Overview of CATALYST

Cooperative Agreement To Analyze variabiLity, change and predictabilitY in the earth SysTem

Gerald A. Meehl

NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

U.S. DEPARTMENT OF ENERGY
Office of Science
Biological and Environmental Research
Regional and Global Climate Modeling Program

Cooperative Agreement To Analyze variabiLity, change and predictabilitY in the earth SysTem

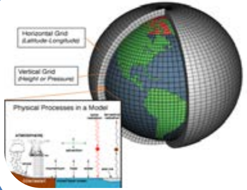
Perform foundational research toward advancing a robust understanding of **modes of variability and change** using models, observations and process studies

External forcing, internal variability, and predictability

- Interplay between external forcing and internal variability
- Earth system simulation capability to study variability and predictability
- Changes of variability on multi-decadal timescales

High impact events

- Processes and mechanisms that produce high impact extremes
- Possible future changes to high impact events
- Global and regional sea level rise



Parametric and structural uncertainty

- Quantify uncertainties and feedbacks; machine learning
- Evaluate model improvements using a hierarchy of models
- Optimization and calibration at the development timescale

CATALYST TEAM

21 scientists funded all or in part from CATALYST (**6 FTEs on CATALYST**)

most of the other fractions of support funded by NCAR

12 female
9 male

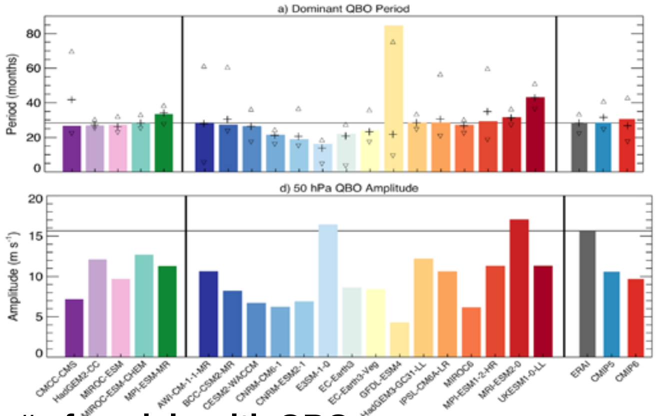
*new since start of CATALYST in 2018

	Catalyst Staff	Job Category	Expertise	FTE
	Arblaster, Julie	Associate Professor	Earth System Dynamics	0.50
	Bates, Susan	Project Scientist II	Computer resource management	0.10
	Caron, Julie	Associate Scientist IV	Subseasonal Precipitation Processes	0.70
*	Dagon, Katie	Project Scientist I	Machine learning, uncertainty quantification	1.00
*	Fasullo, John	Project Scientist III	Sea level rise, hydroclimate	0.75
*	Glanville, Anne (Sasha)	Associate Scientist II	Model analysis, running models	1.00
	Hu, Aixue	Project Scientist II	Ocean and High Latitude Processes	1.00
*	Lehner, Flavio	Project Scientist I	Climate System Processes	0.10
*	Li, Hui	Project Scientist I	Tropical cyclones	1.00
	Medeiros, Brian	Project Scientist II	Model Hierarchy, Feedbacks and Processes	0.60
	Meehl, Gerald	Senior Scientist	Interannual to Decadal Variability	0.33
*	Molina, Maria	Project Scientist I	Machine learning/prediction	1.00
	Neale, Richard	Project Scientist III	Convective Processes	0.05
	Pendergrass, Angeline	Project Scientist I	Precipitation and Hydrologic Cycle Dynamics	0.10
*	Richter, Jadwiga (Yaga)	Scientist III	Modes of variability, initialized prediction	0.05
	Rosenbloom, Nan	Associate Scientist III	Program Mgmt./Decadal Variability Processes	1.00
	Shields, Christine	Associate Scientist IV	Hydroclimate Dynamics	0.86
	Stern, Ilana	Software Engineer I	Data Handling/Publishing	1.00
	Strand, Warren	Software Engineer III	Software Engineering/Data Manager	0.90
	Tribbia, Joseph	Senior Research Assoc.	Subseasonal to Seasonal Processes	0.00
	Truesdale, John	Software Engineer III	Software Engineering/High Res. Modeling	0.20

Research Objective 1 (RO1): modes of variability and change related to forcing/response and decadal prediction

How is subseasonal to interannual to decadal variability represented/predicted in Earth system models, and how may these phenomena change in the future?

