Earth System Modelling Activities at NCAR
(Relevant to CRESCENDO# and PRIMAVERA*)

W.G. Large†

National Center for Atmospheric Research (NCAR)
Boulder Colorado

†CRESCENDO International Advisory Board

NCAR is sponsored by the
National Science Foundation

Outline

- CESM : Developments for CESM2# & CESM2+#*
- CMIP6# :
- High Resolution*:
- Ensemble of Large Ensemble (uncertainty) #* :
- Climate Prediction* :
- Society#:

- DART (Data Assimilation, processes) #*:

#CRESCENDO ***PRIMAVERA**

CESM Component Developments

CESM2 ; CESM2+

- CAM -- CLUBB, MG2, MAM4 ; Strato, CSLAM, Subcol
- Ocean-- diurnal, aniso GM ; wave-driving, bgc
- CLM5 – (next)
- CICE5 -- Salinity, Aerosols ; Drag, Snow
- CISM -- Greenland ; Antarctica
- CHEM -- 2nd Organic Aerosols
- SE -- CIME ; DART ; Pause-Resume

Development Goals for CLM5

- Ecosystem Demography model – future biogeochemical core of CLM

  Goal: Functional CLM5(ED) for use in studies of biome boundaries, trait filtering, etc

  Goal: CESM2 coupled runs with CLM(ED) within CMIP6 timeframe; will not be CESM2 default configuration

- Land cover and land use change

  Goal: Global and transient crop capability with irrigation, fertilization, and cultivation of crops (land management) as default for historical and projection runs

  Goal: More realistic land cover change impact on water and energy fluxes

- Carbon cycle

  Goal: Improved 20th century land carbon storage trend; improved comparison to field fertilization expts

- Hydrology

  Goal: Hydrology representation closer to state-of-art hydrology understanding

  Goal: Increasing utility for use in water resource and water-carbon interaction research

- Land-atmosphere chemistry coupling

  Goal: enhanced interactions, fire emissions, ozone damage to plants, CH_4 emissions

- Water and carbon isotopes

Courtesy of Dave Lawrence

CMIP6 and CESM2 targets (ocean at 1^o):

