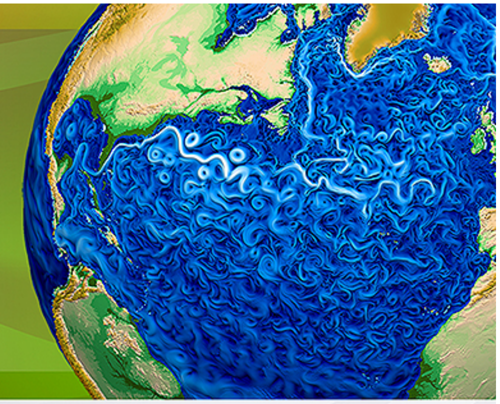
ACME
Accelerated Climate Modeling for Energy



Coupled Experiments Timeline

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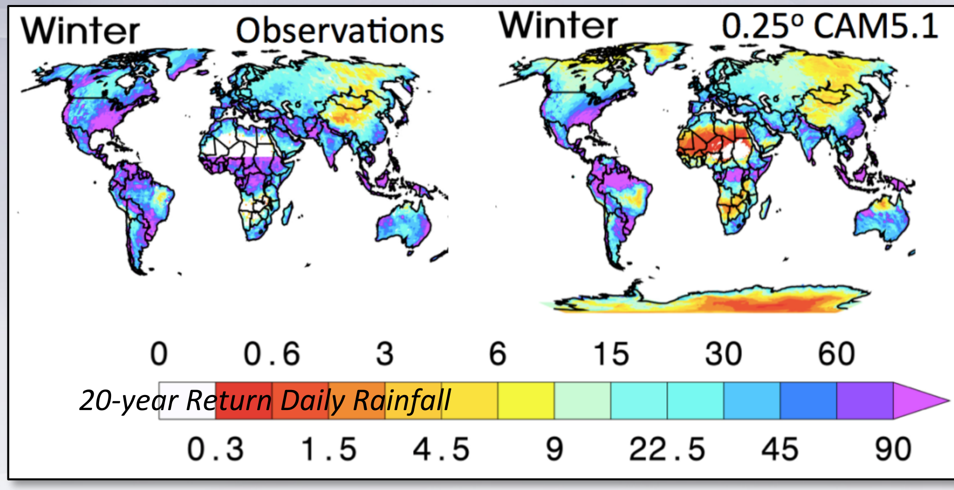
Water Cycle Experiments



Question: How will improved portrayals of earth system features affect the simulation of Earth's water cycle, including river flow and freshwater supplies at the watershed scale?

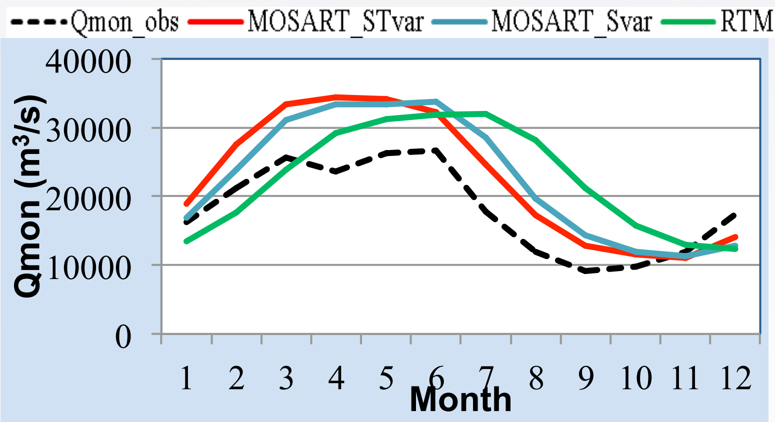
Hypothesis: Changes in river flow over the last 40 years have been dominated primarily by land and water use and climate change associated with aerosol forcing. During the next 40 years GHG emissions following an RCP 4.5 or 8.5 scenario will produce changes to river flow with signatures that dominate those of other forcing agents in at least one of the domains in our experimental framework examines below.