More models now are able to simulate the QBO

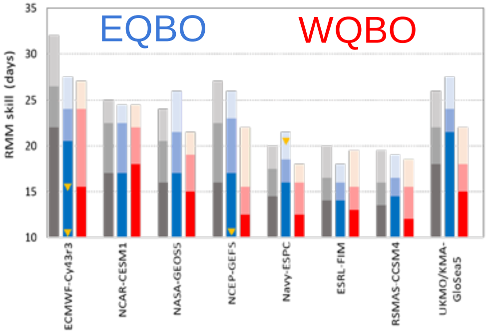


# of models with QBO:

CMIP3: 0, CMIP5: 5, CMIP6: 15

(**Richter** et al., 2020, *JGR*)

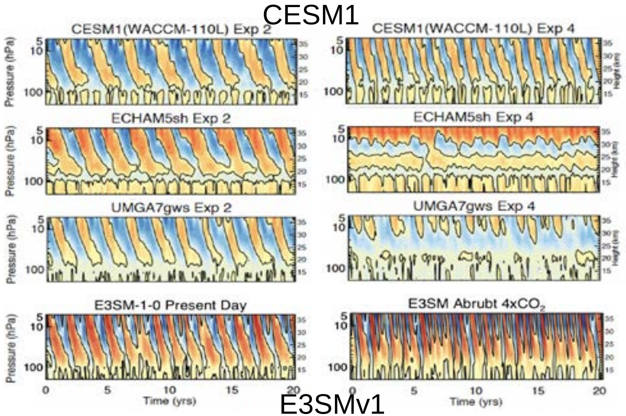
The prediction skill of the MJO in subseasonal reforecasts is higher in the easterly phase of the QBO than the westerly phase



(Kim, **Richter,** and Martin, 2019, *JGR*)

no consistency among climate models with regard to how the QBO will change in the warming climate

Present Climate **4 x CO_2**



(**Richter** and coauthors, 2020, *Q. J. Roy. Meteorol. Soc.*)

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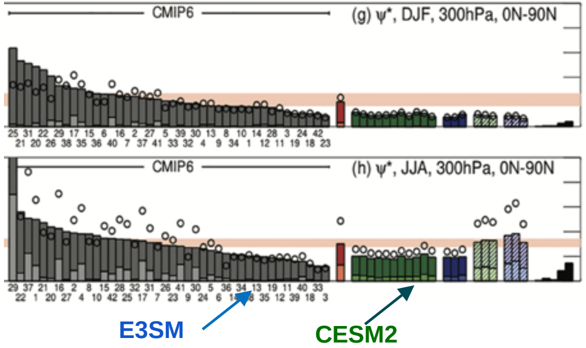
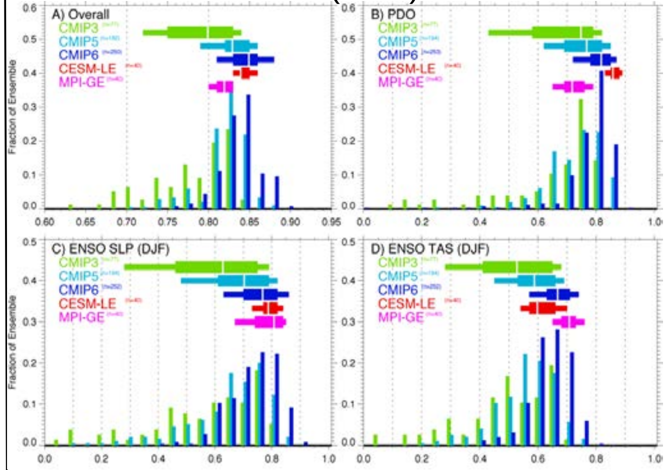
CESM2 and E3SM rank within the top 10% of CMIP class models in the representation of the storm tracks, Northern Hemisphere (NH) stationary waves, NH winter blocking and the global divergent circulation