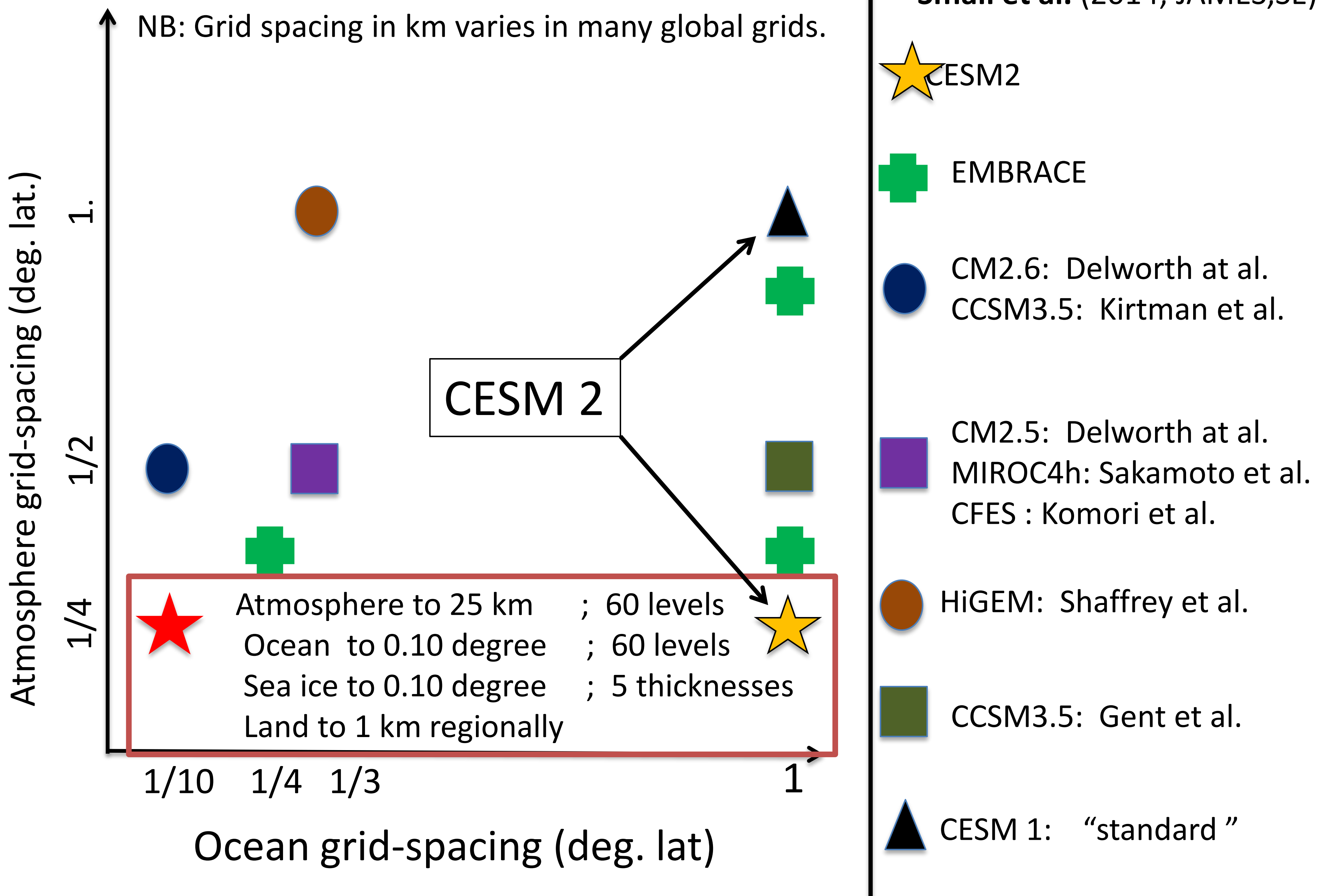
1. physical climate (1^o, low-top) (1x)
2. + biogeochemistry (1^o, CO_2 emission and/or concentration driven, low-top) (1.6x)
3. + atmospheric chemistry + biogeochemistry (1^o, CO_2 emission driven, high-top) (8.5x)
4. physical climate ($1/4^o$ atm, low-top) (150x)