Water Cycle Experiment Strategy

- **Explore the role of physical processes and parameterization in climate models influencing river flow and fresh water supply.**
- **Produce accurate simulation of river flow for major river basins: Mississippi, Amazon, Ganges**
- **These basins represent very different:**
  - Climatic and hydrologic regimes
  - Large-scale ocean-atmosphere interactions
  - Regional land-atmosphere interactions
  - Local human activities

Seasonally inundated river basins in central Amazon

Monthly Mean Flow



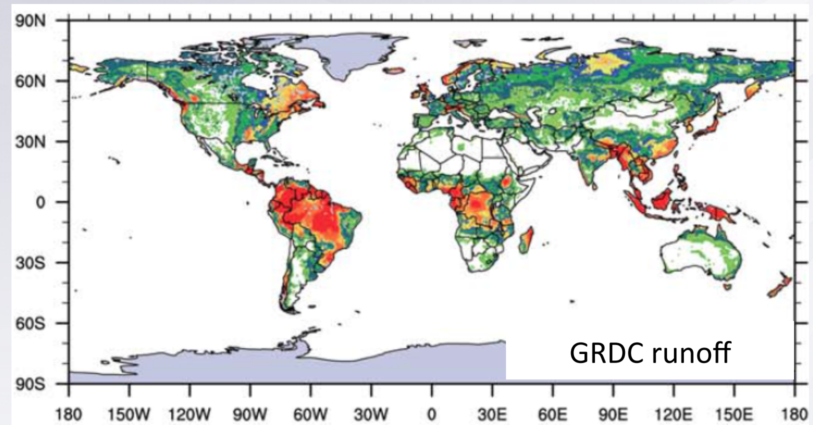
Strategy part I

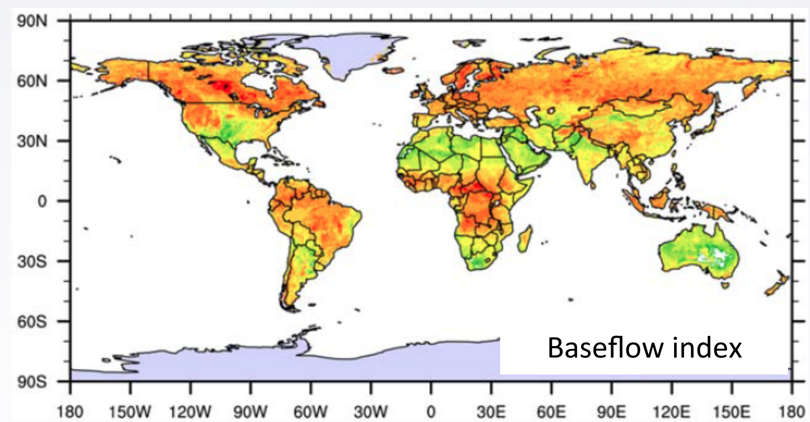
- explore the role of processes and parameterizations influencing river flow and fresh water supply
- Goal --- accurate portrayal of present day river flow for major river basins (e.g., Mississippi, Amazon, Ganges),
  - basins dominated by very different climate and hydrologic regimes
  - influenced by large-scale ocean-atmosphere & regional land-atmosphere interactions,
  - local human activities (strong ties to GEWEX and CLIVAR):
- North America:
  - Mackenzie: High latitude, snow dominated with little human influence.
  - Mississippi: Mid-latitude, summer convective and rain dominated regime, highly developed irrigation systems, groundwater extractions.
- South America:
  - Amazon: Tropical, convective regime, strong water recycling by tropical forests, biomass burning, surface water-groundwater interactions, seasonal inundation.
  - La Plata: Monsoon rainfall, significant human activities including agriculture and hydropower generation
- Asia:
  - Ganges: High altitude processes in the headwaters, monsoon rainfall with sensitivity to Indian Ocean SST and Brown Cloud, water management with developing country technology.
  - Yangtze: High altitude processes in the headwaters, monsoon rainfall, aerosol effects, diverse human activities including agriculture, large reservoirs, water diversion.

Strategy part II

- **Systematically explore the sensitivity of atmospheric and surface water budgets simulated in these river basins to improvements in the ACME model by isolating the effects of**
  - Resolution,
  - treatments of cloud and aerosols,
  - subgrid orographic effects,
  - surface/subsurface hydrology,
  - human activities,
  - ocean-atmosphere interaction.