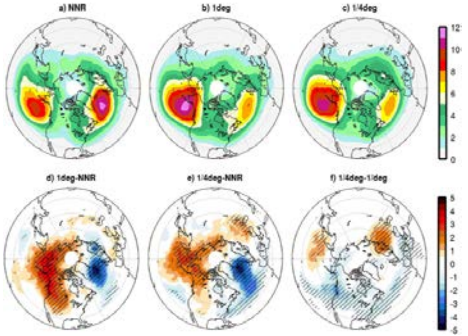
(Simpson, …**Neale**,…**Medeiros** …**Richter**, and coauthors**,** 2020, *JAMES*)

progressive improvement in simulating many modes of variability including the Pacific Decadal Oscillation (PDO) and ENSO



(**Fasullo**, et al., 2020, *J. Climate)*

E3SM generally reproduces the spatial distribution of blocking frequency maxima over the Northern Hemisphere



(Jiang, …**Neale**…and co-authors, 2019, *JGR*)

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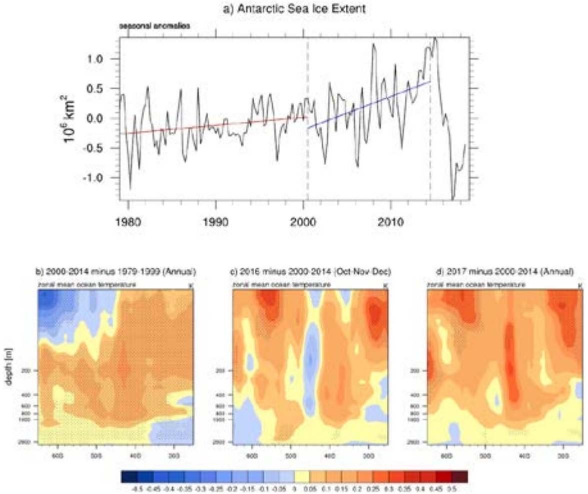
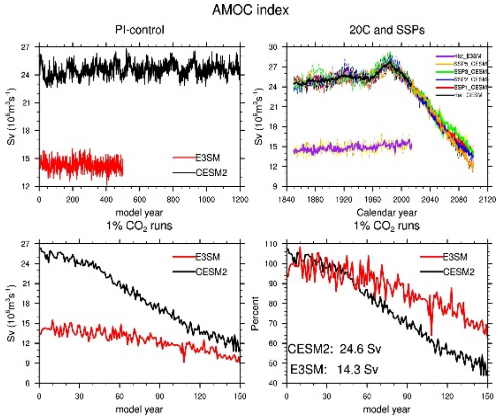
Sudden retreat of Antarctic sea ice in 2016 a combination of forcing from transition to positive IPO and negative Southern Annular Mode in observations



(**Meehl, Arblaster,** et al., 2019, *Nature Geoscience*)

CESM2 and E3SM1 have very similar ECS, but weaker AMOC in E3SM1 contributes higher TCR by permitting a faster warming of the upper ocean



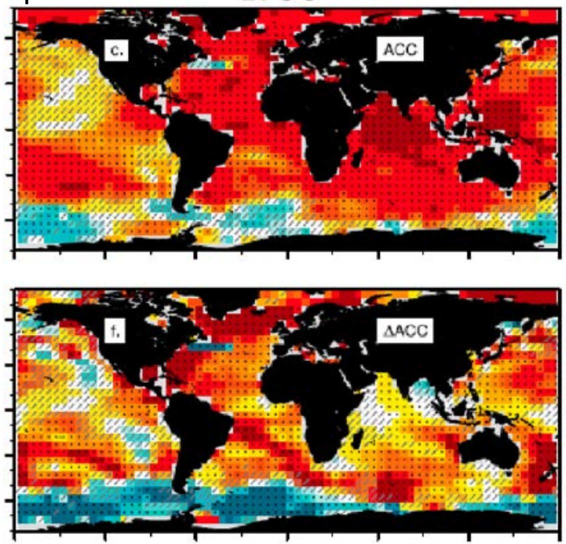
(**Hu** et al., 2020, *J. Climate*)

Research Objective 1 (RO1): modes of variability and change related to forcing/response and decadal prediction

How is subseasonal to interannual to decadal variability represented/predicted in Earth system models, and how may these phenomena change in the future?

