ice retreat; the high-latitudes warm while the midlatitudes cool, thereby amplifying polar warming. These ocean changes interact with climate feedbacks, e.g., midlatitude cooling is propagated to the polar mid-troposphere on isentropic surfaces, augmenting the (positive) lapse rate feedback at high latitudes. These results highlight the key role played by the partitioning of meridional energy transport changes between the atmosphere and ocean in high-latitude climate change.

Hemispheric asymmetries in polar climate sensitivity are also amplified by the ocean. Intermodel comparison of CMIP5 CO_2-quadrupling experiments shows that even in models where hemispheric ocean heat uptake differences are small, Arctic warming still exceeds Antarctic warming. This evolving ocean response to CO_2 forcing is then isolated from fully-coupled GCM simulations, and is imposed in GCM experiments utilizing slab ocean to isolate the evolving ocean's impact on polar climate. Overall, feedbacks over the southern hemisphere more effectively dissipate top-of-atmosphere anomalies than those over the northern hemisphere. Poleward shifts in ocean heat convergence in both hemispheres amplifies destabilizing ice-albedo and lapse rate feedbacks more strongly over the Arctic than over the Antarctic. These results suggest that the Arctic is intrinsically more sensitive to both CO_2 and oceanic forcings than the Antarctic, and that the ocean-driven climate sensitivity asymmetry arises from feedback destabilization over the Arctic rather than feedback stabilization over the Antarctic.

To Develop E-PRIME: A First Look at Connecting Climate Models to Energy Impacts.

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BER Program: ESM
Project: E3SM
Project Website: N/A

Abstract:
An increasing focus for E3SM version 3 is to develop and execute model configurations that focus on a diversity of human dimensions. However, the scope of information and the span of stakeholders for this capability requires a hierarchy of model construction, analyses, and assessments, all of which must be validated and understood. As a first step in addressing these needs, E3SM staff have been evaluating previously available models and next turn to v1 E3SM simulations.

Using a highly-resolved ensemble of CMIP5 climate simulations and empirical relationships between weather and household energy consumption, we provide one of the most detailed estimates to date for potential changes in the United States residential energy demand under the highest greenhouse gas emissions pathway. Our results indicate that more intense and prolonged warm conditions will drive an increase in electricity demand while a shorter and milder cold season will reduce natural gas demand by the mid 21st century. The environmental conditions that favor more cooling-degree days in summer and reduced heating-degree days in winter are driven by changes in daily maximum temperatures and daily minimum temperatures in the respective seasons. The projected changes exhibit impactful regional variations, with a net increase in energy cost in relatively warmer counties in the south and net decrease in energy cost in the counties across the United States that currently experience significant cold season. These projected changes in energy demand and cost have implications for future energy planning and cost management.

From this baseline study, we are leveraging EVE and LIVVkit tools to develop a diagnostics suite, E-PRIME, for E3SM simulations with a host of IAV community prioritized metrics of the hydrology cycle, including extremes and moisture tracking, later to be extended to include agriculture, ground transportation etc.

Mineralogically-speciated global combustion-iron emissions inventory

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BER Program: ESM
Project: Fire, Dust, Air and Water: Improving aerosol biogeochemistry interactions in ACME

Global anthropogenic contribution of bioavailable iron to oceans is perturbing the ocean-atmosphere iron and carbon dioxide budget by enhancing phytoplankton growth (primary oceanic productivity) and carbon dioxide uptake. Quantification of iron, its speciation, and its representation in climate models is poorly understood due to the lack of size-resolved observations and mineral-speciation of iron at source and at oceans. This work presents a global size-resolved total and soluble iron emission inventory based on anthropogenic combustion activities. Iron fractions in particulate matter emitted from fuel-technology combinations are compiled and overlaid on a particulate matter emission inventory generated in SPEW (Speciated Particulate Emissions Wizard). The anthropogenic contribution of total iron for the year 2000 was 0.4(0.1-1.3) Tg/yr as PM_1 and 0.5(0.2-2.5) Tg/yr as PM_{1-10}.

The representation of iron in climate models for their transport and atmospheric processing requires speciated-iron emissions at source. Currently, combustion iron is modeled as a single mineral in the fine mode in CESM. Atmospheric processing is the low-pH iron mobilization in the minerals in particulate matter which enhances its solubility. This work presents speciated-iron emissions at source from combustion activities. Major iron-minerals are grouped into six classes: clays, oxyhydrides, sulfates, sulfides, carbonates, and metals and a temperature-dependent phase transformation model is applied on the initial fuel-iron speciation to estimate the iron speciation at different temperatures. The results from this study will enable model representation of combustion-iron as a combination of different minerals and apply a mineral-specific processing scheme to estimate the atmospheric interactions during transport.

Title: Quantifying overland tropical cyclone precipitation in the Eastern U.S. in CAM5

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BER Program: RGCM

Project: An Integrated Evaluation of the Simulated Hydroclimate System of the Continental US

Project Website: https://climate.ucdavis.edu/hyperion/

Project Abstract:

Recently, the Community Atmosphere Model version 5 (CAM5) at high horizontal resolutions has been used to study the large-scale controls of global and regional tropical cyclone (TC) activity. The main focus of this work is to better understand the extreme precipitation associated with landfalling TCs in the Eastern U.S. In particular, this work uses various variable-resolution configurations of CAM5, a comprehensive atmospheric general circulation model, forced with prescribed sea-surface temperatures (SSTs) and greenhouse gases for present climate. Three different grids with horizontal grid spacing of approximately 28 km over all or parts of the North Atlantic are investigated. The impact of the variable-resolution grid choice on landfalling TCs and their associated precipitation is investigated using the updated TempestExtremes software to calculate storm size and extract storm relative rainfall. This work integrates into the broader Project Hyperion project to quantify the contribution of TCs to extreme rainfall in the Eastern U.S.

Economic and Energy Uncertainty Quantification

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BER Program: IA
Project: An Integrated Framework for Climate Change Assessment (Cooperative Agreement. DE-FG02-94ER61937)

MIT Integrated Global System Modeling (IGSM) framework allows us to quantify economic, energy and earth system uncertainties. The IGSM links the Economic Projection and Policy Analysis (EPPA) model, a multi-sector, multi-region, computable general equilibrium (CGE) model of the world economy to the MIT Earth System Model (MESM) of intermediate complexity.

We investigate uncertainty in meeting various atmospheric stabilization scenarios. Monte Carlo simulation with Latin Hypercube Sampling (LHS) is applied to draw samples from our latest probability distributions for approximately 100 parameters in the EPPA model, including capital and labor productivity growth rates, population, energy efficiency trends, elasticities of substitution, costs of advanced technologies, and fossil fuel resource availability. The efficiency of LHS allows for 400 samples to be sufficient to cover the full range of the distributions.

Here, we focus on energy technologies, uncertainty in their costs, and how their potential role in the energy mix varies in the ensemble results. This provides insight into the “robustness” of investments in different technologies as well as the conditions under which different technologies may be most successful. The ensemble results can also be used to study multi-sector dynamics, including investigation of water, energy and land use interactions.

Title: **Understanding the changing role of mountains as natural reservoirs**

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BER Program: RGCM

Project: An Integrated Evaluation of the Simulated Hydroclimate System of the Continental US

Project Website: https://climate.ucdavis.edu/hyperion/

Project Abstract:

Mountain ranges of the western United States are essential to meeting annual water demand yet are faced with an ever-increasing risk of low-to-no snowpack that undermine their unique role as natural reservoirs. This decline will occur nonlinearly in both space and time making climate models ever-important virtual laboratories to understand the processes that shape this decline. New cutting-edge climate models that can telescope resolution over mountainous regions and capture the global-to-regional scale interactions between atmosphere-land-ocean are now available. To ensure that these models produce the most usable estimates for water management, concerted efforts are underway to assess and intercompare both cutting-edge and conventional climate models through multi-metric model evaluation frameworks that are informed by on-going water stakeholder interactions in the Department of Energy Project Hyperion. One such multi-metric evaluation framework the snow water equivalent (SWE) triangle has been used to distill the annual snow season into six simple, yet informative, metrics that can be used to evaluate and intercompare skill in simulating mountain snowpack. This framework has led to the identification of common fail modes in climate models such as peak snowpack timing and average spring-melt rate. Further, the implications of climate change in altering mountain's unique role as natural reservoirs is also being evaluated. This presentation will discuss these findings and other ongoing research in the mountainous regions of California and Colorado using new and existing climate modeling methods, such as variable-resolution in the Community Earth System Model, as well as ongoing efforts in Project Hyperion to increase the co-production of science.

Improving ESM predictions using new surrogate modeling approaches and observation networks

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BER Program: ESM
Project: Optimization of Sensor networks for Climate Models (OSCM) SciDAC
Project Website: https://climatemodeling.science.energy.gov/projects/optimization-sensor-networks-improving-climate-model-predictions

Earth System models like E3SM are computationally expensive to perform even a single forward simulation, but such models contain hundreds of uncertain parameters and algorithms. The number of model outputs is also large, including many spatially and temporally varying quantities of interest. Uncertainty quantification (UQ) in or calibration of an ESM requires ensembles, which may need to be quite large given the high dimensionality of the problem. Surrogate modeling approaches have been successfully used for UQ, reducing the number of expensive model simulations and corresponding computational cost. However, the need to reconstruct high-resolution model outputs is a challenge for traditional surrogate modeling approaches. Here we advance the state of the art in surrogate modeling by using singular value decomposition (SVD) to reduce the dimensionality of model output with spatially and temporally varying outputs and using Bayesian optimization to quickly generate a high-performing neural network-based surrogate. This surrogate model can represent regional-scale outputs to advance data-model integration for improving model performance and predictive capability. This approach can be used in a new framework to optimize placement of new observations that will optimally reduce uncertainty in quantities of interest such as regional carbon or energy flux. This work will inform E3SM about the key drivers of uncertainty in the land-atmosphere system. We envision that this approach can be used to reduce biases in future simulations, and to help DOE design new observation systems targeted towards reducing model uncertainty.

Non-growing season high-latitude plant nitrogen and phosphorus uptake impact land interactions with the atmosphere and climate

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BER Program: RGMA-Analytics
Project: RUBISCO
Project Website: https://www.bgc-feedbacks.org/

High-latitude systems have very large soil organic carbon (C) stocks which are vulnerable to be released to the atmosphere as CO_2 and CH_4 over the 21st century. On the other hand, CO_2 sequestration by plants may counteract these emissions. High-latitude plant photosynthesis is strongly limited by nutrient (nitrogen (N), phosphorus (P)) availability, and these limitations are expected to increase in the coming decades. Further, high-latitude plant representations in global land models remain uncertain and these models have fared poorly in recent confrontations with observations. We show here that one relevant factor may be plant nutrient acquisition during the non-growing season, a widely observed process ignored by most large-scale land models. To quantify high-latitude nutrient acquisition, we apply ELMv1, a model that explicitly represents nutrient acquisition based on competitor traits (e.g., fine-root biomass and transporter density, microbial V_{max} and affinity). Our results indicate that high-latitude plant nutrient uptake during the non-growing season ranges between ~10 - 60% of annual uptake, with large spatial variability and dependence on plant type. Model experiments excluding non-growing season nutrient uptake demonstrate large effects on N retention and the C cycle, and therefore interactions with the atmosphere and climate.

Title: **A Probabilistic Gridded Product for Daily Precipitation Extremes**

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BER Program: RGCM

Project: CASCADE

Project Website: https://cascade.lbl.gov/

Project Abstract: Gridded data products are commonly used as a convenient substitute for direct observations because these products provide a spatially and temporally continuous and complete source of data. However, when the goal is to characterize climatological features of extreme precipitation over a spatial domain (e.g., a map of return values) at the native spatial scales of these phenomena, then gridded products may lead to incorrect conclusions because daily precipitation is a fractal field and hence any smoothing technique will dampen local extremes. To address this issue, we create a new "probabilistic" gridded product specifically designed to characterize the climatological properties of extreme precipitation by applying spatial statistical analyses to daily measurements of precipitation from the Global Historical Climatology Network over the contiguous United States. We argue that our method yields an improved characterization of the climatology within a grid cell because the probabilistic behavior of extreme precipitation is much better behaved (i.e., smoother) than daily weather. Finally, we compare our probabilistic gridded product with a standard extreme value analysis of the Livneh gridded daily precipitation product.

Title: **Quality Control of the CICE Consortium Sea Ice Model**

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BER Program: ESM, RGCM

Project: E3SM (LANL), RASM (NPS)

Project Website: https://github.com/CICE-Consortium

Project Abstract: The CICE Consortium is leveraging sea ice model development across the Department of Energy, Navy, National Center for Atmospheric Research, Environment Canada, and NOAA for scientific research applications and medium-range to centennial prediction. As part of this work, we have devised quality control procedures to maintain the integrity of the dynamical core and column physics package - Icepack - within the Los Alamos Sea Ice Model, CICE. This work is designed to help facilitate contributions to CICE from within the Consortium as well as from groups using our open software development environment beyond the Consortium. We present a quality control framework for CICE as described in a recent paper published in the Philosophical Transactions of the Royal Society. Using results from five coupled and uncoupled configurations of CICE, we have devised quality control methods that exploit common statistical properties of sea ice thickness, and test for significant changes in model results in a computationally efficient manner. New additions and changes to CICE are graded into four categories, ranging from bit-for-bit amendments to substantial, answer-changing upgrades. These modifications are assessed using criteria that account for the high level of autocorrelation in sea ice time series, along with a quadratic skill metric that searches for hemispheric changes in model answers across an array of different CICE configurations. These metrics also provide objective guidance for assessing new physical representations and code functionality. An essential outcome of this work is that it facilitates early identification of frailties in new model physics and changes to existing CICE configurations ahead of their implementation in coupled frameworks including E3SM. This approach is computationally efficient by way of early detection of component model problems that may otherwise go

undetected until implementation in coupled model configurations, and it serves as an example for a more general strategy to manage community codes used in E3SM.