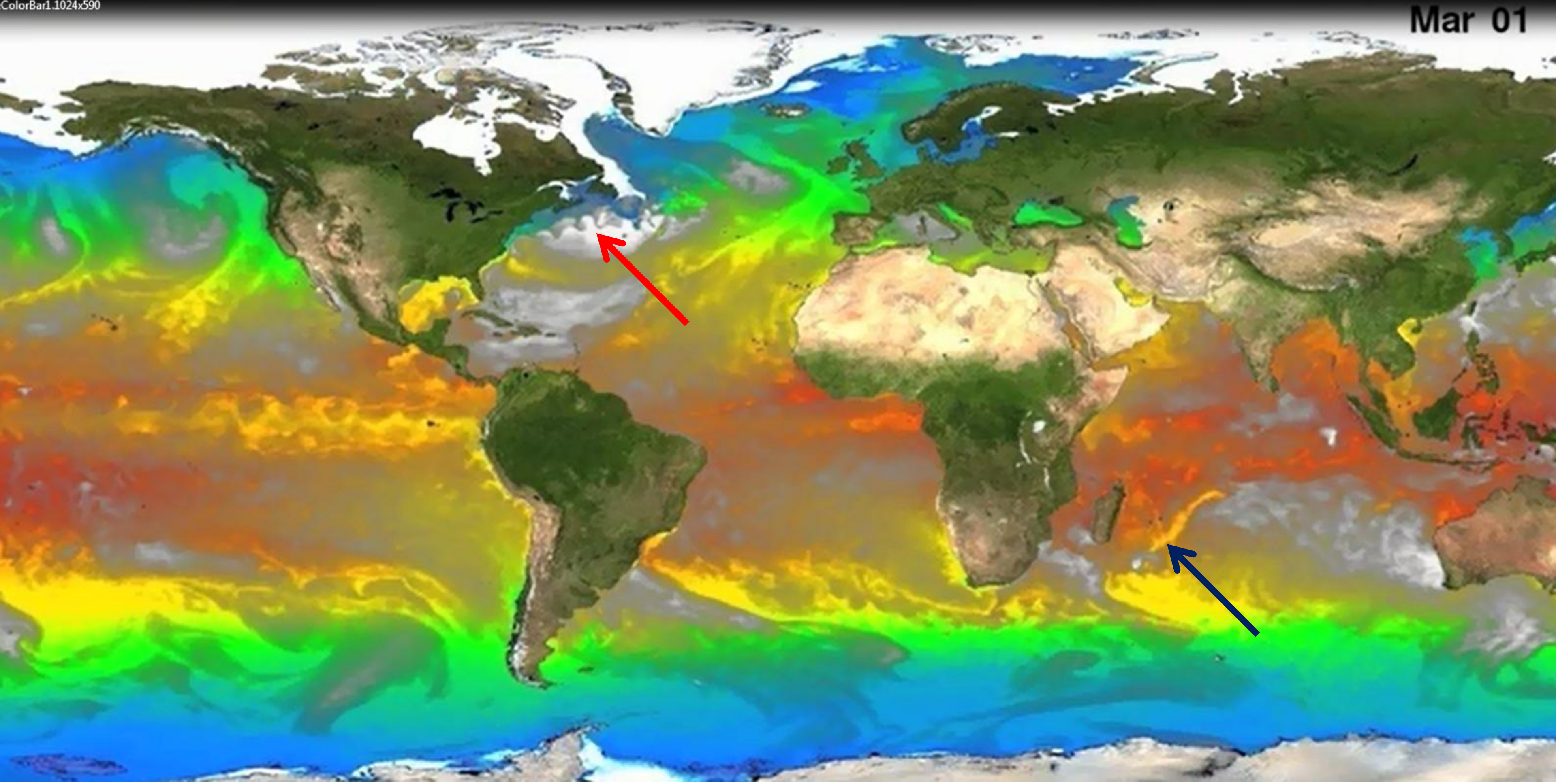
(scaling of computational cost relative to version #1)

CMIP 6: Historical , Deck & MIPs

MIP acronym	MIP name	Interest (H-M-L)	Name of primary sponsor(s)
AerChemMIP	Aerosols and Chemistry Model Intercomparison Project	H	Lamarque/Emmons
C4MIP	Coupled Climate Carbon Cycle Model Intercomparison Project	H	Lindsay
CFMIP	Cloud Feedback Model Intercomparison Project	H	Medeiros/Kay (CU)/Klein (LLNL)
DAMIP	Detection and Attribution Model Intercomparison Project	H	Tebaldi/Arblaster
DCPP	Decadal Climate Prediction Project	H	Danabasoglu/Meehl
GeoMIP	Geoengineering Model Intercomparison Project	H	Tilmes/Mills
GMMIP	Global Monsoons Model Intercomparison Project	M	Fasullo
ISMIP6	Ice Sheet Model Intercomparison Project for CMIP6	H	Lipscomb/Otto-Bliesner
LS3MIP	Land Surface, Snow and Soil Moisture	H	D. Lawrence
LUMIP	Land-Use Model Intercomparison Project	H	D. Lawrence/P. Lawrence
OMIP/OCMIP	Ocean Model Intercomparison Project	H	Danabasoglu/Lindsay
PMIP	Palaeoclimate Modelling Intercomparison Project	H	Otto-Bliesner
RFMIP	Radiative Forcing Model Intercomparison Project	H	Gettelman/Neale
ScenarioMIP	Scenario Model Intercomparison Project	H	Meehl/O'Neill/P. Lawrence
SolarMIP	Solar Model Intercomparison Project	H	Marsh
VolMIP	Volcanic Forcings Model Intercomparison Project	H	Mills/Otto-Bliesner
Data only			
CORDEX	Coordinated Regional Climate Downscaling Experiment	M	Mearns/Gutowski
DynVar	Dynamics and Variability of the Stratosphereâ€Troposphere System	H	Marsh
SIMIP	Sea-Ice Model Intercomparison Project	H	Bailey/Holland/Jahn (CU)/Hunke (LLNL)
VIAAB	VIA Advisory Board for CMIP6	H	Mearns/O'Neill
Not participating			
FAFMIP	Flux-Anomaly-Forced Model Intercomparison Project	M	
HighResMIP	High Resolution Model Intercomparison Project	M	Neale/Bacmeister
Cancelled			
ENSOMIP	ENSO Model Intercomparison Project	H	Deser
PDRMIP	Precipitation Driver and Response Model Intercomparison Project	M	Lamarque
GDDEX	Global Dynamical Downscaling Experiment		