Initialized decadal predictions show increased skill over persistence

LY 5-9



(Yeager.,…**Rosenbloom, Strand, Bates, Meehl, …Teng**, and coauthors, 2018, *BAMS*)

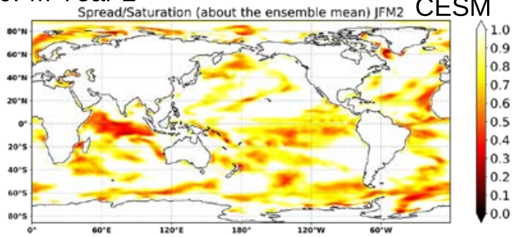
Multi-Model Multi-Year Climate Predictability: E3SM and CESM

Collaboration between CATALYST and University of Miami

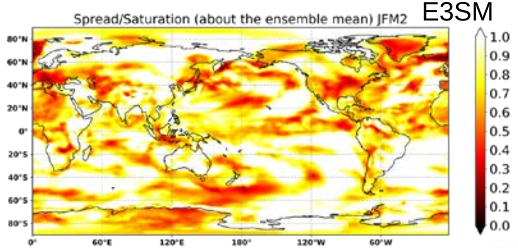
Two models (E3SM and CESM) and two initialization methods (brute force, initialized ocean) and limited set of hindcast start years to quantify effects of model-dependence and initial state in hindcast skill in decadal predictions

Surface Temperature Predictability Ratios: JFM Year 2

CESM



E3SM



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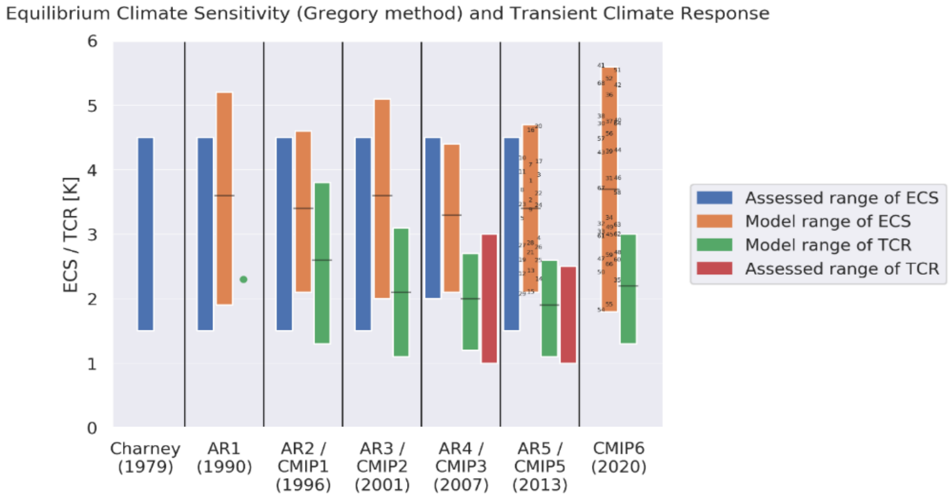
Research Objective 1 (RO1): modes of variability and change related to forcing/response and decadal prediction

How is subseasonal to interannual to decadal variability represented/predicted in Earth system models, and how may these phenomena change in the future?

Longer term projections depend on equilibrium climate sensitivity (ECS) and transient climate response (TCR)



Current CMIP6 ECS range (1.8°C-5.6°C) is largest on record (on high and low end)

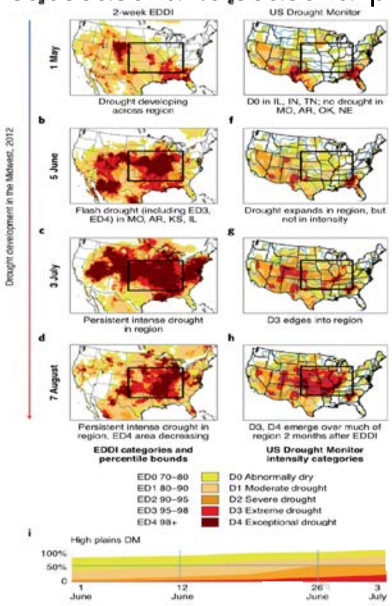
but multi-model mean ECS has stayed near 3.6C, TCR near 2.1C, and range of TCR hasn't changed much since CMIP1

(**Meehl** et al., 2020, *Science Advances*)

Research Objective 2 (RO2): high impact events related to modes of variability and change

What processes and feedbacks influence present-day and future earth system variability and change associated with precipitation and heat extremes?