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The Large-Scale Forcing and Land-Atmosphere Coupling in Variable-Resolution MPAS-CAM Simulations

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BER Program: RGCM

Project: A Hierarchical Evaluation Framework for Assessing Climate Simulations Relevant to the Energy-Water-Land Nexus (Cooperative Agreement)

Project Website: https://facets.agron.iastate.edu/display/ds/FACETS+Homepage

The Framework for Assessing Climate's Energy-Water-Land Nexus using Targeted Simulations (FACETS) project aims to develop a wide range of metrics tailored for the energy-water-land nexus and to understand climate model behavior at local to regional scales. For this goal, we are developing a hierarchical model evaluation framework consisting of a hierarchy of metrics to be applied to a hierarchy of numerical experiments using different modeling systems, horizontal resolutions, and boundary forcings. One of the participating models is the Model for Prediction Across Scales (MPAS) Atmosphere that has been incorporated into the Community Earth System Model. MPAS can be used to perform non-hydrostatic, global variable-resolution climate simulations with the physics parameterizations in the Community Atmosphere Model (CAM). The MPAS-CAM model is configured for three global variable-resolution simulations: 50-200km, 25-100km, and 12-46km grids with a refinement region centered over the contiguous U.S. Similar to other CMIP5 models, MPAS-CAM exhibits a common warm bias in surface temperature and dry bias in precipitation during the summer season (June-July-August) over the central U.S., a hot spot for land-atmosphere coupling. To understand the biases, we evaluate the resolution-sensitivity of the large-scale forcings that are expected to influence land-atmosphere coupling, such as the response of the low-level circulation to topography, land surface conditions, and the thermodynamic state of the lower free troposphere. The analysis is combined with selected land-atmosphere coupling metrics (e.g., Convective Triggering Potential and Humidity Index) to explore how the large-scale forcings and local-scale atmosphere-land coupling covary across resolutions. The implications of these analyses for simulations of mesoscale convective systems will be discussed.

Overview of Uncertainty Quantification Methods for Complex Models

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BER Program: ESM

Project: E3SM, OSCM (BER SciDAC)

Project Abstract: Uncertainty quantification (UQ) is a critical part in any computational model development. However, when dealing with complex climate models, canonical UQ methods face a range of challenges including

- large number of input parameters
- nonlinear input-output maps
- computational expense of a single simulation
- scarcity of available observational data to constrain the models
- spatio-temporal, high-dimensional output fields
- structural errors due to oversimplification and missing physics

This work will highlight state-of-the-art methods for tackling the challenges above, in the context of two major UQ tasks

- forward UQ: uncertainty propagation, surrogate construction and global sensitivity analysis
- inverse UQ: model calibration, parameter estimation

In particular, we will describe polynomial chaos surrogate construction enabling efficient propagation of uncertainty and global sensitivity analysis via variance-based decomposition. Input dimensionality reduction is achieved by sparsity-imposing regularization while high-dimensional spatio-temporal output field is represented by Karhunen-Loeve expansions. The inverse UQ is performed with Bayesian methods, via Markov chain Monte Carlo sampling. Bayesian machinery is well-suited to handle noisy and scarce observational data, while the required multiple model evaluations are alleviated by the pre-constructed surrogate usage. Furthermore, we will enhance the conventional Bayesian machinery to enable representation and propagation of uncertainties due to model structural errors. The overall framework allows efficient automated UQ with predictive uncertainty attributed to various sources such as parameter uncertainty, data noise and structural errors.

The developed workflow is connected to UQ Toolkit (www.sandia.gov/uqtoolkit). We will demonstrate the application of the methods to the E3SM land model using observational data from selected FLUXNET sites.

Confronting Global Water Risks into an Unprecedented Era: Successes and Challenges with Risk-Based, Multi-Sector Predictions

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BER Program: IA

Project: Cooperative Agreement

Project Website: https://globalchange.mit.edu/research/focus-areas/food-water

Society is fast approaching an unprecedented global situation of accessible water supplies no longer capable of sustaining the population's water use at modern standards of living. Now more than ever, the scientific community must conduct assessments of risk that identify the most likely and most damaging trajectories, as well as a balanced analysis to note regions and sectors at low risk. Quantifying risk, and more importantly, identifying adaptive and mitigating measures that reduce future risks, requires predictive tools that describe sectors across the coupled human-Earth system as well as their interactive and interdependent relationships. With these issues in mind, we have assessed trends in managed water stress simulated by the Water Resource System within the IGSM framework (IGSM-WRS). Forced by simulated climate simulated from an Earth-system model and socio-economic drivers from the Economic Projection and Policy Analysis (EPPA), the IGSM-WRS prediction framework constructs large-ensemble scenarios that include a "business-as-usual" future with countries meeting their Paris Agreement commitments. Under this projection, preliminary analyses reveal important regional aspects of impending water-stress risks. Most notably, salient skewness in risk can be seen for a number of basins across the developing world and the United States and favors a stronger increase in water stress (as compared to an equal likelihood of decreased stress). Over the United States, the ensemble central tendency also shows the largest relative increase across the Northeast – and is largely attributable to population growth and economic drivers of water demand. Sensitivity simulations have assessed widespread deployment of efficient water-use technologies and stricter mitigation pathways. All these indicate that hundreds of millions of people could avoid elevated risk to heightened water stress. We have also analyzed climate-change vs. runoff-responses across the Earth-system models of the Coupled Model Intercomparion Project Phase 5 (CMIP5). An analytic framework has been constructed such that the human-forced response due to a shift in the process-level, "local" (i.e. gridpoint) hydrologic functioning can be identified – and this signal is separate from that associated with a change in precipitation and/or meltwater. These

runoff processes vary dramatically across the CMIP models due to their varying degrees of resolution and hydrologic sophistication. Thus, the analysis ultimately serves to more comprehensively express the total range of hydrologic outcomes and risk. Overall, our preliminary analyses across the WRS basins within the contiguous U.S. indicate that a number of basins contain a propensity toward drier runoff responses under human-forced change.

Examining storage-streamflow correlation hypothesis from data mining using a process-based model

In our earlier work (Fang and Shen, 2018), we used classification and regression trees to identify controls of the correlation between storage and streamflow. One hypothesis generated from such analysis is that soil thickness decides how peak streamflow (floods) responds to large precipitation in the Appalachian and Southeastern U.S., which indicates that it is important to correctly the subsurface stratigraphy in order to capture the floods in this region. However, it is challenging to distinguish between causative and associative relationships purely from a data mining perspective. Here we seek to test this hypothesis using CLM-PAWS, a parallel process-based hydrologic and land surface model, with an interface to regional climate model simulations. We seek to reproduce hydrologic responses in these basins and the observed streamflow-storage relationships and use perturbed experiments to analyze the causal relationships. We demonstrate that the collaboration between data mining tools and physically-based models provides stronger confidence in the machine-learning-derived hypotheses.

The Atmospheric River Tracking Method Intercomparison Project (ARTMIP): How Do Atmospheric River Metrics Change Across Different Methodologies?

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BER Program: RGCM

Project: CATALYST

The Atmospheric River Tracking Method Intercomparison Project (ARTMIP) is an effort to understand and quantify the uncertainties in atmospheric river (AR) science based on choice of methodology. ARs are long, filamentary structures, often associated with extratropical cyclones, that transport large amounts of water from the tropics/subtropics into high latitudes. Identifying and tracking these features is often dependent on how an atmospheric river is defined, of which, there is no firm consensus. Given the range of AR definitions, it is not surprising that identification and tracking methodologies for gridded datasets, such as reanalysis products or climate model data, are also diverse and can disagree on the presence of an AR for a particular time and place. This has wide implications for AR metrics such has climatology, frequency, duration, intensity, and precipitation attributable to these storms. ARs heavily influence regional water balances where one storm can act as a drought buster, or conversely, be the catalyst for damaging floods. Understanding how ARs metrics shift in the future, both globally and regionally, is critical to estimating hydrological cycle impacts important to stakeholders such as water managers, local governments, and individuals, alike. ARTMIP attempts to quantify uncertainties by directly comparing across participating identification algorithms under one umbrella project. The effort is divided into two tiers and includes up to 26 different AR tracking methodologies, each applied to a common dataset provided and maintained by ARTMIP. In Tier 1, groups must run their algorithms on MERRA-2 3-hourly ~50km reanalysis and produce AR catalogues (for each time, at each grid point, either an AR exists, or it does not). With Tier 1 catalogues as a baseline, Tier 2 will focus on science questions focused on climate change and reanalysis sensitivity. Here, we present results from Tier 1 ARTMIP catalogues highlighting climatology metrics such as AR frequency, duration, intensity, and precipitation. Algorithms are grouped by similarity of threshold requirements (or "clustered"), compared, and explained. For example, methodologies that require an absolute moisture threshold to identify an AR, e.g. 250 kg $m^{-1}s^{-1}$integrated vapor transport (IVT), produce different frequency statistics than those using a relative measure, e.g. one based on climatology or a zonal anomaly. ARTMIP aims to provide the community with a mechanism to gauge uncertainty in AR diagnostics, to provide guidance

on how to match algorithm types to specific science questions, and to provide catalogues to the community for the advancement AR research.

Title: **Coupled CAPT: Using Ensemble Seasonal Hindcasts for Diagnosis and Attribution of Systematic SST Biases**

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BER Program: RGMA

Project: LLNL Climate Change Research SFA

Project Website: https://pcmdi.llnl.gov/projects/capt/index.html

Project Abstract:

Simulating the observed sea surface temperature (SST) remains a challenge for climate models, resulting in SST biases which impact the fidelity of our future climate projections and seasonal-to-decadal predictions. In this study, we use an ensemble seasonal hindcast approach to investigate the mechanisms leading to the development of SST biases. We first compare short-term hindcasts from models participating in the North American Multi-Model Ensemble (NMME) project to their long-term climatological simulations. Our analysis shows that there is a good SST bias correspondence between the hindcasts and their respective climate runs over most tropical and subtropical oceans. We find that biases such as the equatorial Pacific cold tongue bias, the cold biases over the subtropics in the Pacific and Atlantic, and the warm southeast tropical Atlantic bias emerge within a few months, indicating that climatological SST biases result from relatively fast developing ocean-atmosphere processes. We further investigate the equatorial Pacific cold tongue bias by performing six-month long hindcasts with CESM1 covering the period 2001-2005, with initial conditions derived from ERA-Interim for the atmosphere and from NCAR-DART for the ocean. Whereas the CESM1 climatology exhibits a cold bias during both warm (boreal spring) and cold (boreal fall) phases of eastern equatorial SSTs, the hindcasts develop the cold phase cold bias within six months but not the warm phase cold bias. We find that the fast-emerging cold phase cold bias results from a too strong vertical advection, associated with easterly wind stress anomalies. The warm phase cold bias emerges at lead times more than 6 months, possibly linked with the advection of the northeast Pacific cold bias by anomalous northerly winds associated with the double ITCZ bias. We further explore the sensitivity of the equatorial Pacific cold bias and its annual cycle to the representation of moist convection. Our results demonstrate that the ensemble seasonal hindcast approach is a useful method for diagnosing SST biases and identifying mechanisms which drive the biases.

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Title: **Confronting Uncertainty in Emissions Data for Earth System Models: Next Steps With The Community Emissions Data System (CEDS)**

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BER Program: ESM

Project: Community Emissions Data System (PNNL)

Project Website: http://www.globalchange.umd.edu/ceds/; http://github.com/JGCRI/CEDS

Project Abstract:

Emissions data are key inputs into Earth System Models. The Community Emissions Data System (CEDS) is an open source system that combines energy use and other activity data with emission inventory information to produce consistent anthropogenic emission estimates over time. The CEDS 2016 data release was used as the historical anthropogenic emissions information for CMIP6 and also as the starting point for the CMIP6 future scenarios.

While emissions are often treated as known, emissions data are uncertain. The next steps for the CEDS project will deal with this uncertainty in several ways. One consequence of uncertainty is that new datasets will differ from previously released data, which can lead to altered model results. The CEDS project plans to release annual updates so that changes in emission data can be incrementally tracked as estimates change, allowing the community to access the impact of these changes. As an open-source system CEDS also facilitates transparency in assumptions and their changes over time.

A second step is to quantify emissions uncertainty. We have developed an approach that focuses on uncertainty from the prospective of a time series, instead of uncertainty bounds. This allow us to produce ensembles of emission time series estimates, which will allow emissions uncertainty to be treated on par with other sources of Earth system uncertainty.

Not all uncertainties are equally important. In proposed new work, we aim to perform multi-model sensitivity tests to determine which uncertain emission aspects are important to Earth System model results, allowing prioritization of work to improve emissions data.

Finally, we also have proposed to use new methods to better constrain emission magnitudes and spatial locations by using remote sensing data. By combining satellite emission estimates with the detailed sectoral information in CEDS we aim to create a hybrid emissions inventory that combines the best of both datasets.

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Coherent joint emulation of Earth System Model temperature-precipitation realizations: fldgen v2.0

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BER Program: Multi-sector Dynamics Program

Project: iHESD SFA PNNL

Project Websites:

https://climatemodeling.science.energy.gov/projects/integrating-human-and-earth-system-dynamics-ihesd-scientific-focus-area

https://github.com/jgcri/fldgen

Two important topics to researchers in earth sciences and integrated human-Earth systems are the effects of extreme events and uncertainty in climate projections. Understanding the uncertainty around extreme events also has direct relevance for decision makers, the U.S. energy grid, and other stakeholders. Nowhere is this more important than in the water cycle, for which the precise distribution of precipitation over space and time is a primary driver of extreme events like drought and flooding, as well as a key contributor to the energy-water-land nexus through its impact on agricultural performance and water for energy.

Studying these topics requires large ensembles of high-resolution future climate scenarios, which are generally too expensive to produce directly by running Earth System Models (ESMs). Climate model emulators attempt to solve this problem by approximating the output a climate model *would have* produced had it been run for a specified scenario. These emulators are cheap to run, but typically capture only the mean response of the climate and little to none of the variability that would be present in a real ESM output. Attempts to add interannual variability to such emulations often lose important spatial and temporal correlations that fundamentally define ESM patterns (such as the El Nino–Southern Oscillation), or else cannot produce the number of realizations necessary for extreme event or uncertainty studies. We have solved many of these problems for the case of global temperature (Link et al. (2018), https://github.com/jgcri/fldgen), and have recently extended this method to produce *joint* realizations of temperature and precipitation global gridded time series that retain the spatial and temporal variance and covariance structures of the input ESM data (at a much lower computational cost compared to the ESMs being emulated). This joint approach was chosen in light of recent research showing that modeling temperature and precipitation extremes independently mischaracterizes drought hazards (Zscheischler & Seneviratne (2017)). Crucially, the fldgen method does so without placing *a priori* limits on the form of the correlation function and without using bootstrap resampling of existing ESM output (Castruccio & Stein (2013); Osborn et al. (2015); Alexee et al. (2016)), and is available as open source, installable software with rigorous documentation and integrated testing.