High-res global scales



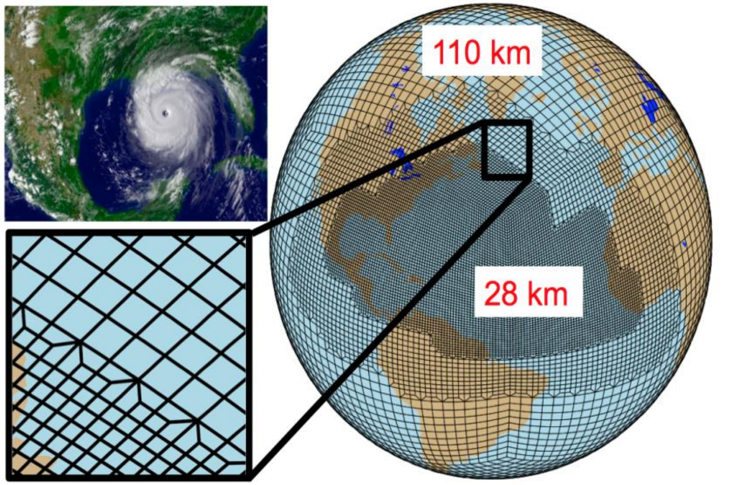


High-resolution CESM simulation run on Yellowstone. This featured CAM-5 spectral element at roughly 0.25 deg grid spacing, and POP2 on a nominal 0.1 deg grid. Funding from DOE (SCIDAC) and NSF. Pis: Small, Bryan, Tribbia, Dennis, Saravanan, Kwon, Schneider. Image by CISL VIS Lab.

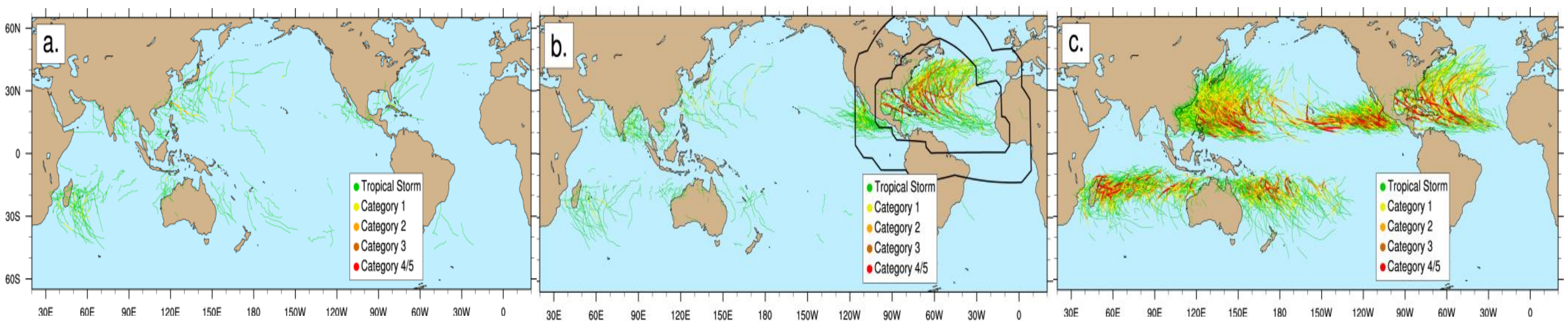
A snapshot showing latent heat flux (grey scale, largest values shown in bright white are over 500Wm^{-2}) overlaid on sea surface temperature (color). Warmest ocean temperatures are red, followed by yellow, green and blue. Note the influence of Gulf Stream meanders on a cold-air outbreak in the North-West Atlantic (red arrow) and a cold temperature wake beneath a Tropical Cyclone in the Indian Ocean (blue arrow), both features are not well simulated by standard resolution climate models.