- **How does water availability in the major river basins respond to anthropogenic forcing including emissions, land use, and water use.**





Atm Model Configs

- AG100: Global 100km resolution Atmosphere
- AG025: Global 25km resolution Atmosphere
- ANA025: Reg. refined model over North America at 25km resolution (100km elsewhere)
- ASA025: Reg .refined model over South America at 25km resolution (100km elsewhere)
- AAS025: Reg. refined model over Asia at 25km resolution (100km elsewhere)

Ocean Model Configs

- OD: Ocean data model (e.g. SSTs are prescribed)
- OLR: Low resolution Ocean Model (grid 30 km at equator, expanding to 60 km at poles)
- OHR: High resolution Ocean Model (grid: 15 km at equator, contracting to 5 km at poles)
- OVR: Regionally refined : Distribution of resolution will vary depending on the regional water cycle of interest and known sensitivity of water cycle to SST biases -- targeting grid scale resolutions ranging from 5 to 30 km.

Land Model Configs

- LLR: Low resolution land globally with watershed delineation at equivalent of 0.5 degree resolution
- LHR: High resolution land globally with watershed delineation at equivalent of 1/8 degree resolution
- LNA025: Regionally refined over North America at 1/8 degree and 1 degree elsewhere
- LSA025: Regionally refined over South America at 1/8 degree and 1 degree elsewhere
- LAS025: Regionally refined over Asia at 1/8 degree and 1 degree elsewhere

Proposed Stage I simulations
Data Ocean

- AG100-LLR-OD
- AG025-LHR-OD
- A{NA, SA, AS}025 + L{NA, SA, AS}025 + OD
  LR regions nudged by reanalyses (to expose the role of historically accurate meteorology and SSTs external to the RR.)
- A{NA, SA, AS}025 + L{NA, SA, AS}025 + OD
  LR nudged by AG100-OD forced by AMIP SSTS (to expose the role of LR model biases on RR simulations when SSTs are right)

Proposed Stage II Fully Coupled Simulations

- AG100 + LLR + OLR
  (first preview of the coupled simulation at low resolution)
- AG100 + LLR + OVR
  (first demo of the impact of ocean eddy resolving impacts)
- AG025 + LHR + OHR
  (full high resolution simulation. The ultimate goal)

Practicalities

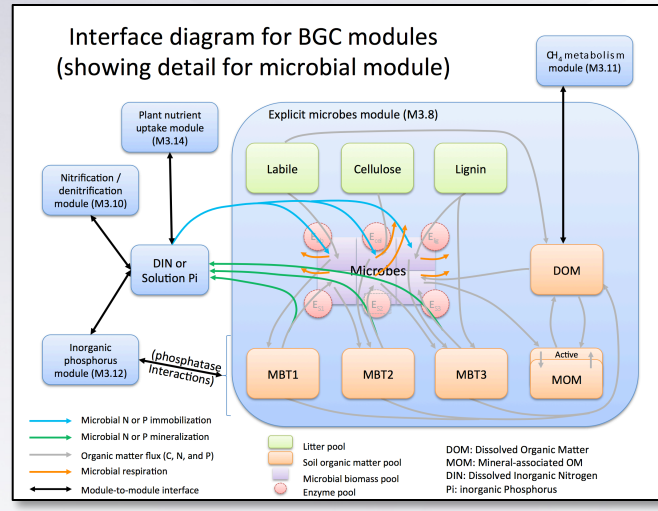
- Q7-Q8:
  - A100 + LLR + OD
  - A{NA, SA, AS}025 + L{NA, SA, AS}025 + OD
    LR nudged by reanalyses (historically accurate meteorology and SSTs)
  - Credible coupled uniform present day simulations AG100-LLR-OLR, AG025-LHR-OHR
- Q9-Q12: AG100-LLR-OLR
  - Fix aerosol emissions at PI levels to expose role of aerosol forcing
  - Fix Land Use / Water Use at PI to expose role of surface processes
  - Fix aerosols, LU, WU to expose role of CO2 forcing