References:

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Hamiltonian Structure Preserving Reduced-Order Model for the Shallow Water Equations

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BER Program: ESM

Project: University Award

Reduced order modeling (ROM) provides a way to decrease the degrees of freedom of large-scale ocean models (such as MPAS-O) using a reduced, data-driven basis. This can be useful to reduce the time-to-solution in simulations and has applications in data assimilation and uncertainty quantification. The computational effort in ROM is split between a costly offline phase, which identifies the globally orthogonal basis functions corresponding to the dominant modes of the system and constructs the reduced model, and the much cheaper online phase, which evolves the reduced model in time. The online phase can potentially be reused for multiple parameter sets, leading to efficient simulations. Another benefit of ROM is that the reduced model, which excludes the highest frequency modes, typically eases the time-step restriction existing for explicit methods. The long time-horizons required in climate modeling make the long-term stability of the reduced model critical. For this reason, a Hamiltonian structure preserving ROM (HSP-ROM) method has been developed for the rotating shallow water equations (discretized in space with the TRiSK scheme), leading to a more stable reduced model than conventional ROM methods. In particular, the mass and energy conserving properties of the full order model are inherited by the reduced model. Additionally, if the original model is augmented by additional dissipation terms such as drag or diffusion, the reduced model is dissipative as well. Moreover, the HSP-ROM is constructed in an approximate energy norm which increases the accuracy of the method. Special attention is paid to the efficient numerical treatment of the nonlinear terms appearing in the reduced model, which requires additional approximation steps. Results are presented for different simulations of a single-layer ocean model, which is set up to be either energy conserving, energy dissipating, or includes additional wind forcing terms. The latter setup is inspired by the SOMA testcase. The reduced model will be compared to the original model to assess its potential viability.

Extreme Events Frequency Analysis Using Remote Sensing Precipitation Information

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BER Program: CESD
Project: CERC-WET
Project Website: https://cerc-wet.berkeley.edu

Utilizing satellite data with high resolution has become crucial in analysis and estimation of extreme precipitation events. In the Center for Hydrometeorology and Remote Sensing at UC Irvine, a near-global high resolution precipitation data set known as PERSIANN-CDR is developed for long term studies. It provides daily rainfall estimates at 0.25×0.25 degree spatial resolution for more than 30 years since 01/01/1983. Accordingly, two independent studies in rainfall frequency analysis has been performed. The first study (Faridzad et al. 2018) is based on developing a Bayesian hierarchical framework together with PERSIAN-CDR dataset in order to estimate extreme precipitation return levels. Our algorithm, jointly utilizes Markov Chain Monte Carlo and Bayesian hierarchical method to estimate the posterior distribution of the Generalized Extreme Value (GEV) parameters. A tri-variate Gaussian distribution is assumed as prior information. Preliminary results demonstrated that the Bayesian approach produced more accurate estimates of the GEV parameters, compared to the other popular parameter estimation methods such as maximum likelihood and L-moments methods, especially for the shape parameter. The second study (Ombadi et al. 2018), proposes a methodological framework for developing Intensity Duration Curves from satellite-based precipitation data especially in data-scarce regions. The framework is also responsive to regions with different climatic and precipitation regimes. Our goal is achieved by primarily identifying the systematic bias in extreme satellite-retrieved precipitation and then applying the area-to-point rainfall transformation which accounts for the characteristics of areal rainfall estimates provided by satellite-based precipitation products and plays a considerable role in reducing the relative error of IDF estimates. IDF curves derived from PERSIANN-CDR are then evaluated against NOAA-Atlas 14 precipitation frequency estimates. Results have shown significant percentage of satellite-based IDF curves fall within the confidence interval of NOAA Atlas 14 for most geographic sections of CONUS with the best results over the Northeastern States with 77%, 86% and 84% of 1-day, 2-days and 3-days IDFs within the confidence interval respectively. Our future goal is to extend non-parametric distributional robustness to GEV estimation. In particular, we consider a family of probability models, all of which lie in a *neighborhood* of a reference GEV model, and compute a conservative worst-case estimate of V@R over all of these candidate models.

Tropical Radiative Feedback Relative to Tropospheric Temperature Variations in Models and Observations, 2000-2017

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BER Program: RGCM

Project: Toward an Improved Estimate of Climate Sensitivity and its Application to Key Climate Metrics

Abstract: In recent decades, global warming has arguably progressed at a somewhat slower rate than projected by climate models forced with increasing anthropogenic greenhouse gas concentrations, with the most marked discrepancy in the tropical troposphere. Diagnosing radiative feedbacks from observational data in order to explain the reduced rate of warming has proved difficult, with a variety of ambiguous results. From an analysis of 89 climate model experiments averaged from 20 different models we show that radiative feedback parameters calculated from de-trended tropospheric temperature and top-of-atmosphere radiative flux data are correlated (r=0.74) with the models' tropospheric temperature trends during the 18 year period 2000-2017. This suggests some utility in diagnosing short term (~20 year) warming rates from feedbacks diagnosed from interannual variability. Similarly-computed feedback parameters from CERES satellite radiative budget observations and tropospheric temperature observations are outside the range of 96% of the models from radiosonde temperature data, and 99% of the models from satellite (UAH & RSS) temperature data. The results suggest the weaker tropospheric warming in the observations is the result of weaker longwave radiative feedback than in the models, nominally supportive of a weak infrared iris effect. There is little average difference between models and observations for shortwave feedback. The results also demonstrate the greater utility of tropospheric over surface temperature for diagnosing feedback parameters from relatively short datasets. There is some uncertainty in our results since the model tropospheric temperatures are based upon 1000-200 hPa thicknesses, which have different tropospheric weighting (linear in geopotential height) than do the satellite temperature weighting functions. The intercomparisons should be performed again with model-calculated equivalents of the satellite data.

Pinning the Tails on HECTOR: Recent Model Developments and Bayesian Calibration using Global Sea-level Rise Information

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BER Program: Multi-sector Dynamics
Project: PNNL, IHESD SFA
Project Website: https://github.com/bvegawe/hector_probabilistic

Probabilistic climate assessments require robust characterizations of decision-relevant uncertainties. Reduced complexity climate models are useful tools for quantifying uncertainty, given their flexibility, computational efficiency, ability to provide sound mechanistically-based emulators, and suitability for large-ensemble frameworks necessary for statistical estimation using resampling techniques (e.g. Markov chain Monte Carlo—MCMC). Here we document a new version of the simple, open-source, global climate model Hector, coupled with a one-dimensional diffusive heat and energy balance model (Diffusion Ocean Energy balance CLIMate model; DOECLIM) and a sea-level rise module (Building blocks for Relevant Ice and Climate Knowledge; BRICK) that also represents contributions from thermal expansion, glaciers, and polar ice sheets. We apply an adaptive MCMC method to quantify model uncertainties surrounding 39 model parameters with prescribed radiative forcing, using observational information from global surface temperature, ocean heat content, and sea-level rise. We find the addition of sea-level rise as an observational constraint sharpens the upper tail of the model's climate sensitivity estimate (the 97.5 percentile is reduced from 6.5 K to 5.3 K), which has implications for probabilistic projections of global surface temperature and sea-level rise. Our results demonstrate the effects of observational ocean constraints on future projections of key climate variables, such as global mean temperatures and sea-level rise, in particular for the tails of the distributions.

Influence of uncertainties on the tails of climate projections on decision-relevant spatial and temporal scales

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BER Program: Multi-sector Dynamics
Project: Cooperative Agreement
Project Website: https://www.pches.psu.edu

The frequency, duration, and intensity of climate and weather extremes (such as extreme precipitation events, droughts, heat waves, floods, and severe weather outbreaks) are changing. This PCHES subproject addresses the driving mechanisms and magnitudes of observed and modeled changes in extremes. Here we highlight recent analysis of warm temperature extremes in several recent global climate model ensembles, focusing specifically on uncertainties due to structural model differences, grid resolution, and internal variability. Results show that models and ensembles differ greatly in the representation of extreme temperature over the United States, and variability in tail events is dependent on time and anthropogenic warming, which can influence estimates of key decision-relevant temperature metrics, such as return periods of extreme temperature events. These effects can considerably influence the uncertainty of model hindcasts and projections of extremes. Several idealized regional applications are highlighted for evaluating ensemble skill and trends, based on quantile analysis and root mean square errors in the overall sample and the upper tail. The results are relevant to regional climate assessments that use global model outputs and that are sensitive to extreme warm temperature.

As part of this work, we are developing simple toolkits using the R statistical programming language for characterizing temperature in gridded datasets.

Title: **Mechanisms for Extreme El Nino Events in Large Model Ensembles**

Samantha Stevenson,[1]* Emanuele Di Lorenzo[2], Matthew Newman[3]

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BER Program: RGCM

Project:University Award entitled: "*Mechanisms of Pacific decadal variability in ESMs: the roles of stochastic forcing, feedbacks & external forcing*"

Project Website:

Project Abstract: The effect of climate change on the El Nino/Southern Oscillation (ENSO) is critical for impact assessments, but is not well constrained by climate model projections. Although there are indications that ENSO-driven precipitation extremes may increase in the future, the possible range of such changes is likewise still uncertain. Here we use suites of climate model simulations to show that future changes to `extreme El Nino' events are strongly linked with both the historical mean state climate and its response to 21st century warming. Models robustly show an increase in the sensitivity of precipitation to SST anomalies in the 21st century, which drives an increase in rainfall during El Nino. However, diversity in projected future SST variance drives inter-model differences in the occurrence frequency of extreme El Nino events, which in the Coupled Model Intercomparison Project (CMIP5) range from a 28% increase to a 12% decrease. Crucially, these effects are systematically related to mean climate: models with a larger proportion of 21st century precipitation extremes tend to exhibit both colder mean 20th century SSTs and a weakening of the 21st century zonal SST gradient, in addition to a more pronounced strengthening of ENSO-driven SST variations. This implies that improving biases in simulated 20th century mean climate may be key to reducing uncertainty in projected extremes in both precipitation and SST.

Title: **CESM2 Workflow Development and Implementation**

Gary Strand,[1*] Sheri Mickelson,[1] Kevin Paul,[1] Alice Bertini [1]

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BER Program: RGCM

Project: CATALYST (DOE/UCAR Cooperative Agreement)

Project Website: http://www.cgd.ucar.edu/projects/catalyst

Project Abstract: The new CESM2 workflow has been implemented and is being used for the CESM2 contribution to CMIP6, currently underway. The workflow consists of parallel Python-based tools that transpose the raw CESM2 model output from timeslice to timeseries format and convert the timeseries data to be compliant with the CMIP6 data requirements. The *cylc* workflow manager oversees both processes as well as running CESM2 itself and performing periodic diagnostics of the model state. It also interacts with the database of the CMIP6 simulations, updating the database as the model executes. The development and implementation of the workflow are described and detailed in the presentation.

Rossby Wave Breaking and Transient Eddy Forcing during Euro-Atlantic Circulation Regimes

Erik Swenson,[1] David Straus,[1]*

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BER Program: RGCM

Project: Mid-Latitude Circulation & Extremes in Changing Climate, University Agreement (AOES Dep., GMU)

Project Abstract:

The occurrence of boreal winter Rossby wave breaking (RWB) along with the quantitative role of synoptic transient eddy momentum and heat fluxes directly associated with RWB are examined during the development of Euro-Atlantic circulation regimes using ERA-Interim. Results are compared to those from seasonal reforecasts made using the Integrated Forecast System model of ECWMF coupled to the NEMO ocean model. The development of both Scandinavian blocking and the Atlantic ridge is directly coincident with anticyclonic wave breaking (AWB); however, the associated transient eddy fluxes do not contribute to (and, in fact, oppose) ridge growth, as indicated by the local Eliassen–Palm (EP) flux divergence. Evidently, other factors drive development, and it appears that wave breaking assists more with ridge decay. The growth of the North Atlantic Oscillation (NAO) in its positive phase is independent of RWB in the western Atlantic but strongly linked to AWB farther downstream. During AWB, the equatorward flux of cold air at upper levels contributes to a westerly tendency just as much as the poleward flux of momentum. The growth of the negative phase of the NAO is almost entirely related to cyclonic wave breaking (CWB), during which equatorward momentum flux dominates at jet level, yet low-level heat fluxes dominate below. The reforecasts yield realistic frequencies of CWB and AWB during different regimes, as well as realistic estimates of their roles during development. However, a slightly weaker role of RWB is simulated, generally consistent with a weaker anomalous circulation.

Publications:

Swenson, E. T., and D. M. Straus, 2017: Rossby wave breaking and transient eddy forcing during Euro-Atlantic circulation regimes. *J. Atmos. Sci.*, **74**, 1735-1755, doi: http://dx.doi.org/10.1175/JAS-D-16-0263.1

Title: **Technology Adoption as Climate Adaptation: Evidence from US Air Conditioning**

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BER Program: Multi-sector Dynamics

Project: Cooperative Agreement

Project Website: https://www.pches.psu.edu

Project Abstract:

This project is a component of PCHES Sub-Project 1.3 (Integrated assessment of climate change impact risk on the food-energy-water nexus) investigating the energy system impacts of climate change at the intensive and extensive margins.

Climate change is projected to induce more frequent high temperature extremes—increasing demands for cooling services, and associated electricity use, and less frequent low temperature extremes—reducing demands for heating, and associated consumption of multiple fuels. Sue Wing and De Cian (2018) and Van Ruijven et al (2018) demonstrate that, circa mid-century, the consequence at the intensive margin will be increases energy demand globally and in most world regions. An additional impact pathway that is less well understood is households' propensities to adapt by investing in space conditioning capital (especially air conditioners, ACs), and, simultaneously, changing their consumption of energy by adjusting their utilization of stocks of heating and cooling capital. A key concern is that climate change will hasten the penetration of AC in developing countries, particularly those in the tropics (where extreme high temperature exposures are projected to increase substantially even as early as the middle of the century), and thereby stimulate increases in electricity demand, consumption of fossil fuels for electricity generation, and emissions of greenhouse gases.

We investigate the aforementioned positive feedback loop (where adaptation to climate change either exacerbates warming itself, or hinders attempts to mitigate further emissions of GHGs) using theoretical and empirical evidence regarding the joint decisions to adopt AC and consume electricity to maintain thermal comfort. Using econometric modeling techniques, we exploit households' responses to questions about the presence of air conditioners and the value of their electricity bills from the 1960, '70 and '80 waves of the decennial Census, as well as multiple waves of Annual Housing Survey and the bi-annual American Housing Survey to elucidate the effects of temperature on AC adoption and electricity consumption. Our results elucidate the effects of weather household AC adoption and the consequences of AC penetration for

residential electricity demand, and draw implications for the extensive margin impacts of future climate change.

Publications:

De Cian, E. and I. Sue Wing (2018). Global Energy Consumption in a Warming Climate, Environmental and Resource Economics, in press.

Van Ruijven, B., E. De Cian and I Sue Wing (2018). Robust Amplification of Future Energy Demand Growth due to Climate Change, in review.