Variable resolution

- CAM5-SE is configured with a variable-resolution grid that ranges from 111-28 km. The 28 km grid zooms into the Atlantic basin to focus on hurricanes.
- Factor of 6 quicker than uniform 28 km simulation. Identical physics time step is used.



Variable-resolution grid of the model CAM5-SE that bridges the grid spacings 110-28 km in a single AMIP simulation. \



1-degree everywhere

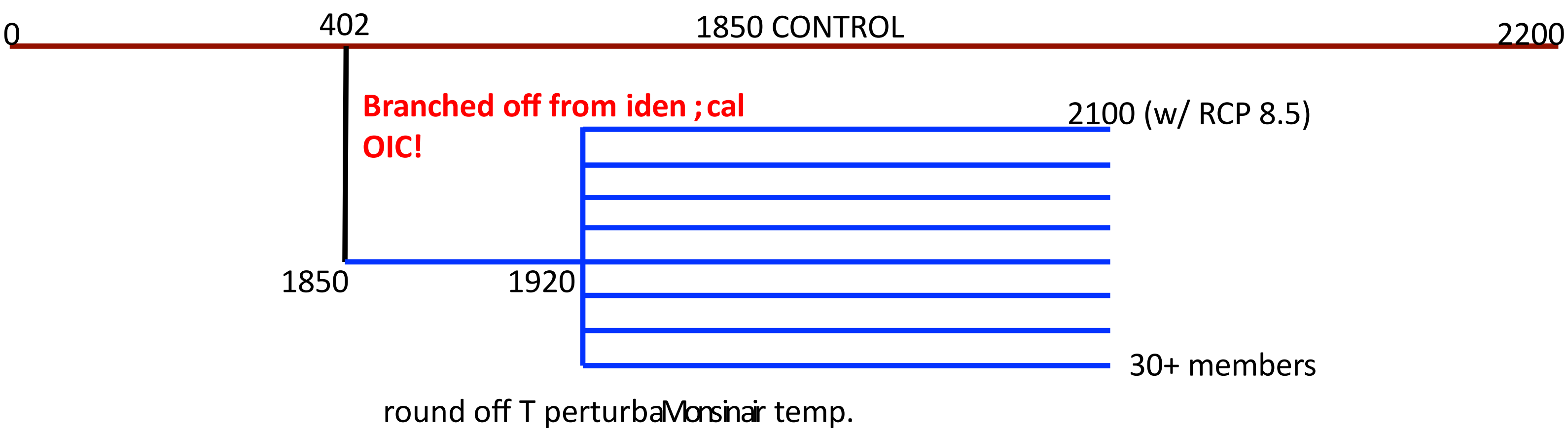
1-degree to ¼-degree

Observations

Zarzycki, C. M. and C. Jablonowski (2014) J. Adv. Model. Earth Syst.