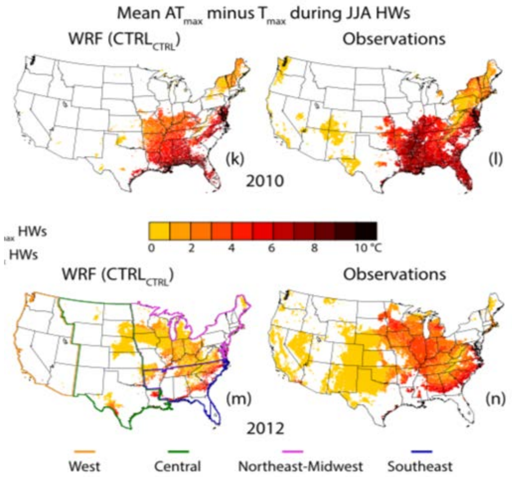
Flash droughts are a challenge for subseasonal to seasonal prediction



2 definitions proposed as a for analysis and prediction

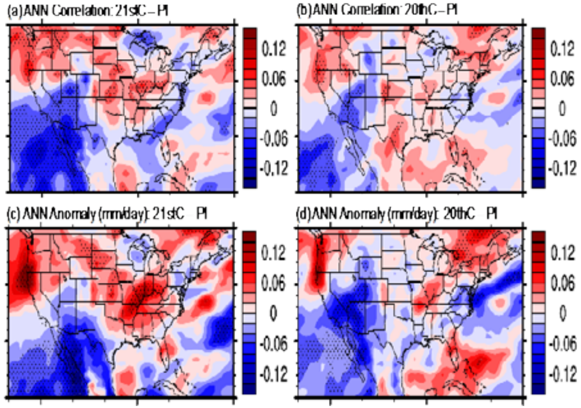
(**Pendergrass**, **Meehl**,…**Lehner**, …**Neale**, and coauthors., 2020. *Nature Climate Change*)

Dry heat waves become drier, and humid heat waves stay humid in a warmer climate



(Rastogi, **Lehner**, Ashfaq, 2020, *GRL*)

In a future warmer climate, the IPO has a weaker amplitude in space, a higher frequency in time, and a muted impact on global and North American temperature and rainfall.



(Xu and **Hu**, 2017, *J. Climate*)

Research Objective 2 (RO2): high impact events related to modes of variability and change

What specific synoptic weather events contribute to precipitation extremes?

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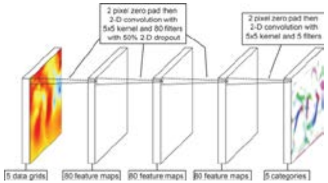
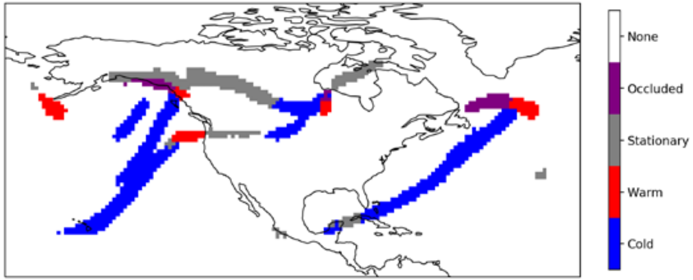
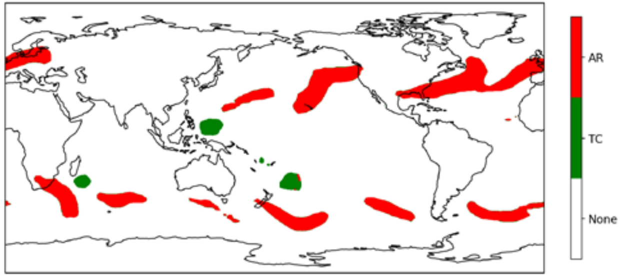
Use machine learning and deep learning to identify synoptic weather systems (fronts, midlatitude cyclones, tropical cyclones, atmospheric rivers, and mesoscale convective systems (MCSs) and associate those systems with precipitation extremes:
collaborative research with CATALYST, CASCADE (LBL), and N.C. State



Biard and Kunkel frontal ID methodology applied to CESM1 (Katie Dagon)