Resolution Dependence and Rossby Wave Modulation of Atmospheric Rivers in an Aquaplanet Model

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BER Program: RGCM

Project: Mid-Latitude Circulation & Extremes in Changing Climate, University Agreement (AOES Dep., GMU)

Project Abstract:

Atmospheric rivers (ARs) are examined in a set of aquaplanet simulations using the Model for Prediction Across Scales dynamical core run at multiple horizontal resolutions, namely, 240, 120, and 60 km. As the resolution is increased, there is an increase in the occurrence of long-lasting ARs. At the same time there is also an increase in the local finite-amplitude wave activity (LWA) of upper-tropospheric absolute vorticity, a measure for Rossby wave phase and amplitude that is closely linked with wave breaking. Consistent with the notion that changes in ARs are driven by midlatitude dynamics, a strong relationship is identified between ARs and the equatorward component of LWA. A logistic regression model is used to quantify the probability of AR occurrence based solely on LWA and explains most of the change in AR frequency with resolution. LWA is a diagnostic that may be easily applied to the broadly available output of phase 6 of the Coupled Model Intercomparison project and other model simulations, thus enabling scientists to infer AR and Rossby wave characteristics. AR characteristics, in particular, require higher-resolution moisture and winds at multiple levels that are not always easily available.

Publications:

Swenson, E. T., J. Lu, and D. M. Straus, 2018: Resolution dependence and Rossby wave modulation of atmospheric rivers in an aquaplanet model. *J. Geophys. Res. Atmos.*, **123**, 6297-6311, doi: https://doi.org/10.1029/2017JD027899

Title: **Soil Erosion Causes Substantial Loss of Terrestrial Organic Carbon and Nutrients from the Conterminous United States to the Coastal Zone**

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BER Program: ESM

Project: Earth system modeling program through the Energy Exascale Earth System Model (E3SM)

Project Website: https://acme-climate.atlassian.net/wiki/spaces/ACME/overview?mode=global

Although the loss of organic carbon and nutrients from land to rivers by soil erosion is well documented, the spatial and temporal variability of this carbon and nutrient loss and its role in the global carbon and nutrient cycles are poorly understood. To fill this knowledge gap, we integrated a well-validated sediment yield model based on the improved Morgan model into the DOE Energy Exascale Earth System Model (E3SM) to investigate the spatial and temporal variability of terrestrial organic carbon and nutrient loss in the conterminous U.S. The modeled yield of sediment and particulate organic carbon in large river basins is consistent with previous reports. Our simulations showed that soil erosion causes substantial loss of terrestrial organic carbon and nutrients from the conterminous United States to the coastal zone. More importantly, this loss is only a small fraction of the amounts of terrestrial organic carbon and nutrients disturbed by soil erosion. Although the carbon and nutrient loss is controlled mainly by the rate of soil loss, the abundance of organic carbon and nutrients in soils is also an important factor. The Mississippi River Basin contributes the most organic carbon and nutrient loss by soil erosion in the conterminous U.S., with the majority of the loss occurring in its Ohio and Missouri sub-basins where the temporal variability of the loss is closely correlated with the land hydrology. The model showed that large carbon sequestration can be achieved in well-managed croplands that are under wet forest climate. In contrast, little carbon sequestration can be achieved in croplands that are under dry forest climate when compared with natural vegetations. The simulations also showed that by increasing the rate of soil erosion wildfires and landslides elevate the loss of terrestrial organic carbon and nutrients. Our study highlights the large impacts of soil erosion on terrestrial, aquatic and coastal ecosystems.

Using the BeTR soil model farm to support hierarchical soil biogeochemistry model development and evaluation from topsoil to single soil column to global scales

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Program: RGCM and ESM
Projects: RGCM and E3SM
Project Website: https://www.bgc-feedbacks.org, https://e3sm.org/

Soil biogeochemistry (BGC) modeling contributes uncertainty to earth system model predictions comparable to that of other components, such as clouds. This large uncertainty has been attributed to several factors, including forcing data, parameterization, model structure, and numerical implementations. However, while there are now many soil BGC model formulations used in the modeling community, a numerically robust framework does not exist to support a systematic evaluation of how these different soil BGC formulations will perform within the same land model. This then raises several risks in quantifying and constraining soil BGC modeling uncertainties, including: (1) attributing poor performance of a land model incorrectly to its soil BGC, although the problem may be associated with its vegetation component, or vice versa; (2) asserting a good soil BGC formulation as inappropriate even though its poor performance could be due to inappropriate numerical implementation; and (3) stating that different soil BGC models are incomparable because they are not implemented and parameterized in a consistent manner. The first two of these risks will cause a misplacement of parameterization uncertainty to soil BGC, and the three together present a barrier to the selection of which model formulation should be preferred in an Earth System Model, such as E3SM. Using the soil BGC reactive transport solver BeTR, which is successfully integrated in v1 of ELM (Tang and Riley, 2018), we demonstrate that BeTR's polymorphism feature supports consistent implementations of different soil BGC models (including a single layer topsoil, single soil column, and fully coupled) with ELMv1. This ELMv1-BeTR "soil BGC model farm" allows one to evaluate different soil BGC formulations within ELM, while harmonizing uncertainties due to differences in forcing, numerical implementations, and simulation protocols. This ELMv1-BeTR hierarchical modeling capability is a valuable platform for soil BGC model development and field testing, and provides more comprehensive quantification and constraint of land soil BGC modeling in E3SM.

Reference

Tang, J. Y., and W. J. Riley (2018), Predicted Land Carbon Dynamics Are Strongly Dependent on the Numerical Coupling of Nitrogen Mobilizing and Immobilizing Processes: A Demonstration with the E3SM Land Model, *Earth Interactions*, doi: 10.1175/EI-D-17-0023.1

Fostering Scientific Discovery through Model Intercomparisons

Karl E. Taylor*,[1] Paul J. Durack,[1] Charles Doutriaux,[1] Sasha K. Ames,[1] Denis Nadeau,[1] and Peter J. Gleckler[1]

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BER Program: RGCM
Project: Program for Climate Model Diagnosis and Intercomparison
Project Website: https://pcmdi.llnl.gov/index.html, https://pcmdi.llnl.gov/CMIP6

In advancing our understanding of climate, the potential and realized value of model intercomparisons can largely be attributed to two things: 1) multi-model results help focus ongoing model development on those processes that are discovered to be misrepresented, and 2) the analysis of model behavior is no longer limited to model development groups but now benefits from an enormous and diverse community of experts who can scrutinize the model simulations more comprehensively.

For model intercomparison projects to be successful, however, considerable attention must be paid to careful experiment design and to developing a robust infrastructure that supports the collection, management, and dissemination of model results and documentation, and is designed to facilitate analysis by data users. For the first model intercomparisons, DOE provided nearly all the support for the coordinating leadership and infrastructure. Today, there is a broader international ownership of those responsibilities to better serve CMIP's expanded scope and diversity.

In this talk, we describe coordination of the MIPs participating in CMIP6 and the targeted contributions by PCMDI and its partners. We provide an overview of the evolution of the CMIP6 management structure, the new experimental framework, the new technologies relied on in supporting the infrastructure, and progress in developing wider community ownership and in bringing an unprecedented level of transparency to the process.

Title: On the scalability of a suite of extreme indices

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BER Program: RGCM

Project: UCAR-DOE Cooperative Agreement CATALYST

Project Abstract: Taking advantage of a suite of simulations with CESM1-CAM5 under a range of scenarios we test the performance of well established emulation techniques, like pattern scaling, for a suite of extreme indicators. These techniques have been long tested and applied for traditional transient scenarios but have less frequently been applied to strongly mitigated, stabilized trajectories, which are the focus of this exercise.
I will present results from testing emulation techniques on a suite of 10 ETCCDI indices of extremes. The suite addresses the behaviour of daily minimum and maximum temperature and precipitation, synthesizing annual values of extremes. Performance is measured by a decomposition of the error that allows us to distinguish the emulation error per se from noise due to internal variability, thanks to the availability of ensembles from perturbed initial conditions for both the scenario used as input and that used as target output. As to be expected, the performance of the emulation techniques varies among the indices and, for a given index, across space, but in general the approximation works surprisingly well across many of the indicators. The index that presents the major challenge is an indicator of warm spells defined as exceedances of a fixed threshold. The large errors have a very characteristic spatial pattern and we show how that be can be understood as a function of the interplay between the warming experienced at a given location and the size of internal variability at that location.

Notes on abstract:

- Please Bold the Abstract title
- Note the placement of superscripts in the authors and affiliations.
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- Do not include any personal identifiable information (PII) or confidential information since abstracts will be publicly posted online.
- If you have questions, please contact Bob Vallario (bob.vallario@science.doe.gov; Renu Joseph (renu.joseph@science.doe.gov); or Dorothy Koch (dorothy.koch@science.doe.gov).

Title: **Circumglobal teleconnections and linkages with climate extremes in the Northern Hemisphere summer**

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BER Program: RGCM

Project: CATALYST

Project Website:

Project Abstract:

In contrast to some well-known teleconnection patterns that have strong variations in the meridional direction, such as the NAO and PNA, there is a class of intrinsic planetary wave patterns of subseasonal and longer co-variability that are primarily orientated in the zonal direction. Following Branstator (2002), these patterns are often referred to as circumglobal telenconnections (CGTs). In recent years, many studies have reported close linkages between midlatitude extremes (heat waves, flood) and CGTs in the northern summer, although the mechanisms for the CGTs in the northern summer has not been well understood. In this talk, I shall review our recent work on the seasonality of the tropospheric waveguide teleconnections and their connections with the US heat waves. I shall use a series of CESM1 prescribed soil moisture experiments as an example, to discuss how land surface forcing, together with synoptic eddies, can force circumglobal teleconnection response despite much weaker mean jets and waveguide effects in the northern summer.

Title: **ENSO Related Extremes: A Rossby Wave Source Perspective**

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BER Program: RGCM

Project: Catalyst (DOE-UCAR Cooperative Agreement)

Project Website: http://www.cgd.ucar.edu/projects/catalyst

Project Abstract:

Using the hindcast database on the CESM1 NMME experiments we examine the accuracy of historical seasonal predictions from the perspective of the ability to capture the correct atmospheric response to the predicted anomalous SST. Within the multi-model NMME contributions nearly all of the contributing models (GFDL-FLOR, NCAR-CCSM4, CFSv2, CanCM3, NASA-GMAO, NCAR-CESM1, IRI-ECHAM4p5) accurately predict ENSO-driven SST anomalies at 1-3 month leads. However, the predictions of the atmospheric response to these SST anomalies is less consistent from model to model, particularly with respect to precipitation predictions over the continental US, even at 1 month lead. We examine the role of the local response to equatorial SST anomalies, in the form of the Rossby Wave Source in this variable continental precipitation signal in individual ENSO event case studies. A prime example of this rapid loss of predictive skill is the winter season of 2015-2016 where most model predictions rendered a typical El Nino precipitation pattern over the western US and the actual pattern was significantly different. This is compared to the winter of 1997-98 in which the canonical El Nino prevailed in both the models and observations.

Kirtman, B. et al, .2014: The North American Multimodel Ensemble: Phase-1 Seasonal-to-Interannual Prediction; Phase-2 toward Developing Intraseasonal Prediction. BAMS , April 2014.

Title: **The Discrete Element Model for Sea Ice**

Adrian K. Turner[1*], Kara J. Peterson[2], Andrew F. Roberts[1], Dan Bolintineanu[2], Dan Ibanez[2], Min Wang[1], Travis Davis[3]

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[3]Naval Postgraduate School, Monterrey, California.

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BER Program: ESM

Project: Discrete Element Model for Sea Ice (DEMSI)

Project Abstract:

We present progress on the development of the Discrete Element Model for Sea Ice (DEMSI). This sea ice model represents regions of sea ice as disc shaped Lagrangian elements. Inter-element forces are combined with external body forces and integrated in time to determine sea-ice motion. DEMSI uses the Sandia National Laboratories LAMMPS molecular dynamics code for its dynamical core. Here, we describe efforts to develop an element contact model appropriate for sea-ice and efforts to ameliorate the effects of shrinking elements during sea-ice ridge formation during deformation. We also discuss the development of methods to couple the particle distributions of DEMSI to traditional Eulerian climate models, and efforts to utilize future heterogenous computing architectures using the Kokkos programming model.

Hyperion: Understanding Hydroclimate Data with Use-Inspired Metrics: Progress and Plans

Paul Ullrich[1*], Andrew Jones[2], William Collins[2], Richard Grotjahn[1], Alex Hall[3], Ruby Leung[4], Kevin Reed[5], Travis O'Brien[2], Sara Rauscher[6], William Riley[2], Bruce Riordan[7], Chaopeng Shen[8], Dana Veron[6], Simon Wang[9], David Yates[10], Colin Zarzycki[10], Neil Berg[3], Xingying Huang[3], Kripa Jagganathan[2], Binod Pokharel[9], Lele Shu[1], Leif Swenson[1], Wen-Ping Tsai[8], Yun Xu[2], Priyanka Yadav[6]

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BER Program: RGCM
Project: An Integrated Evaluation of the Simulated Hydroclimate System of the Continental US
Project Website: https://climate.ucdavis.edu/hyperion/

A varied and growing group of users now require accurate climate projections, particularly high-resolution projections and projections incorporating meteorological and hydrologic extremes, for all manner of impacts, adaptation, and vulnerability assessments. There has recently been explosive growth in the number of regional climate datasets to address these needs, with varied accuracy in different metrics and incomplete validation. However, with little guidance on how to choose among them, a usability gap continues to exist between their production and their use in addressing outstanding questions in climate science. Stakeholders (particularly water managers) often have difficulty using these datasets as well and have loudly called for "actionable science" and "co-production" of science: The core idea being that stakeholders and scientists should be engaged in a two-way exchange about each others' needs and capabilities. These circumstances have arisen largely because no standardized procedure exists for validating regional climate datasets and communicating their associated credibility information. To address this need, our project has developed seven tasks that will build a use-inspired assessment capability, explain why certain biases arise in regional climate modeling systems, and better understand human impacts on the climate system. With two years now complete of our three-year project, we will present on what has been accomplished to date and what remains to be addressed. Our developments to date include new hydroclimate metrics based on our interactions with stakeholders, ongoing studies of structural uncertainty in climate models (particularly resolution and resolved domain sensitivity), a new software system for data pre-processing and model evaluation, and two new ensemble regional climate datasets.

"Translational science: An architecture for climate resilience studies with an application to coastal impacts"

Nathan M. Urban (LANL), Alice Barthel (LANL), Mira Berdahl (LANL), Darin Comeau (LANL), Mike Dinniman (Old Dominion), Matthew Hecht (LANL), John Klinck (Old Dominion), Gunter Leguy (NCAR), Bill Lipscomb (NCAR), Chris Little (AER, Inc.), Balu Nadiga (LANL), Donatella Pasqualini (LANL), Joel Rowland (LANL), Ryan Sriver (UIUC), Eric Steig (UW), Milena Veneziani (LANL), Tarun Verma (LANL), and the LANL Coastal LDRD Team

There are large scientific gaps between raw climate model output and actionable predictions. Decision makers desire a synthesis of the best available scientific information, such as national and international assessment reports. However, these reports are rapidly outdated and do not provide a mechanism for users to interrogate and interact quantitatively and probabilistically with the assumptions upon which their conclusions are based. DOE science in this area is often fragmented, providing no clear guidance for mission applications that need to incorporate both DOE Earth system modeling as well as multi-model uncertainties, accounting for model biases and scale mismatches.