Land BGC 3-year Objectives

- Science Question
  - What are the impacts of nutrients on terrestrial C-Climate feedbacks?
- Motivation
  - Globally, many ecosystems are N, P, or N and P limited
  - Current suite of nutrient-enabled models show poor performance when compared to perturbation and transect observations
    - E.g., Thomas et al. (2013a,b); Zaehle et al. (2014); Walker et al. (2014); DeKauwe et al. (2014)
  - ACME Land model team proposed to address, and improve model representation of, nutrient dynamics and C-Climate feedbacks
- Goals
  - Quantify impacts on C-climate system feedbacks by nutrients (nitrogen, phosphorus)
  - Investigate structural uncertainty in representations of nutrient controls on C-cycle dynamics

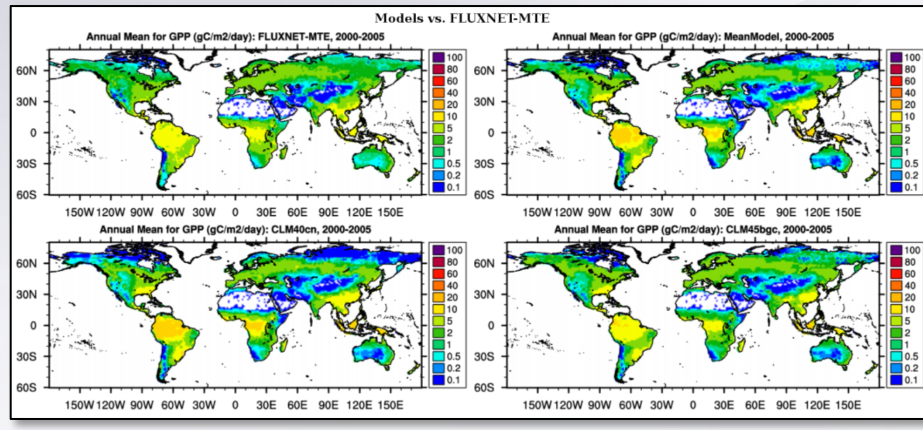
Land BGC 3-year Experiment

- **Evaluate role of nutrients on constraining ecosystem processes.**
- **Define basic model structures to be explored:**
  - Elements of CLM4-CNP
  - Elements of CLM4.5-BGC
- **Begin model development for these structures**
- **Define simulation scenarios (e.g., C4MIP, C, CN, CNP)**
  - Evaluate computational needs for coupled experiments
- **Benchmarking approaches**
  - Collaborative with the Land Benchmarking team



Land BGC Experimental Protocol

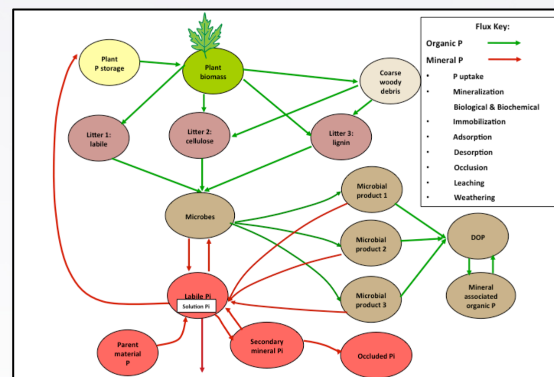
- **Simulation design:**
  - (CMIP5 C4MIP) x (Land Use) x (nutrients) x (model configuration)
  - RCP8.5 (has non-CO2 GHG and land-use)
  - 1 degree
  - Concentration forced
  - Ocean BGC on?



- **CMIP5 C4MIP protocol:**
  - Biogeochemically uncoupled
  - Biogeochemically radiatively coupled
  - Biogeochemically concentration-coupled
  - Biogeochemically fully-coupled

- **Model configuration options:**
  - #1: CLM4.5-BGC with P belowground BGC and aboveground P limitation
  - #2: CLM4.5 with ECA kinetics, leaf N&P constraints, TRY database, etc.