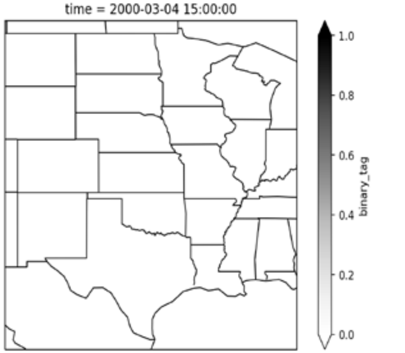


ClimateNet: Machine learning-based detection algorithm for atmospheric rivers and tropical cyclones applied in test to CESM1 (John Truesdale)



(Prabhat, Kashinath,...., **Dagon**, **Shields,** O'Brien, T., Wehner, W., and Collins, W., 2020, *GMDD*)

Train a deep learning model to detect mesoscale convective systems (MCSs) using similar input fields to frontal detection algorithm applied in test to CESM1 (Maria Molina)



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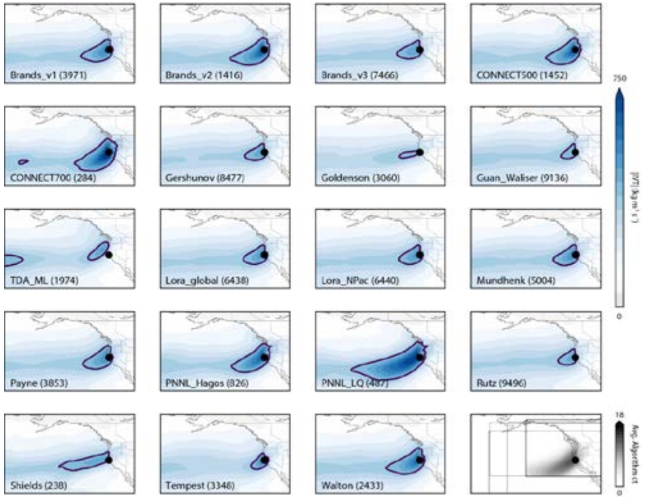
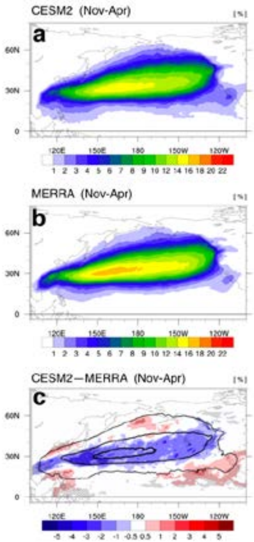
ARTMIP: first define atmospheric rivers



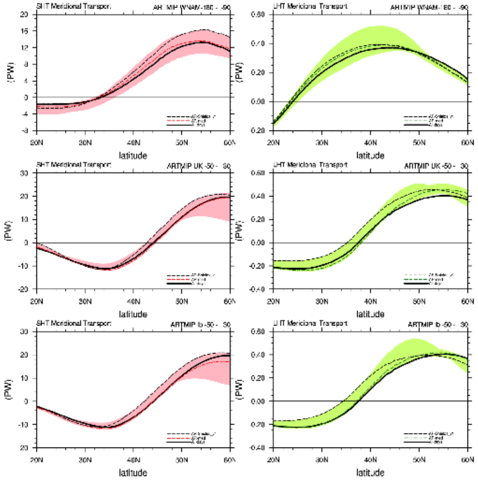
(Rutz, **Shields**, and coauthors, 2019, *JGR)*

Blocking and ARs: Landfalling atmospheric rivers tend to follow the formation of a blocking ridge about 10-days prior.



(Benedict, Clement, **Medeiros** 2019, *JGR*)

In a warmer climate, AR latent heat transport increases where sensible heat decreases (increases) for Western North America (Europe).