We discuss an architecture for translating climate science into decision making. One central component is a statistical information fusion framework for combining hierarchies of models (DOE E3SM, CMIP models, regional climate models, impacts models, etc.) with observational data constraints to produce dynamically bias-corrected multi-model predictive uncertainties of regional climate extremes. This allows for transparent and traceable quantification of uncertainties and assumptions about model and data biases. A second component is high-fidelity local impacts modeling and stochastic optimization techniques for decision making under uncertainty. We present an application study currently in progress on end-to-end decision making for coastal energy-water infrastructure network adaptation in the Delaware Bay, propagating uncertainties from polar ice sheet disintegration and other climate change through impacts modeling to decisions about infrastructure asset protection.

Urban Micro-climate and Hydroclimate Modeling: Case Studies of Urban Irrigation, Heat Extremes, and Heat Mitigation

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BER Program: RGMA and Multi Sector Dynamics

Project: Hyperion (Cooperative Agreement led by UC Davis)

Project Website: https://climate.ucdavis.edu/hyperion/participants.

We live in an era when accelerated population growth and urban development is challenged by the risks and consequences of climate change and extremes. Developing a built system that is resilient to these new environmental realities relies on advanced understanding and accurate prediction of the principal stressors such as climate change, extreme weather, and shifting resource demands. Meanwhile land use and irrigation practices have important feedbacks to regional climate.

Here we use a suite of high-resolution (1.5 km) regional climate simulations driven by global climate models and enhanced by satellite-based information, an urban canopy model (UCM), and urban morphology data to investigate 1) water conservation benefits of heat mitigation; 2) impacts of urban irrigation on the regional climate; and 3) implications of cool roofs for future exposure to heat extremes in California. We show that broad implementation of cool roofs not only results in significant cooling of air temperature, but also can be effective in countering the climate-change-induced increases in outdoor water consumption by reducing evaporative water demands. We further show that this synergistic relationship between heat mitigation and water conservation is asymmetrical - policies that encourage direct reductions in irrigation water use can lead to substantial regional warming, potentially conflicting with heat mitigation efforts designed to counter the effects of the projected warming climate.

Using mid-century climate projections and a spatially explicit population projection we assess the changes in the population exposure to the heat extremes. We find that population exposure to extreme heat days in California increases by three- to fivefold across major urban counties and that climate change, population growth, and their compounding effects all play significant roles in driving this outcome. We illustrate that broad implementation of cool roofs, an urban heat mitigation strategy, can meaningfully offset a significant percentage of future increases in frequency, intensity, and duration of extreme heat events in urban areas and growing population exposure to these conditions.

We are also taking initial steps towards developing a process-based urban hydroclimate modeling capability, grounded in remotely sensed and ground-based observations, that integrates atmospheric, land surface, urban canopy, surface water, groundwater, and coastal processes. These efforts will lead to a physics-based integrated urban hydroclimate modeling capability with multi-scale functionality that permits resolving atmospheric, land surface, urban canopy, and hydrologic processes on different spatial grids and allows incorporating other terrestrial hydrologic processes such as drainage systems, channel flow, and lake/reservoir flow.

Coupled Energy-Water-Agriculture Dynamics: Biomass Co-Firing in the MISO region

Thomas Hertel[1], Mort Webster[2], Shanxia Sun[1], Jing Liu[1], Brayam Valqui[2]*

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BER Program: Multi-sector Dynamics

Project: Cooperative Agreement

Project Website: www.pches.psu.edu

We present a novel framework for coupling the multi-sector dynamics and feedbacks between the electric power sector, agricultural markets, and water quality. As an illustrative case study, we use this framework to explore the impacts of an incentive to use biomass to reduce the carbon emissions of coal-fired power plants in the Midwestern U.S. The Midwestern region has both a large share of coal generation for electricity and significant coal production. We investigate the effects of a hypothetical modification to the existing Renewable Portfolio Standards (RPS) in the Midwestern Independent System Operator (MISO) region to incentivize biomass co-firing of coal plants, assuming that the biomass source is locally-produced corn stover. Such a modification could be proposed to assist in extending the life of coal plants, provide additional income to corn producers, and reduce the environmental impact of the coal generation.

Our modeling framework consists of (1) location-specific representations and estimates of the supply of corn residue; (2) a unit commitment model that simulates generator scheduling and dispatch for the MISO power system (3) Identification of location-specific regions of biomass supply and competition among coal generators; and (4) a spatially resolved land-use and agricultural market model to simulate the impact of additional revenue to corn producers on land use decisions, nitrogen fertilizer applications and nitrate leaching. Using this framework, we demonstrate that the incentive for biomass co-firing in coal plants will shift the spatial pattern of corn production and fertilizer application that has potentially significant consequences for water quality in this region.

Predictability of Arctic freshwater content in CESM decadal predictability large ensemble experiment

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Arctic Ocean has experienced dramatic changes in the last few decades. The sea ice volume has shrunk considerably, while the surface ocean has warmed, and freshened at a rate greater than anywhere else over the globe. These changes, which have been primarily attributed to anthropogenic forcing, have exposed the deeper ocean to the wind-driven mixing, and have modified the mean ocean stratification. Despite a clear forced signal of anthropogenic origin over the Arctic, the predictive understanding of Arctic climate on decadal timescale remains unsatisfactory. The dynamical model's forecast skill of the Arctic sea ice is limited to a season or at best a year in advance. In this study, we use a recently completed large ensemble of decadal hindcasts (CESM-DPLE) at NCAR to evaluate multi-year predictability of liquid and solid Arctic freshwater content. In addition to assessing the skill, we also study physical mechanisms that contribute to forecast skill, as well as the errors. The large ensemble size (62 x 42) helps maximize the predictive signal, and its comparison with corresponding uninitialized predictions (CESM-LE) brings out the role of realistically initializing the ocean state. In this presentation, we will highlight skill improvements due to ocean initialization, its connection to Atlantic Ocean circulation, and potential impacts on local and remote climate.

Considering the combined impacts of sea-level rise, subsidence, and induced storm surge when evaluating electricity capacity expansion planning

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BER Program: Multi-sector Dynamics

Project: Integrated Multi-sector, Multi-scale Modeling (IM3) Science Focus Area

Project Website: https://im3.pnnl.gov/

Project Abstract:

Many coastal zones feature high concentrations of infrastructure, such as power plants and other parts of the electricity system, which are increasingly vulnerable to hurricane storm surge due to sea level rise and increasing strength of the most powerful storms. For example, hurricane Florence reportedly caused a power outage affecting 1.7 million customers, and hurricane Katrina caused many power plants to shut down for days or weeks. Improving our understanding of how the combined impacts from hurricanes affect the US electricity system will provide insight to help identify potential vulnerabilities and build more resilient energy systems. To assess the specific question of how hurricanes may influence power plant siting—an important issue for electricity infrastructure planning—we employ a multi-sector, multi-scale modeling system capable of evaluating spatiotemporal variation in power plant siting feasibility associated with a wide range of factors. The Capacity Expansion Regional Feasibility (CERF) geospatial model ingests electricity capacity expansion plans and technology-specific assumptions from integrated human-Earth system models such as GCAM, available cooling water from Earth system models such as E3SM or CESM, and economic information from a power system model. In this analysis, we adopt an additional set of siting constraints from modeled hurricane impacts as additional barriers to siting in CERF. The results suggest that increasing storm surge risks could have a significant impact on power plant siting feasibility in several regions across the United States. As we expand this analysis we plan to consider additional impacts of extreme events on different electricity system build-out scenarios.

Flow of Agricultural Nitrogen (FAN): mechanistic modeling of NH3 volatilization in ELM

Julius Vira, Jeff Melkonian, Will Wieder and Peter Hess

The emission, atmospheric transport and deposition of ammonia (NH3) forms an important link between the terrestrial nitrogen cycle, atmospheric chemistry and agricultural productivity. This presentation discusses the FAN process model, which has been incorporated into both the E3SM land model (ELM) and the Community Land Model (CLM). FAN simulates atmospheric NH3 emission in agricultural activities such as fertilizer application and manure management, and includes sufficient mechanistic detail to simulate responses to both environmental and agricultural drivers. Comparison between global, multi-year FAN simulations and existing NH3 emission inventories shows that the simulated volatilization losses are compatible with the current estimates for North America and Europe and China but differ over the data sparse regions of Africa, Latin America and India. Coupling FAN with an atmospheric model allows us to evaluate the model through atmospheric measurements of ammonia and ammonium concentration and deposition. Using data from atmospheric monitoring networks, we show that FAN captures these measurements as well as regionally based inventories. This is a first step in simulating the coupled land-atmosphere nitrogen cycle through process-based modeling suitable for climate and N-cycle simulations.

Modeling Case Study Development of an Extensive Surface Melt Event in West Antarctica

Andrew Vogelmann[1*], Dan Lubin[2], Wuyin Lin[1], David Bromwich[3,4], Keith Hines[3], Julien Nicolas[3], Israel Silber[5], Ann Fridlind[6], Hans Verlinde[5], Aaron Wilson[3], Maria Cadeddu[6], Ryan Scott[2], and Damao Zhang[1]

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BER Program: ASR and ARM

Projects: Polar Cloud Microphysics and Surface Energy Budget from AWARE (University ASR Award) & Influence of Aerosol and Cloud Processes on Climate (BNL ASR SFA)

Project Website: https://www.arm.gov/research/campaigns/amf2015aware

Over the past two decades the primary driver of mass loss from the West Antarctic Ice Sheet (WAIS) has been warm ocean water underneath coastal ice shelves, not a warmer atmosphere. Yet, episodes of widespread summer melt have been sporadic in West Antarctica since the phenomenon started being monitored from space in the late 1970s. Both the geography and climate of West Antarctica conspire to make such events more likely to occur under relatively modest atmospheric warming. Further, large-scale modes of climate variability and their mutual interactions are also responsible for important disruptions of the regional atmospheric circulation that can sustain warm air advection towards the continent for extended periods. Finally, the increase in the number of extreme El Niño events projected for the twenty-first century could expose the WAIS to more frequent major melt events (Nicolas et al., 2017).

We report here on a modeling case study being developed for an extensive surface melt event that occurred in the Ross Sea sector of the WAIS in January 2016. In addition to satellite data and analyses of the large-scale circulation, comprehensive surface observations are available from the Atmospheric Radiation Measurement (ARM) West Antarctic Radiation Experiment (AWARE) that was ongoing in central West Antarctica. These observations provide unique insight into the physical mechanisms governing the surface melt in this otherwise data-sparse region, including observations of cloud properties, the surface energy balance, and frequent balloon sondes. Long-term satellite observations are used to place this event within the context of the of previous melt events and their association with El Niño events and the phase of the Southern Annular Mode (SAM).

Reference:

Nicolas, J.P., A.M. Vogelmann, R.C. Scott, A.B. Wilson, M.P. Cadeddu, D.H. Bromwich, J. Verlinde, D. Lubin, L.M. Russell, C. Jenkinson, H.H. Powers, M. Ryczek, G. Stone, and J.D. Wille, January 2016 extensive summer melt in West Antarctica favored by strong El Niño, *Nature Commun.*, 8:15799, doi: 10.1038/ncomms15799, 2017.

Title: **Regional water-energy dynamics and extreme events**

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BER Program: Multi-sector Dynamics

Project: Integrated Multi-sector, Multi-scale Modeling (IM3) Science Focus Area

Project Abstract:

With 67% of electricity generation capacity dependent on water over the Western U.S., it is critical to understand how droughts and other extreme events could impact the resilience of the power system. As part of the Integrated Multi-scale, Multi-sector Modeling (IM3) Scientific Focus Area, we are using a variety of modeling tools to study different aspects of how water-energy dynamics influence electricity grid resilience at scales ranging from the entire Western interconnection, i.e. half a continent, to energy reserve regions, which vary in size but tend to overlap with one or more large river basins. We have enhanced the representation of water management, including hydropower, in multiple Earth System Models (i.e., E3SM and CESM). This improvement led us to better understand how the regulation of in-stream river flows influences the emergence of significant changes in water availability over the next several decades. We have also used the water availability from this integrated modeling framework to drive power system models (e.g., PLEXOS and PROMOD) to develop a benchmark of power system responses to historical hydro-climatological conditions and further explore the sensitivity of power systems resilience under climate change, extreme events such as droughts and heat waves, and compounded extreme events. We also demonstrated that large scale power system operations over the Western United States can be predicted based on climate indices and associated regional water availability conditions. Finally, because long term power system planning are strongly influenced by technological and economic shocks, we have evaluated the sensitivity of power systems to compounded extremes in hydro-climatological conditions and economic drivers, such as large changes in natural gas prices. Collectively, these coordinated efforts to better understand regional water-energy dynamics are helping improve our representation of human-Earth system interactions in multiple modeling contexts, and the tools we have developed are also being used to support multi sectoral decision making across a range of institutions and scales.

State-Altering Extreme and Disruptive Events

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Abstract

Human and physical Earth systems evolve over time, but not always smoothly. The evolutionary path of history is periodically punctuated by extreme or disruptive events that are more than minor perturbations. Yet, the scenarios that are used to inform decision making assume a smooth transitions over time. They "do not take into account the effects of extreme events or provide probabilities or uncertainty information regarding the scenario." (US Global Change Research Program 2016) While decision makers may prefer a single deterministic scenario around which to plan, they need relevant information about other potential pathways, and associated likelihoods, that might emerge and which could inform the development of a more robust planning process (IPCC 2012). Not all extreme/disruptive events are alike. Some occur with sufficient regularity that they become part of the planning background. Their precise location and timing may not be known, but they can be planned for – systems exist to restore society to its prior state. Existing institutions limit long-term vulnerability. Other extreme/disruptive events are of a different character. They set events off on a new course, for better or worse. **We will refer to such events as *state-altering* events**. We define state-altering extreme or disruptive events as ones that perturb the system in a way that it no longer returns to its previous state or path. Robust decision making requires consideration of both the likely and unlikely, but important, potential events (Lempert 2013). State-altering events may be either positive or negative in character. The advent of a new technology could take the economy and society off in previously unanticipated directions. It may open opportunities previously closed and curtail activities that were previously mainstream. In 1800 the fastest a human had ever traveled was the speed of a horse. The advent of the steam engine in 1801 changed that, and the global economy, forever (Ambrose 1996). State-altering extreme/disruptive events can also destroy previously prosperous economic sectors. The advent of electronic calculators not only opened the door to the information age, it also killed the mechanical calculator business. The focus of this research is to identify methods, models, and data that will inform decision makers, both in the identification of potentially state-altering events and measuring their likelihood and consequences. This work will lay the foundations for examining, anticipating, and better understanding the broad implications of state-altering events.