- **Model configurations will be based on CLM4.5-BGC**
  - Century decomposition structure
  - Century nitrification and denitrification
  - CLM4.5 leaching
  - Photosynthesis calculated as in CLM4.5 (Bonan et al. (2011, 2012))



Methods

- Application of evaluation metrics with ACME-ILAMB (uncoupled and coupled)
- Use global offline and coupled simulations and analyze global-scale feedback mechanisms
- Options for exploring nutrient controls on C-Climate feedbacks using CLM4.5 with:
  - CLM4-CNP
    - Yang et al. (2014 *Biogeosciences*)
  - ECA (Equilibrium Chemistry Approximation)
    - Represents multi-substrate and multi-nutrient competition
    - Tang and Riley (2013 *Biogeosciences*, 2014 *Nature Climate Change*); Tang et al. (2013 *Biogeosciences*); Xu et al. (submitted *Biogeosciences*)

Coupled Simulation Timeline

- Timeline for 3-year BGC Experiment simulations using v1
  - Model development and offline testing: Q1-Q6 (December 31, 2015)
  - Coupled system tuning: Q7, Q8 (Jan 2016 – Jun 2016)
  - Coupled experiment simulations: Q9-Q12 (July 2016 – Jun 2017)

Offline Simulations

- Each of the two structures has multiple configurations to test (e.g., parameterizations, C, C+N, C+N+P)
- Multiple single forcing factors: CO_2, LULCC, climate forcing
- Single-point simulations for experimental manipulations (e.g., FACE)
- Will require multiple spin-ups
- Use ACME-ILAMB evaluation framework to test impact of model changes

ACME-ILAMB Benchmarking

Global Variables

	MeanModel	CLM40cn	CLM45bgc
Aboveground Live Biomass	0.72	0.65	0.76
Burned Area	0.45	0.33	0.58
Gross Primary Production	0.58	0.54	0.57
Leaf Area Index	0.44	0.41	0.42
Net Ecosystem Exchange	0.37	0.36	0.37
Global Net Land Flux	0.80	0.27	0.39
Ecosystem Respiration	0.52	0.49	0.52
Soil Carbon	0.67	0.37	0.61
Summary	0.57	0.43	0.53
Evapotranspiration	0.60	0.59	0.60

Uncoupled evaluation

Coupled evaluation

	Global Patterns			Scoring			
	Annual Mean (PgC/yr)	Bias (PgC/yr)	RMSE (PgC/month)	Global Bias	RMSE	Interannual Variability	Overall
BenchMark [Le Quere et al. (2012)]	-0.49	-	-	-	-	-	-
MeanModel	0.50	0.99	1.40	0.00	0.02	0.51	0.17
bcc-csm1-1	-	-	-	-	-	-	-
CanESM2	-0.23	0.26	1.75	0.47	0.00	0.74	0.56
CCSM4	0.27	0.76	1.29	0.00	0.00	0.48	0.16

Coupled Simulations

- CMIP5 C^4MIP protocol
  - Biogeochemically radiatively coupled
  - Biogeochemically concentration coupled
  - Biogeochemically fully-coupled
- C, C + N, C + N + P
- Historical + RCP8.5
  - 250 transient years per experiment
- ~1 degree (f09)
- Concentration forced
- Ocean BGC (being discussed)