(**Shields** et al., 2019, *GRL*)

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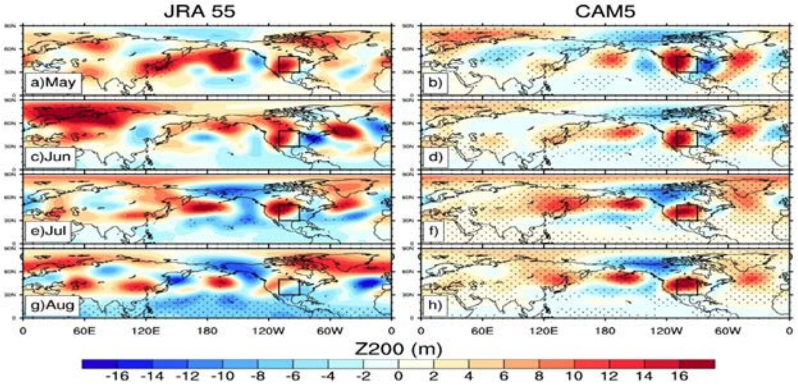
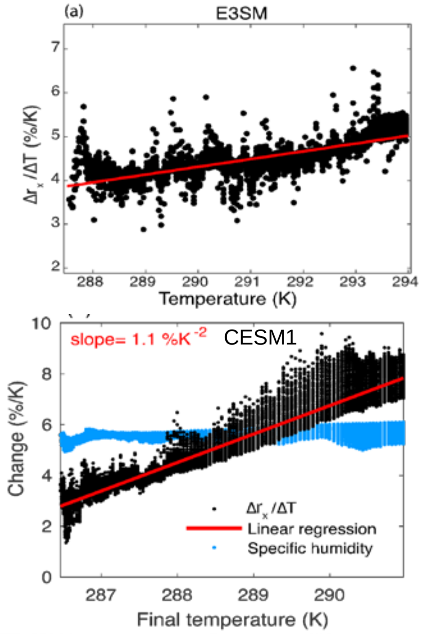
Research Objective 2 (RO2): high impact events related to modes of variability and change

What processes and feedbacks influence present-day and future earth system variability and change associated with precipitation and heat extremes?

Severe drought (completely dry Great Plains) produces summer Northern Hemisphere-wide teleconnections that spread the influence of a severe regional drought to far-field regions with implications for extended predictability for high-impact stationary wave events



(**Teng** et al., 2019, *J. Climate*)



Comparing E3SM and CESM1: extreme precipitation is non-linearly related to global-mean surface temperature, CESM1 has a larger nonlinearity than E3SM associated with circulation changes and increases in large-scale precipitation

(**Pendergrass** et al., 2019, *GRL*)

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Research Objective 3 (RO3): Uncertainty and model hierarchy related to modes of variability and change

What are the sources of structural model uncertainty, and can these uncertainties be reduced through judicious use of modeling hierarchies and advanced diagnostic techniques?

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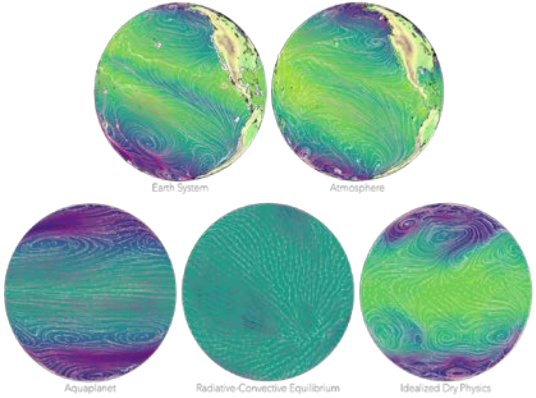
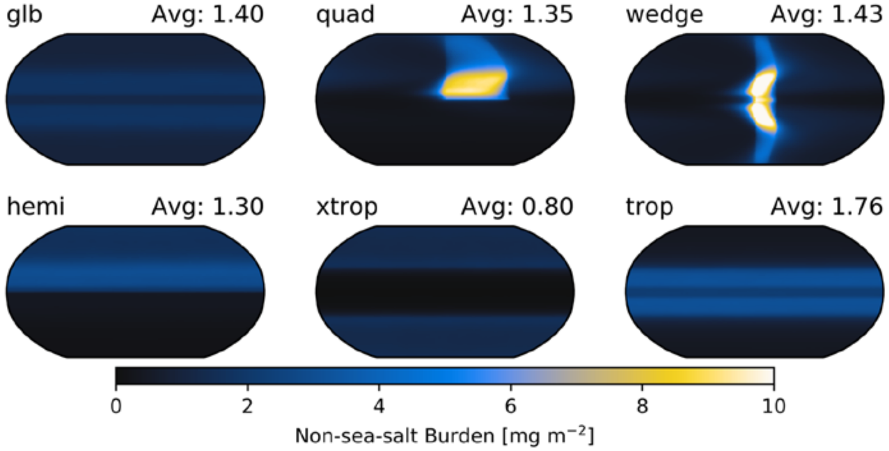
A model hierarchy: Earth system model, atmosphere only model (AGCM with prescribed SST), Aquaplanet, Radiative-convective equilibrium (RCE), and idealized dry physics



(Maher…**Medeiros**, and co-authors, 2019, *Rev. Geophys*.)