Reference

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IPCC (2012). Managing the risks of extreme events and disasters to advance climate change adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. C. B. Field, V. Barros, T. F. Stocker et al. Cambridge, UK.

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US Global Change Research Program (2016). Multi-scale economic methodologies and scenarios workshop.

Efficient Sensitivity Analysis and Automatic Parameter Tuning Using Compressive Sensing

Hui Wan[1], Xiu Yang[1], Phil Rasch[1], Alex Tartakovsky[1], Xinya Li[1], Huying Ren[1], Jason Hou[1], Yun Qian[1], Haipeng Zhang[2], Minghuai Wang[2]

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Relevant BER Program: ESM
Funding Source: PNNL LDRD
Project: Breaking the curse of dimensionality in atmosphere modeling: new methods for uncertainty quantification and parameter estimation

Project Abstract:

Quantifying sensitives of model results to uncertain parameters and tuning the parameter values to improve a model's simulation/prediction skills are important tasks in the development of Earth System Models like E3SM. A systematic exploration of the parameter space typically requires a large number of simulations and hence are computationally expensive or even prohibitive. Manual tuning of parameter values based on experts' educated guesses is tedious and the results cannot be guaranteed to be reproducible. This project addresses these challenges by applying cutting-edge methods from the applied math field. A signal processing technique called compressive sensing is used to construct emulators (i.e., statistical surrogate models) that describe the relationships between simulated climate features and the values of uncertain parameters in the E3SMv1 atmosphere model. The emulators are then used for sensitivity analysis and automatic parameter tuning. The first phase of the project focuses on large-scale features of the simulated climate. The presentation will demonstrate that the compressive-sensing-based emulation method requires substantially fewer E3SM simulations and provides higher emulation accuracy. Variance analysis based on those surrogate models gives robust results in the identification of impactful model parameters. A multi-objective optimization algorithm manages to identify parameter sets that lead to the desired model features within the user-specified tolerance. These results provide a solid basis for future steps, where we plan to develop emulation methods for spatial and temporal variations in the simulated climate, and provide our algorithms to the model developers in the form of user-friendly software packages.

Impact of Sea Ice anomaly on Antarctic Precipitation and Its Source Attribution

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BER Program: RGCM

Project: HiLAT

Project Website: https://www.hilat.org

Modeling and experimental evidence suggests that Antarctic Ice Sheet (AIS) surface mass balance increases in a warming climate due to increased precipitation. We use the Community Earth System Model (CESM) with an explicit water tagging capability to understand the causes of increased precipitation on AIS and, particularly, changes associated with sea ice anomalies. Sensitivity experiments have been conducted to understand the impact of sea ice anomalies on regional evaporation, moisture transport, and source-receptor relationships for precipitation over the Antarctica. Three composites of sea ice concentrations (SIC), constructed from the 1800-year CESM Large Ensemble Project using mean, 10% lowest, and 10% highest southern hemispheric SIC years (and corresponding global sea surface temperatures), respectively, have been employed to drive three atmosphere-only simulations. Moisture sources in a number of geographical regions, including continents, major ocean basins, and various sub-sectors of the Southern Ocean (south of 50°S), are explicitly tracked using the water tagging capability to establish source-receptor relationships of vapor and regional precipitation over the Antarctica. Results show that vapor sources for the Antarctic precipitation primarily originate from lower latitudes through elevated pathways. Among the tagged source regions, the Southern Ocean contributes about 40% to the annual mean precipitation over the Antarctica, mostly, along the coastal areas. The tagged vapor source regions in the Southern Ocean have discernable changes in their contributions to regional precipitation over the Antarctica in response to the SIC anomalies. There is also a strong regional and seasonal variability in vapor source attributions and the impact of SIC anomaly on the Antarctic precipitation, primarily determined by the geographical location of source regions and atmospheric circulation patterns.

Quantifying the Arctic Local Radiative Feedbacks Based on Observed Short-Term Climate Variations

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BER Program: RGCM

Project: HiLAT

Project Website: https://www.hilat.org

The Arctic has warmed dramatically in recent decades, with temperature increasing at a rate of about twice as fast as the global mean value. This phenomenon, commonly known as Arctic amplification (AA), has been found in the observed and modeled climate changes. Several feedback mechanisms were shown to contribute to AA, but their relative importance is still very uncertain. In this study we use a variety of 35-year reanalysis and 15-year satellite (CERES EBAF) datasets to quantify the Arctic local feedbacks based on short-term climate variations, evaluate the feedbacks simulated in the Community Earth System Model (CESM), diagnose the impact of dataset choices on the feedback estimates, and identify the sources of main uncertainties. All datasets agree that the lapse rate (LR) and surface albedo feedbacks are positive and their magnitudes are comparable. Compared to the tropics, the lapse rate feedback is the largest contributor to AA among all feedbacks, followed by surface albedo feedback and Planck feedback deviation from its global mean. Both shortwave and longwave water vapor (WV) feedbacks are positive, leading to a significant positive net WV feedback over the Arctic. Our best estimates (based on datasets from ERA-Interim, JRA-55 and MERRA-2) for Planck, LR, albedo and net WV feedbacks over the Arctic are 0.54±0.03, 1.34±0.2, 1.33±0.32, and 0.26±0.1 W m^{-2} K^{-1}, respectively. The net cloud feedback has large uncertainties including its sign, which strongly depends on the data used for all-sky and clear-sky radiative fluxes at the top of the atmosphere, the time periods considered, and the methods used to estimate the cloud feedback. Most of the uncertainty in cloud feedback is from its shortwave component. A better understanding of fine-scale Arctic cloud processes and improvement to their representation in climate models would be required to reduce uncertainties in estimating cloud feedback and its contribution to the Arctic warming.

Title: **Changes in the North American winter regime towards more climate extremes**

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BER Program: RGCM

Project: An Integrated Evaluation of the Simulated Hydroclimate System of the Continental US

Project Website: https://climate.ucdavis.edu/hyperion/

Project Abstract: The early-2018 extreme coldness in the eastern U.S. that created heightened energy crisis is a brutal reminder of the 2014 and 2015 winter freezes. Meanwhile, western states including California underwent a wild swing from deluge to drip and then fires. The wintertime circulation over North America, known as stationary waves, comprise the signature 'ridge–trough' pattern in the upper atmosphere, forming a “winter dipole”. This stationary-wave dipole establishes the climatological surface temperature division of the warmer west and colder eastern U.S. The western ridge and eastern trough are very much anti-correlated, due to Rossby wave dispersion. Thus, any amplification of the dipole enhances the surface climate division while the attenuation of the dipole reverses it. Observational and modeling evidence suggests that the winter dipole (stationary waves) has indeed intensified, but the causes are under debate and will require advanced modeling development to reveal.

Analysis presented here shows that the leading mode of intraseasonal-to-interannual variability in North America's winter circulation has seen a change around 1990. The prominent Pacific-North America (PNA) mode used to dominate the North America circulation was undertaken by the dipole after 1990, based on the EOF analysis. The striking coincidence between the dipole pattern and the mean-state circulation suggests that the stationary waves’ maintenance has been modified, but to what extent the forcing source is internal or external is unclear. The presenter provides an overview and update about the consensus and debate centered around the source of the dipole’s variability and increasing magnitude, as well as its projected future. Warming in the Pacific and Indian Oceans is linked to the ridge side of the dipole, while other factors such as mid-latitude internal atmospheric dynamics can power the dipole variation and amplitude. The Arctic amplification and Arctic oscillation together affect the jet stream and subsequently influence the dipole. The effect of an anthropogenic climate warming on tropical teleconnections and jet stream shifts, and how these affect the dipole variation deserves further investigation, one that requires a community effort to achieve.

Development of A New Sediment Flux Model: Application in Chesapeake Bay

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Project: Improving tide-estuary representation in MPAS-Ocean

Strong coupling between pelagic and benthic habitats is a fundamental feature of most shallow coastal aquatic ecosystems. However, a flexible, conservative, process-based and computation-efficient 'sediment flux model' (SFM) is still lacking although many SFMs of different complexities are available. Here, we present a new SFM that has a similar structure to DiToro's (2001) SFM, but with a simpler structure and fewer parameters. The model is driven by the depositional fluxes of Particulate Organic Matters (POM) from water column. To simulate the remineralization of POM in sediment, a method based on bacteria mediated processes is introduced, which can describe the accumulation and decay of POM. The remineralization processes produce sediment fluxes for NH_4, NO_3, PO_4, Silicate, and SOD. This new SFM is then applied to the Chesapeake Bay where abundant water quality and sediment flux measurements are available. The comparison between model results and sediment flux measurements is good regarding the seasonal cycles at different stations, which validates the model. The new SFM should facilitate the water column ecosystem modeling by providing a flexible framework to include the sediment effects on nutrient budgets.

Localized Exponential Time Differencing Methods Based on Domain Decomposition

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BER Program: ESM

Project: University Award

Exponential time differencing (ETD) methods have been proven to be very effective for solving stiff evolution problems in the past decades due to rapid development of computing techniques and capacities. On the other hand, these methods still could become prohibitively expensive for large scale simulations due to the high computational costs for evaluating the products of matrix exponentials and vectors through the Krylov subspace iterative algorithm at each time step. Direct parallelization of the ETD methods is also rarely of good scalability due to the needed global data communication. Therefore, we develop localized ETD methods that use domain decomposition techniques to reduce the size of the problem, in which one instead solves a group of smaller-sized subdomain problems simultaneously with locally computed matrix exponentials. The proposed methods are less expensive and are also more scalable on parallel computers than the classic global ETD methods since only boundary data communication between subdomains is required. We study in algorithm and analysis the localized ETD methods for the time-dependent diffusion problem and the shallow water equations, and some of our progresses and test results will be presented.

CMEC early results: Extreme temperature and precipitation metrics

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BER Program: RGCM
Project: CASCADE & PCMDI SFA & a separate LBNL project

The incorporation of selected extreme weather metrics, developed under the CASCADE SFA at LBNL are being incorporated into the PCMDI Metrics Package developed at LLNL. We present early model evaluation results of extreme values of RX5day, the pentadal accumulated precipitation and TX3x, the three day average of the hottest time of the day. We will also discuss plans forward for storm statistics evaluation targeted at the HighResMIP-class climate models.

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An Ocean/Sea Ice Configuration of E3SMv1 with Arctic Regional Refinement

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BER Program: ESM, RGCM

Project: E3SM SFA, HiLAT SFA, RASM.

The Arctic Ocean is characterized by small-scale features: for instance, it exchanges water and sea ice with the Atlantic and Pacific Oceans through narrow passages, like the Bering Strait and the Canadian Archipelago; the size of mesoscale features, which facilitate much of the horizontal transports, are several kilometers at most; and the ice edge, including leads and polynyas, generates stark contrasts between ocean and sea ice on the sub-kilometer scale. An accurate representation of these processes in Earth system models critically improves our ability to simulate the mean state of the Arctic ocean/sea ice system, its variability, trends, predictability, and impacts on other Earth system components.

The signature capability of E3SMv1 is its ability to enhance spatial resolution in specific regions of interest, while still operating in a global context. The Arctic Ocean is a region where this capability will be particularly impactful. Here we report on a joint RGMA/ESM activity to configure a first-ever global ocean/sea ice model with regional refinement in the Arctic. Our prototype grids have spatial resolution of 10 and 6 km in the Arctic, while the resolution in the rest of the ocean ranges from 30 to 60 km. In this presentation, we will show proof-of-concept results from this configuration, and discuss the computational performance, remaining challenges, and our initial target applications.

Open Ocean Polynyas in the Southern Ocean: formation mechanisms and atmospheric response

Open ocean polynyas (OOPs) in the Southern Ocean are ice-free areas within the winter ice pack that are associated with deep convection, potentially contributing to the formation of Antarctic Bottom Water. We investigated OOP formation mechanisms in a high-resolution preindustrial simulation with the Energy Exascale Earth System Model (E3SMv0-HR), an offspring of the Community Earth System Model (CESM). While a low-resolution E3SMv0 counterpart simulation shows no signs of OOPs, E3SMv0-HR produces both large Weddell Sea polynyas and small Maud Rise polynyas (MRPs), similar in size and location to observations. Aided by an accumulation of heat in the Weddell Deep Water layer, the ultimate trigger of convection that leads to MRPs is the advection of anomalously high upper ocean salinity, in a region already preconditioned for convection due to the presence of a semi-permanent Taylor cap near the Maud Rise seamount. Further analysis of the atmospheric conditions following the formation of OOPs shows that not only the local atmosphere is impacted in the form of surface turbulent fluxes and precipitation patterns, but also the overall Southern Hemisphere atmosphere responds through a significant change in the meridional heat transport, overcompensating for a similar response in the ocean.

Title: Containerized E3SM Workflows

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BER Program: ESM

Project: E3SM

Project Website: https://e3sm.org

Project Abstract:

With recent developments in operating systems, containers allow a process and all of its dependencies to be isolated. Containers are a file archive format that allow for packaging the entire application environment above the level of the Linux kernel. This makes running software across many diverse environments more straightforward, reducing the need for installing many different dependencies for various software to work together in harmony. The goal of this work is to introduce container technology into E3SM workflows starting with diagnostics and analysis.

There are various container runtime environments such as Docker, Shifter, Singularity, and udocker, all present on different machines and which provide some degree of interoperability. We present an overview of containers technology, detailing advantages of containerizing software. The process of containerizing a software package, e3ms_diags, across these diverse container runtime environments is also covered.

Title: **Enabling a holistic understanding and predictive capability of the coastal zone through novel developments in the MPAS-O and E3SM modeling system**

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BER Program: ESM

Project: SFA (Los Alamos National Laboratory)

Project Website: http://e3sm.org/

Project Abstract: Coastal climate change evolution will affect approximately 40% of the population who live in communities directly impacted by coastal flow-induced processes. Decadal scale evolution fundamentally depends on the flow of water across range of scales spanning from the deep ocean (1 deg) to geomorphological scales of shoreline evolution (<100m) where ocean, river, and land meet. The opportunity to resolve coastal system evolution is now possible because of improved high-performance computing resources and advanced multiscale algorithms. In particular, the unique unstructured grid capabilities of the Model for Prediction Across Scales Ocean (MPAS-O) allows model resolution to be applied in regions of interest without resorting to statistical or "box" models within the DOE Energy Exascale Earth System Model (E3SM). MPAS-O provides the opportunity to simulate a range of coastal processes. Planned process developments leveraging rapid resolution change from the global ocean into the coast include simulation of wind waves, sediment transport, and wetting and drying for flooding. This will allow coastal process simulations such as: flooding due to long-term effects of sea level rise and short-term effect of hurricanes and their associated storm surges arising from wind waves; salinity intrusion into coastal water supplies; sediment transport and shoreline evolution; and transport of heat and nutrients from coastal shelf waters to the deep ocean, e.g., mediating production of algal biomass; assessment of mixing and onshelf coastal currents that affect heat fluxes to melt ice sheets and increase sea level rise; etc. Within the E3SM, coastal flows simulated with MPAS-O are subject to evolving drivers such as atmospherically produced hurricanes and land-generated flooding and sediment transport due to stormwater off the land. Improvement in representation of waves and tides in the ocean will allow for the quantification of the balance of wave-tide-river forcing in determining the stability and evolution of coastal systems under future forcings. Ongoing coastal ocean capability developments in E3SM are opening up new opportunities to resolve the climate at the coast.