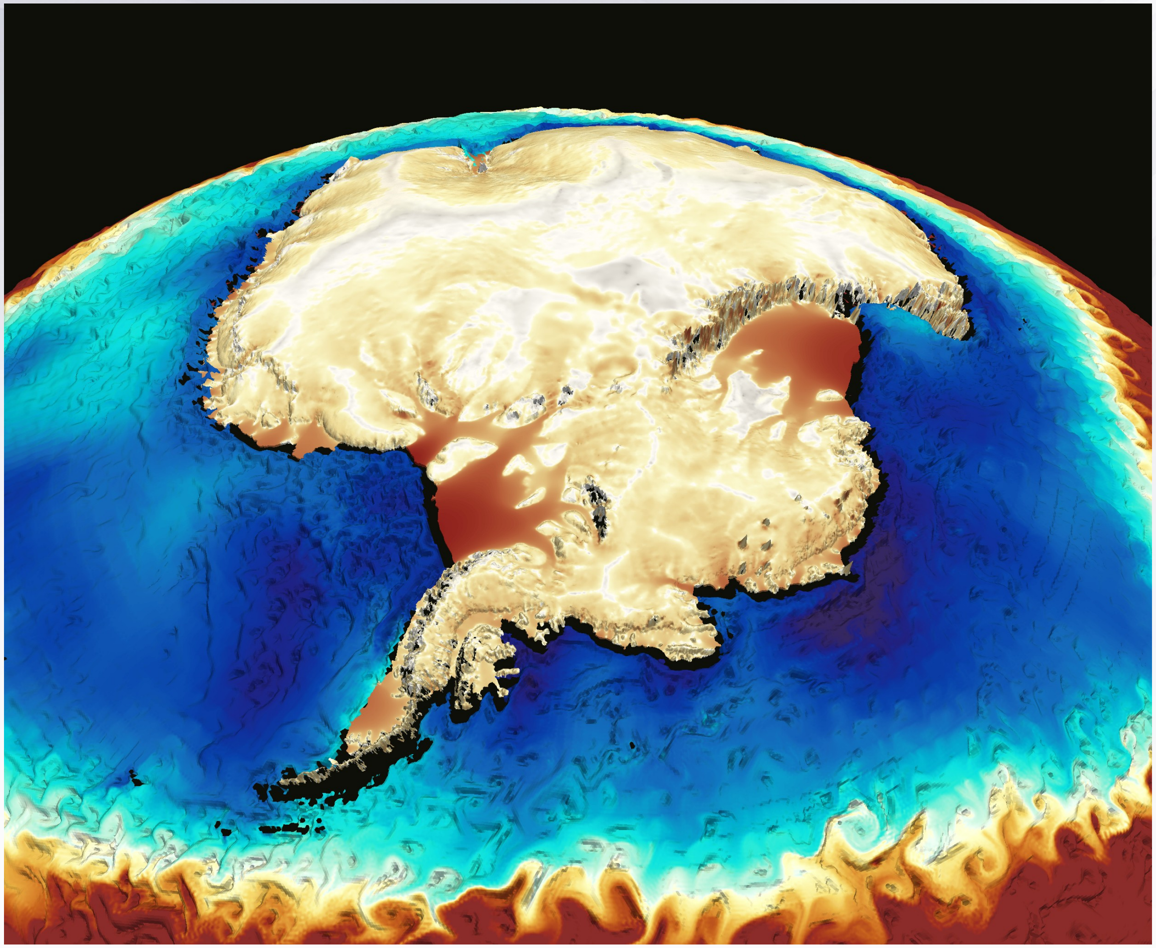
Science Driver: How do rapid changes in cryospheric systems interact with the climate system?

Effort focused on Antarctica.

Motivation is to explore likelihood of rapid sea-level rise due to ocean-land ice interaction.

Target simulations include dynamically-coupled ocean-land ice systems.

Challenges include:
- new models
- spatial scales ~1 km
- ocean/ice initial conditions
- sparse observations
- equilibrium of system



Target Simulation

Time: 1970-2050

Components:

- atmosphere, default ACME v1
- land: default ACME v1
- land-ice: MPAS-LI, 0.5 to 1 km in regions
- ocean: MPAS-Ocean, RRS 5 km (possibly ~1 km in regions)
- sea-ice: MPAS-CICE, same mesh as ocean

Initial conditions:

- land-ice: optimized initial conditions from PISCEES
- ocean: from CORE-II spin-up
- sea-ice: from CORE-II spin-up

A Staged, Hierarchical Simulation

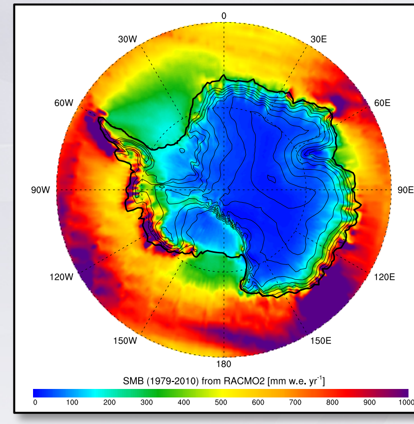
land ice	stand-alone standard test cases	realistic configuration data melt rates	ISOMIP Goldberg ISOMIP+	CORE-II	target coupled simulation
ocean	stand-alone standard test cases	CORE-II data land ice			
sea-ice	stand-alone standard test cases				
atmos land					