An aquaplanet with redistributed pre-industrial aerosol emissions shows tropical clouds are very sensitive to changes in aerosols, signaling a regime-dependence of aerosol effects



(**Medeiros**, 2020, *JAMES*)

Research Objective 3 (RO3): Uncertainty and model hierarchy related to modes of variability and change

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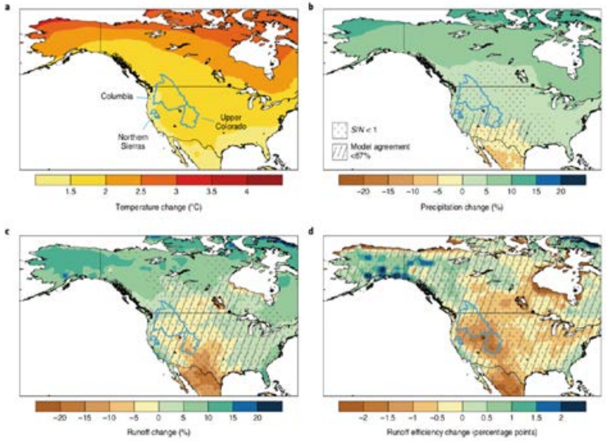
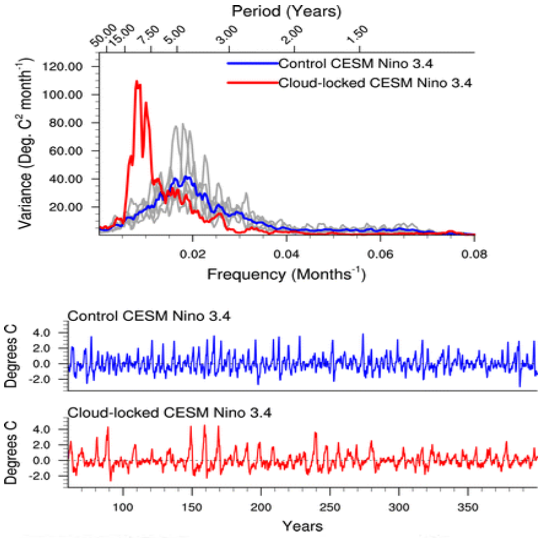
What are the sources of structural model uncertainty, and can these uncertainties be reduced through judicious use of modeling hierarchies and advanced diagnostic techniques?

Benchmark climate models with observational estimates of runoff sensitivity and derive an observational constraint on future runoff projections.



(**Lehner** et al., 2019, *Nature Clim. Change*)

Cloud locking technique shows that cloud feedbacks impact SST anomalies through local shortwave feedbacks, alter the wind-evaporation-SST feedback in the southeast Pacific, and alter the strength of tropical winds that impact ENSO periodicity through Rossby waves.



(Middlemas, Clement, **Medeiros**, Kirtman, 2019, *J. Climate*)


Julie Arblaster


Susan Bates


Julie Caron


Katie Dagon

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Thank you!


John Fasullo


Sasha Glanville


Aixue Hu


Flavio Lehner


Hui Li


Brian Medeiros


Jerry Meehl


Maria Molina


Rich Neale


Angie Pendergrass


Yaga Richter


Nan Rosenbloom


Christine Shields


Ilana Stern


Gary Strand


Joe Tribbia


John Truesdale

Three research objectives and associated science questions are addressed using:

Models: E3SM, CESM, CMIP5, CMIP6, SubX, pacemaker, model hierarchy

Observations: ERA Reanalyses, Argo float data, HadISST, Hurrell SST, ocean reanalyses

Research Objective 1 (RO1): modes of variability and change related to forcing/response and decadal prediction

Research Objective 2 (RO2): high impact events related to modes of variability and change

Research Objective 3 (RO3): Uncertainty and model hierarchy related to modes of variability and change

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