Assessing the impact of assimilating atmospheric data on the ocean state estimation and climate forecast in an ensemble coupled data assimilation system

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BER Program: ESM
Project: University Award
Project Website: None

The ocean initial condition is usually considered to the most important factor for climate forecast. It is unclear if assimilation of atmospheric data is helpful or not to get a good ocean initial condition. In this paper, we use an Ensemble Coupled Data Assimilation system (ECDA) to explore the impacts of assimilating atmosphere data on ocean state estimation and climate forecast. Through several idealized twin experiments by ECDA system, we demonstrate that the achieved ocean initial conditions are improved significantly by further adding the atmospheric observation as constrains. Further analysis reveals that the use of atmosphere data leads to more accurate estimation of the ocean surface flux terms including the heat flux, the fresh water flux and the wind stress, consequently, better estimation of ocean SST, SSS, and the surface ocean currents. It is also demonstrated that the atmosphere data's impact is not just limited to the surface layers, rather the impact can penetrate all the way to the deep ocean. By decomposing the velocity into barotropic and baroclinic part, we found that the deep penetration of the atmosphere data's impact may be through the correction of the barotropic part of the ocean currents. This impact also differs by oceans.

Understanding Cloud and Convective Characteristics in Version 1 of the E3SM Atmosphere Model

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Abstract

This study provides comprehensive insight into the notable differences in clouds and precipitation simulated by the Energy Exascale Earth System Model (E3SM) atmosphere model version 0 (EAMv0) and version 1 (EAMv1). Several sensitivity experiments are conducted to isolate the impact of changes in model physics, resolution, and parameter choices on these differences. The overall improvement in EAMv1 clouds and precipitation is primarily attributed to the introduction of a simplified third-order turbulence parameterization (CLUBB; Cloud Layers Unified By Binormals) (along with the companion changes) for a unified treatment of boundary layer turbulence, shallow convection, and cloud macrophysics, though it also leads to a reduction in subtropical coastal stratocumulus clouds (Sc). This lack of Sc is considerably improved by increasing vertical resolution from 30 to 72 layers, but the gain is unfortunately subsequently offset by other retuning to reach the top-of-atmosphere (TOA) energy balance. Increasing vertical resolution also results in a considerable underestimation of high clouds over the Tropical Warm Pool, primarily due to the selection for numerical stability of a higher air parcel launch level in the deep convection scheme. Increasing horizontal resolution from 1° to 0.25° without retuning leads to considerable degradation in cloud and precipitation fields, with much weaker tropical and subtropical short- and longwave cloud radiative forcing and much stronger precipitation in the intertropical convergence zone, indicating poor scale-awareness of the cloud parameterizations. To avoid this degradation, significantly different parameter settings for the low-resolution (1°) and high-resolution (0.25°) were required to achieve optimal performance in EAMv1.

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Improving Clouds in E3SM by Framework for Improvement by Vertical Enhancement Coupled with Adaptive Vertical Grid Enhancement

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BER Program: SciDAC
Project: E3SM-FIVE
Project Website: https://cloudmodeling.colorado.edu

Bias associated with representation of clouds, especially low and high clouds, in large scale atmospheric models remains an unsolved problem. Progress toward alleviating this bias is limited despite the decades of community effort expended on developing and advancing microphysics and turbulence parameterizations. DOE's Energy Exascale Earth System Model (E3SM), one of the state-of-the-art global models, is no exception for this matter. Recently, several studies have demonstrated that higher vertical resolution results in improved representation of high and low clouds for parameterizations similar to those used in E3SM. This is a relatively unexplored area due to limitations in computational resources. This project will bring improved cloud representation to E3SM by implementing a novel computational framework that uses high vertical resolution at a computationally affordable cost. The Framework for Improvement by Vertical Enhancement (FIVE) has been shown to offer better representation of atmospheric boundary layer clouds with reduced cost. FIVE allocates additional prognostic variables in high vertical resolution and these high resolution prognostic variables are used for computing tendencies for selected physical processes. The computed tendencies from the Vertically Enhanced Physics are then passed to E3SM for predicting E3SM's prognostic variables. To further reduce the computational cost, we will implement FIVE on an Adaptive Vertical Grid (AVG), which will dynamically adjust vertical resolution depending on the atmospheric state for each grid column. In this presentation, we will discuss a path to E3SM coupled with FIVE-AVG, challenges for developing a computationally efficient FIVE-AVG, and current progress.

Boundary Layer Diabatic Processes, the Virtual Effect, and Convective Self-Aggregation

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The atmosphere can self-organize into long-lasting large-scale overturning circulations over an ocean surface with uniform temperature. This phenomenon is referred to as convective self-aggregation and is fundamental to the development of the Madden-Julian Oscillation (MJO). Here we present a boundary layer centric framework based on the *available potential energy (APE) budget* of convective self-aggregation. We show that *boundary layer* diabatic processes dominate the available potential energy production and are, therefore, essential to convective self-aggregation. We further show that the enhanced virtual effect of water vapor can lead to convective self-aggregation. Our results challenge the prevailing paradigm that focused on free-troposphere processes and suggest that boundary-layer diabatic processes may be key to the development of the MJO.

Key words: APE budget; boundary layer diabatic processes; organized convection; the MJO

Reference:

Yang, D. (2018). Boundary layer diabatic processes, the virtual effect, and convective self-aggregation. *Journal of Advances in Modeling Earth Systems*, 10. https://doi.org/10.1029/2017MS001261

How the sources and sinks of carbon are affected by phosphorus cycle dynamics in the Amazon region - a modeling study using ELM v1

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Tropical forests play a crucial role in the global carbon cycle, accounting for one third of the global NPP and containing about 25% of global vegetation biomass and soil carbon. This is particularly true for tropical forests in the Amazon region, as it comprises approximately 50% of the world's tropical forests. It is therefore important for us to understand and represent the processes that determine the fluxes and storage of carbon in these forests. In this study, we show that the implementation of phosphorus (P) cycle and P limitation in E3SM land model (ELM v1) improves simulated spatial pattern of NPP. The P-enabled ELM-v1 is able to capture the west-to-east gradient of productivity, consistent with field observations. We also show that by improving the representation of mortality processes, ELMv1 is able to reproduce the observed spatial pattern of above ground biomass. Our model simulations show that the consideration of P availability leads to a smaller carbon sink associated with CO2 fertilization effect, and lower carbon emissions due to land use and land cover change (LULCC). Our study suggests that terrestrial ecosystems in the Amazon region make an approximately neutral contribution to the global carbon cycle in recent decades, with the carbon sink associated with increasing atmospheric CO2 roughly cancelled out by the carbon emission associated with LULCC. Our study has important implications for projections of future carbon balance in this region. P limitation could become increasing important in the Amazon region as more P is immobilized into vegetation and SOM, which would constrain productivity stimulated by increasing [CO2] and lead to a source of carbon in the Amazon region.

Aerosol Source Attribution, Radiative Forcing and Climate Impact in the Arctic

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BER Program: RGCM
Project: HiLAT
Project Website: https://www.hilat.org

Knowing the source of aerosols in the Arctic and their contribution to energy balance is important for understanding Arctic climate systems. In this study, we quantify source attribution of black carbon (BC) and sulfate in the Arctic and their impacts on Arctic radiation budget and climate change using the Community Atmosphere Model version 5 (CAM5) equipped with an explicit aerosol source tagging technique. With the aerosol source tagging technique, emission, evolution, transport, and removal of sulfate and BC aerosols from fifteen independent source regions and two natural source sectors (for sulfate) are tracked separately. Regions that have high emissions or are near/within the Arctic present relatively large contributions to Arctic BC and sulfate burden. Emissions from East Asia contribute the most to Arctic sulfate and BC burden (29%). However, the near-surface aerosol concentrations are dominated by Arctic local emissions, which account for 50% of the sulfate and BC concentration. These indicate that sources have different contributions at different altitudes, depending on their transport pathways. Distant source regions have larger contributions to Arctic sulfate and BC at higher altitudes. East Asia and South Asia have their maximum contribution around 8 km, whereas Arctic local sources and emission from Russia account largely for the Arctic sulfate and BC below 2 km. Emissions from Europe and North America have relatively small contributions at all levels due to relatively low emissions. Comparison of forcing efficiency (calculated as the ratio of forcing to emissions from a specific source region) suggests that source regions with short transport pathways and meteorological conditions favoring longer lifetimes are more efficient in influencing the Arctic aerosol radiative forcing. Cooling from sulfates can partially offset Arctic heating from BC. Relative to the preindustrial condition, sulfate contributes 0.19 K of the Arctic surface temperature cooling, with 0.05 K of that contributed by sources from East Asia.

Climate Responses to Extreme Perturbation in Black Carbon Emissions in the Arctic and Mid-latitudes

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BER Program: RGCM
Project: HiLAT
Project Website: https://www.hilat.org

Black carbon (BC) is one of the most important light-absorbing aerosols that impose large impacts to various components of the Earth system. For the first time, we evaluate regional climate responses, their non-linearity, and short-term transient responses to extreme BC emission perturbations in the Arctic and mid-latitudes based on emission-driven experiments using the coupled Community Earth System Model (CESM). Present-day BC emissions are scaled by factors of 75 and150 over the Arctic and 3.5, 7 and 14 over mid-latitudes. Surface temperature responses to BC emissions are complex, with surface warming over land from extreme mid-latitude BC perturbations partially offset by ocean cooling, while a significant warming is found over the entire Northern Hemisphere due to the extreme Arctic BC perturbations. The BC effects do not scale linearly with the amount of emissions. While stronger BC emission perturbations have a higher burden efficiency (defined as the ratio of burden to emission), their temperature sensitivity is lower. BC can impact temperature much faster than greenhouse gases, with transient temperature responses in the Arctic and mid-latitudes approaching a quasi-equilibrium state at a timescale of 2–3 years.

With ocean and cloud feedbacks included in the simulations, we found that BC transported from mid-latitude continental sources changes cloud structure over ocean and reduces land-sea thermal contrast and, consequently, weakens the wind speed of East Asian winter monsoon. The increased Arctic BC also weakens East Asian winter monsoon through changing large-scale circulations, but this effect is quite uncertain. In addition, the extreme increases in both Arctic and mid-latitude BC emissions are found to weaken latitudinal temperature gradient and poleward heat transport, lead to tropical energy convergence, increase surface temperature of the tropical oceans, and consequently increase the frequency of extreme ENSO events.

Assessing Energy-Water Dynamics under Extremes with Scalable Agent-Based Modeling Approaches

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Multi-sector Dynamics
Project: Integrated Multi-sector Multi-scale Modeling (IM3)
Project website: https://im3.pnnl.gov/

Abstract

With the growing concern about the connection between energy and water systems, process-based modeling is a popular method to evaluate energy-water dynamics and assess potential extremes (e.g., droughts and floods) under future conditions. However, a common limitation for these types of models is the adoption of a fixed scale across complex system components and dynamics, which could lead to misrepresentation of metrics characterizing resilience. Usually, an energy-water coupled-natural-human system will be identified first (e.g. a city, a basin, a state or a country) and a specific water-energy trade off model will be developed for such system. Under the assumption that interactions are similar, these case study models might be generalizable such that they can be applied to other similar systems with available data. However, such models cannot be applied to other scales due to lack of a systematic approach to address the scalability of human decision uncertainty inside the modeling structure. This presentation summarizes the progress of the first two years of a DOE-funded project that focus on developing and utilizing a scalable agent-based modeling approach to address this research gap. Using the Colorado River Basin and its subbasin, the San Juan River Watershed, as examples, we will demonstrate how to use a Bayesian Inference mapping approach combined with the Cost-Loss method to quantify risk aversion among geographically defined agents at different spatial scales. We define agents as groups of water users, water regulators, energy users and energy producers. And we argue that capturing an agent's risk aversion plays a critical role in overall energy-water system's operation under extremes and affect system-wide performance and resilience. The scalable agent-based model also allows us to explicitly test and evaluate the adoption of adaptation. This includes the adoption of new technology, the implementation of new policy or changes in the way that agents operate, all of which are complicated by the perceived position of the agent with respect to future extreme events and how water/energy/food markets are evolving (e.g., differences in utility, uncertainty, and risk aversion parameters) across scales.

Title: Investigating new coastal storm metrics and domain size sensitivity over the Eastern U.S. with a multidecadal VR-CESM ensemble

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BER Program: RGCM

Project: An Integrated Evaluation of the Simulated Hydroclimate System of the Continental US

Project Website: https://climate.ucdavis.edu/hyperion/

Project Abstract:

Variable-resolution configurations of earth system models, such as CESM and E3SM, possess the capability to simulate user-specified geographic regions at high spatial resolution in order to capture hydrological extremes at reduced computational cost. As these setups grow in popularity, it is prudent to investigate how choices of refinement areas impact relevant climatological statistics for stakeholders.

We complete a nine-member, multidecadal, ensemble of simulations with fine grid spacing over the eastern United States in order to capture impacts associated with coastal cyclonic storms. The ensemble is divided into three subsets, each utilizing a grid of varying high-resolution extent into the North Atlantic Ocean. We investigate how the near-CONUS climatological distribution of A) tropical cyclones and their extratropical transition and B) winter coastal extratropical cyclones is impacted by choice of domain size. We also use this ensemble to demonstrate the capabilities of new metrics that tie dynamical systems to end-user hydrological impacts developed as part of Project Hyperion and investigate the improvements in these climatological statistics with an ensemble framework.

A unified snow and sea-ice radiative transfer algorithm for Earth System Models

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BER Program: ESM
Project: Snow Radiative Harmonization across ACME (CA to UC Irvine)
Project Website: N/A

Solar properties of snow can be computed by the SNow ICe and Aerosol Radiative (SNICAR) model widely used in land models, and by Icepack, the column physics used in CICE and MPAS-seaice. These models adopt 2-stream approximations (TSAs) with different radiative transfer techniques, as a result, the same snow has different solar radiative properties depending whether it is on land or on sea ice in the Energy Exascale Earth System Model (E3SM). A unified cryospheric surface radiative model in E3SM is thus crucial for constraining modeling uncertainties and studying climate/hydrology. We evaluate the current TSA models in E3SM (SNICAR and MPAS-seaice) and a 2-stream discrete ordinate model (2SD) against benchmark models, for their simulations of snow and sea-ice solar properties.