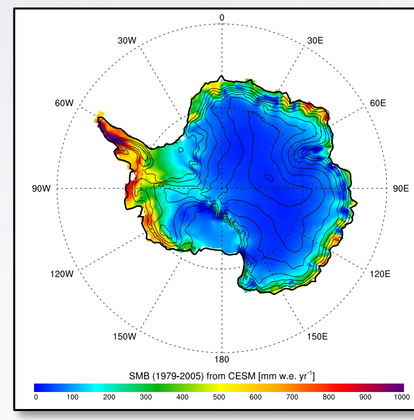
Status and Timeline for Simulation

land ice	stand-alone standard test cases **completed**	realistic configuration data melt rates **April 2015**	ISOMIP Goldberg ISOMIP+ MISOMIP **April 2015**	CORE-II **June 2015**	target coupled simulation **July 2016**
ocean	stand-alone standard test cases **completed**	CORE-II data land ice **starting – data sea ice adding embayment**			
sea-ice	stand-alone standard test cases **starting**				

Land-Ice Experimental Progression

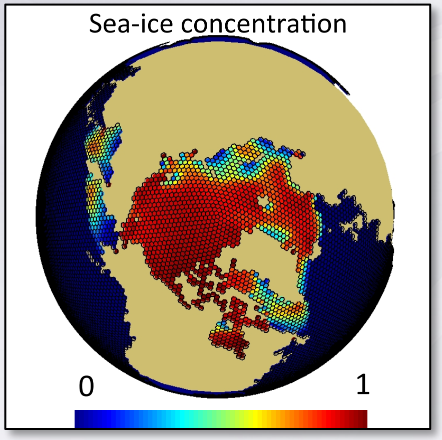
- **Stand-alone ice sheets**
- **Stand-alone land (for mass balances)**
- **Stand-alone ocean and sea ice (coupling tests)**
- **Coupled land ice, ocean, and sea ice**
- **Fully coupled simulations:**
  - Pre-industrial control run
  - Transient forcing simulations through mid-21 C

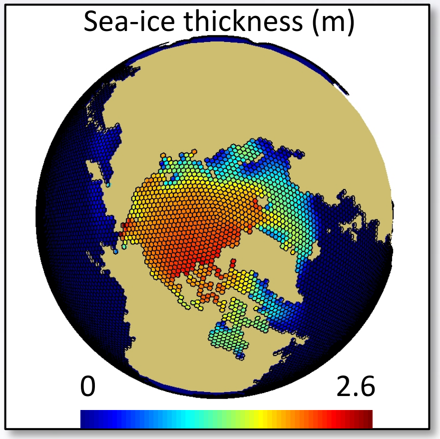




Sea Ice Experimental Progression

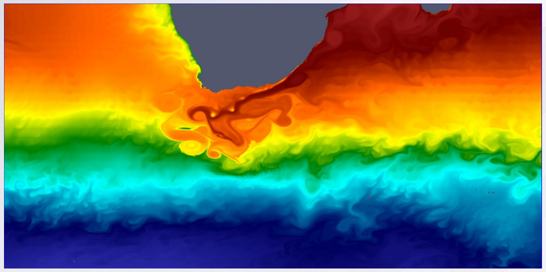
- **MPAS-CICE model development**
- **Column physics for MPAS-CICE**
- **Iceberg model development**
- **Ice-Ocean testing and development**
- **Fully coupled testing and evaluation**
- **Integration into main SLR experiments**

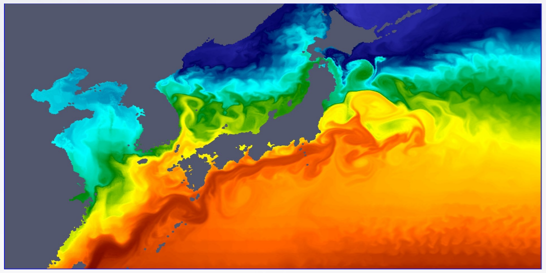




Ocean Experimental Protocol

- **Eddy parameterized Common Ocean Reference Experiment (CORE) simulation**
  - Nearly all of MPAS-Ocean to be exercised.
- **Southern Ocean Enhanced CORE simulation:**
  - Capability to employ variable resolution to be exercised in an eddying Southern Ocean
- **High resolution 15-5 km CORE simulation**
  - Exercise and evaluation of MPAS in configuration similar to that required for main high resolution ACME V1 simulations





QUESTIONS?