Compared with a 16-stream benchmark model, the errors in snow visible albedo for a direct-incident beam from all three TSA models are small ($<\pm0.005$) and increase as snow becomes shallower, especially for aged snow when the Sun is low. The errors in near-IR albedo are small ($<\pm0.005$) for solar zenith angles $\theta < 75°$, and increase (up to 0.1 or larger for melting snow) as θ increases. For diffuse incidence under cloudy skies, MPAS-seaice produces the most accurate snow albedo for both visible and near-IR ($<\pm0.0002$) with the lowest underestimate (-0.01) for melting thin snow. SNICAR performs similarly to MPAS-seaice for visible albedos, with a slightly larger underestimate (-0.02), while it overestimates the near-IR albedo by an order of magnitude more (up to 0.04). 2SD overestimates both visible and near-IR albedo by up to 0.03. Unlike SNICAR, MPAS-seaice and 2SD can also simulate bare, ponded, and snow-covered sea ice. Compared to MPAS-seaice, 2SD produces higher sea ice albedos, except for bare sea ice thinner than 1 meter. More tests are in progress to evaluate their performance against a benchmark sea-ice model.

Based on these offline tests, we correct the snow-covered sea ice albedo for $\theta > 75°$, merge the SNICAR snow properties into MPAS-seaice, and keep its radiative algorithm. Preliminary 1-year tests of the modified snow treatments in the MPAS-seaice driven by offline analyses show reduced summer sea-ice areas of approximate 0.3 million km^2 in both hemispheres.

Impacts of spectrally resolved emissivity on the surface energy balance and state of Arctic sea ice

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BER Program: ESM
Project: Realistic surface-atmosphere radiative coupling in E3SM (CA to U. Michigan/UC Irvine)
Project Website: N/A

Most simulations of longwave emission from sea ice assume a single greybody emissivity. It is increasingly recognized that sea-ice emissivity varies significantly across the electromagnetic spectrum, including in the infrared (IR) region of terrestrial radiation. Thus far coupled-model studies have focused on spectrally varying emissivity effects within the atmospheric model since it already uses multi-band longwave radiative transfer. These studies indicate that the reduced terrestrial emission from open ocean compared to sea ice in the far IR due to emissivity differences is a potential feedback, which has yet to be represented fully in the surface models. This study changes a sea-ice model (CICE) to employ a multi-band longwave physics with spectrally varying emissivity in order to re-examine the surface energy balance of sea ice Physically realistic ice emissivity in the far IR can differ from greybody emissivity by roughly 12%. Using CICE forced by atmospheric reanalyses we isolate the effects of spectrally resolved emissivity on the sea-ice state and surface energy balance. Preliminary results show that this spectrally dependant emissivity decreases the average longwave emission from the sea ice in the Arctic by ~0.2 W m-2 over areas that show no change in ice coverage, with decreases in monthly averages as large as ~0.7 W m-2 in summer. Arctic sea ice annual average area was similarly decreased ~5,580 km2 with a summer monthly decrease of up to ~ 26,000 km2. An experiment with atmospheric coupling would likely lead to larger changes due to feedbacks. This experiment is a first step toward fully coupled ESM experiments with spectrally varying emissivity in all surface model components.

Title: Diagnostics Package for Energy Exascale Earth System Model (E3SM_diags)

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BER Program: ESM

Project: E3SM

Project Website: https://e3sm.org

Project Abstract:

A modern, Python-based diagnostics package for evaluating earth system models has been developed by the E3SM project. The goal of this work is to build a comprehensive diagnostics software package as an essential E3SM tool to facilitate the diagnosis of the next generation earth system models. This package is embedded into the E3SM automated process flow to enable seamless transition between model run and diagnostics.

Modeled after NCAR's atmosphere diagnostics package, this software is designed in a flexible, modular and object-oriented fashion, enabling users to manipulate different processes in a diagnostics workflow. Numerous configuration options for metrics computation (i.e., regridding options) and visualization (i.e., graphical backend, color maps, contour levels) are customizable. Built-in functions to generate derived variables and to select diagnostics regions are supported and can be easily expanded. An updated observational data repository is developed and maintained by this activity.

The architecture of this package follows the Community Diagnostics Package framework, which is also applied by two other DOE funded diagnostics efforts (PCMDI metrics package and ARM diagnostics package), to facilitate effective interactions between different projects.

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Enhancing Convection Parameterization for Next Generation E3SM

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BER Program: Earth System Modeling

Project: University

Convective parameterization is one of the major factors responsible for biases in global climate model (GCM) simulations. At a scale of ~100 km or larger, there exists a quasi-equilibrium between convection and the large-scale forcing. At grey zone scales (e.g., ~10 km), convection becomes more stochastic within a GCM grid box, and many important assumptions in conventional parameterization break down. Therefore, the representation of stochasticity of convection is a critical scientific issue in high-resolution E3SM development, and a scale-aware convection scheme is also urgently needed. The parameterization of microphysical processes within convective clouds is another issue of fundamental importance in climate simulations. Both hydrometeor detrainment into anvil clouds and precipitation efficiency depend on microphysical processes in convective updrafts and downdrafts. In this project, we will 1) incorporate a stochastic convective parameterization and couple it with a deterministic convection scheme; 2) improve the scale-awareness of existing convection schemes; 3) enhance and incorporate a two-moment convective microphysics parameterization for use in the next generation E3SM.

Our recent work to introduce a stochastic convective scheme into the NCAR CAM5 largely eliminated the "too-much-drizzle and too little heavy rain" bias. We will incorporate it into E3SM to address similar issues in E3SM and investigate its effects in the model. We will test it at 100 km and 25 km resolutions and use the Regionally Refined Meshes (RRM) tool to test at 12 km resolution at Southern Great Plains (SGP) and Tropical Western Pacific (TWP). We will improve the scale-awareness of convective trigger function, closure and horizontal eddy transport by convection in convection schemes and incorporate them into the E3SM. For convective microphysics parameterization, we will implement a two-moment microphysics parameterization for convective updrafts into E3SM and further evaluate it. We will parameterize the impact of microphysics on cumulus dynamics by including the effect of ice-phase latent heat release on the intensity and depth of convective updrafts. We will develop a two-moment microphysics parameterization for downdrafts to better represent the evaporation of rain and melting of snow. Since all these enhancements of convective parameterization are important to the simulation of clouds and precipitation, we expect them to have significant impacts on climate simulations in E3SM.

Multi-objective automatic optimization for simultaneous calibration of E3SM atmosphere model at different resolutions

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Abstract

Physical parameterization schemes in general circulation models (GCMs) often require substantial tunings that are done separately for low- and high-resolution configurations and are mostly based on trial-and-error. In recent years, automatic tuning has been gaining recognition for model development but the work mainly concentrates on a single metric objective, either using a single variable or an average of several normalized variables. This study aims to jointly calibrate the tunable parameters for low resolution and high resolution atmosphere model of DOE Energy Exascale Earth system model (E3SM) using short-term hindcast simulations. The goal is to achieve improvements for both model resolutions compared to the default parameters in terms of a pre-defined metric. This metric combines the mean square error and variance of precipitation, humidity, cloud and longwave/shortwave cloud forcing, as well as the distribution of precipitation. Considering the computational cost of the high-resolution model and the multi-objective optimization algorithms, we use a regional refinement grid over the Tropical Western Pacific (TWP) to represent the simulation at high resolution. Furthermore, we propose to optimize the low resolution simulation over the TWP region while subjecting the high resolution TWP simulation and the low resolution global simulation to observational constraints using the sequential weight increasing factor technique (SWIFT) with the downhill-simplex method. By this design, the calibrated parameters will ensure improvement of the first objective while the latter two objectives do not get worse than the default configurations. We consider this to be an exploratory effort towards a unified tuning for the E3SM atmosphere model at multiple grid resolutions.

Title: A coastal component of MPAS-Ocean

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BER Program: SciDac

Project: E3SM (university collaboration)

Project Website: on Confluence

We have developed a new coastal component that can be coupled to the global ocean model MPAS-O. The new model, MPAS-OI, uses a semi-implicit finite-volume approach in order to achieve maximum efficiency for complex coastal geometry while trying to conform to the mimetic methods used by MPAS-O as much as possible. A new sub-grid capability is implemented in MPAS-OI that can very faithfully capture the underlying high-resolution bathy-topo surface as given by LiDAR. A nonlinear Newton-type solver is implemented to efficiently and accurately simulate wetting and drying processes in a conservative way with arbitrarily large time steps. The model has been successfully validated with several storm surge cases, with average errors of ~10cm for High Water Marks, and ~80% match for the maximum inundation extent. A finite-volume solver is implemented for tracer transport in MPAS-OI, and preliminary tests in a few estuaries (San Francisco Bay, Columbia River) suggest that the new coastal model can reasonably capture some estuarine processes. On-going work involves coupling of this new model as well as a well-tested finite-element model (SCHISM.wiki) to the global MPAS-O.

Title: **Subgrid Variations of the Cloud Water and Droplet Number Concentration Over Tropical Ocean: Satellite Observations and Implications for Warm Rain Simulation in Climate Models**

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BER Program: **RGMA-Analytics**

Project: Evaluation Of NCAR CAM5 Simulated Marine Boundary Layer Cloud Properties Using A Combination Of Satellite And Surface Observations

Project Abstract:

One of the difficulties of simulating the warm rain process in global climate models (GCM) is how to account for the impact of subgrid variations of cloud properties, such as cloud water and cloud droplet number concertation, on the nonlinear precipitation processes such as autoconversion. In practice, this impact is often treated by adding a so-called enhancement factor term to the parameterization scheme. In this study, we derive the subgrid variations of liquid-phase cloud properties over the tropical ocean using the satellite remote sensing products from MODIS (Moderate Resolution Imaging Spectroradiometer) and investigate the corresponding enhancement factors for the GCM parameterization of autoconversion rate. The wide spatial coverage of the MODIS product enables us to depict a detailed quantitative picture of the enhancement factor E_q due to the subgrid variation of cloud water, which shows a clear cloud regime dependence, namely a significant increase from the stratocumulus (Sc) to cumulus (Cu) cloud regions. Assuming a constant $E_q = 3.2$ would overestimate the observed E_q in the Sc regions and underestimate it in the Cu regions. We also found that the E_q based on the Lognormal PDF assumption performs slightly better than that based on the Gamma PDF assumption. A simple parameterization scheme is provided to relate the E_q to the grid-mean liquid cloud fraction, which can be readily used in GCMs. For the first time, the enhancement factor E_N due to the subgrid variation of CDNC is derived from satellite observation, and results reveal several regions downwind of biomass burning aerosols (e.g., Gulf of Guinea, East Coast of South Africa), air pollution (i.e., Eastern China Sea), and active volcanos (e.g., Kilauea Hawaii and Ambae Vanuatu), where the E_N is comparable, or even larger than E_q, even after the optically thin clouds are screened out.

A Study on the Summer Precipitation Bias in E3SM over the Central U.S. with the RRM Grid and the CAPT Approach

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The summer precipitation bias over the central US is a persistent challenge for climate models and it is closely linked to surface temperature bias. The Energy Exascale Earth System Model (E3SM) v1 Atmosphere Model (EAM) has implemented many new features in the physical parameterizations and developed two different horizontal resolutions: 1^o (ne30) and 0.25^o (ne120). Each resolution has its own tuning parameter setting. It is important to assess the persistent precipitation bias over the central US in EAM v1 and exam how the bias respond to different model settings.

This study conducts EAM v1 5-year AMIP simulations and short-term hindcasts (i.e. CAPT simulations) for the summer of 2011 with the regular ne30 grid and the CONUS RRM grid (the resolution is 0.25^o over CONUS, and 1^o elsewhere) All simulations manifest a wet precipitation bias over the Rocky Mountains and a dry bias over the Great Plains. The relative differences in the biases among different settings are the same between AMIP and CAPT simulations. The results indicate that EAM v1 tends to generate too strong deep convection system slightly too west over the Rocky Mountains. The system is trapped in the west likely due to the unfavored environment east of it and the triggering mechanism of ZM scheme. EAM1 also tends to produce too weak northward moisture transport east of 100^{o}W, which has been found to be a key factor controlling the precipitation over the central US, especially during the nighttime. Increasing model resolution to 0.25^o can help reduce the portion of the ZM convective precipitation and generate stronger convection systems over the central US but it is still not good enough. The current tuning practice in EAM1 shows little impact on the diurnal cycle of precipitation, which is mainly controlled by the triggering mechanism of ZM scheme.

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Title: Spatiotemporal Characteristics of Historical Global Flood Inundation

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Abstract:

Floodplain plays an important role in modulating the magnitude and movements of river flow through inundation and flood events. However, floodplain dynamics is under-represented in most current large-scale river routing models and the spatiotemporal characteristics of flood inundation events are not well understood. In this study we applied a physically based inundation model coupled with a river routing model (Model for Scale Adaptive River Transport, MOSART) within the Energy Exascale Earth System Model (E3SM) framework to investigate the global spatiotemporal characteristics of flood inundation dynamics. The model features a DEM-based floodplain storage connecting to the river channel and a diffusion wave routing scheme to represent the back water effect. After calibrating against the satellite-based flood inundation extent data, river stage data and observed river discharge, the model reasonably captures the historical flood events in terms of the frequency and the spatial extent in 15 global river basins. We applied the model globally for simulations of 15 years long (1993-2007) and analyzed the spatial patterns and the temporal characteristics of the flood events in major global basins. We also explored the linkages between the flood inundation events and the climate as well as local water conditions such as snow storage and soil moisture, with the goals of improving prediction of future flood risk, providing guidance on flood control, and understanding the impacts of climate change.

E3SM land biogeochemistry modeling and benchmarking: offline and coupled BGC simulations

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Abstract

Land biogeochemistry (BGC) dynamically responds to the changing climate and significantly feeds back with climate system via multiple avenues, either positively or negatively. Land BGC thus plays an important role in shaping the future climate. Accurate simulation of land BGC is, however, challenging due to the limited process level understanding of land surface biogeochemistry, model structural uncertainty as well as model parameterization bias. Here, we reported improvements on E3SM land surface biogeochemistry process representation, and demonstrated the improved model fidelity through a comprehensive benchmarking approach using the International Land Model Benchmarking (ILAMB) infrastructure. We showed that offline simulations of major components (fluxes and pools) of land surface Carbon, Water, and Energy cycles have been largely improved, compared with CLM4.5, from which ELM started. We also showed some preliminary results from the Coupled Biogeochemistry (CBGC) simulations (ongoing efforts), and diagnosed potential bias across the land surface for different biogeochemical processes.