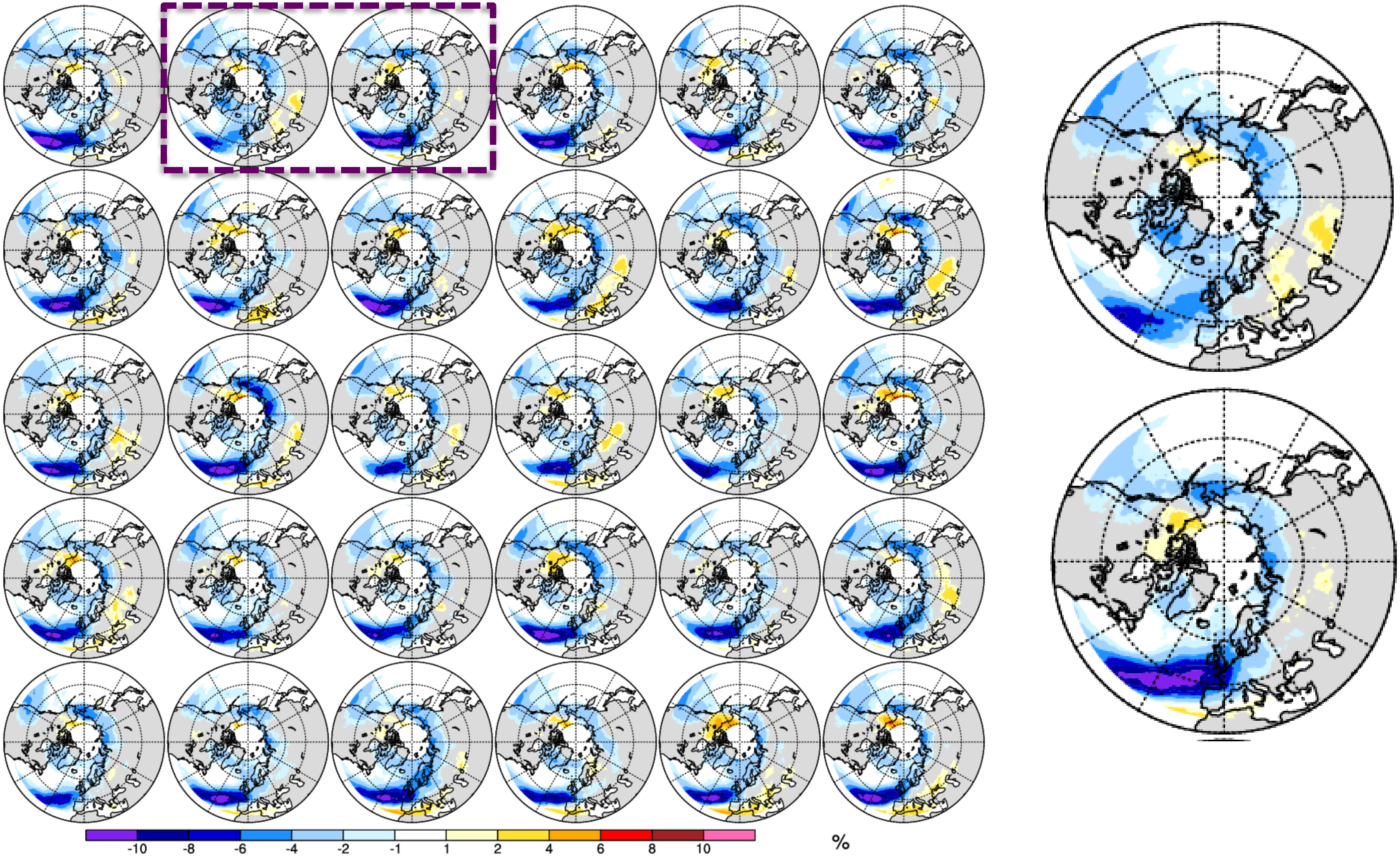
CESM-Large Ensemble (LE)

- A CESM community project
  - 30+ ensemble members for historical (1920–2005) and RCP8.5 (2006–2100) simulations
- To investigate climate change in the presence of internal climate variability (Kay et al. 2015, BAMS)
  - **Key issue: how to sample internal climate variability?**

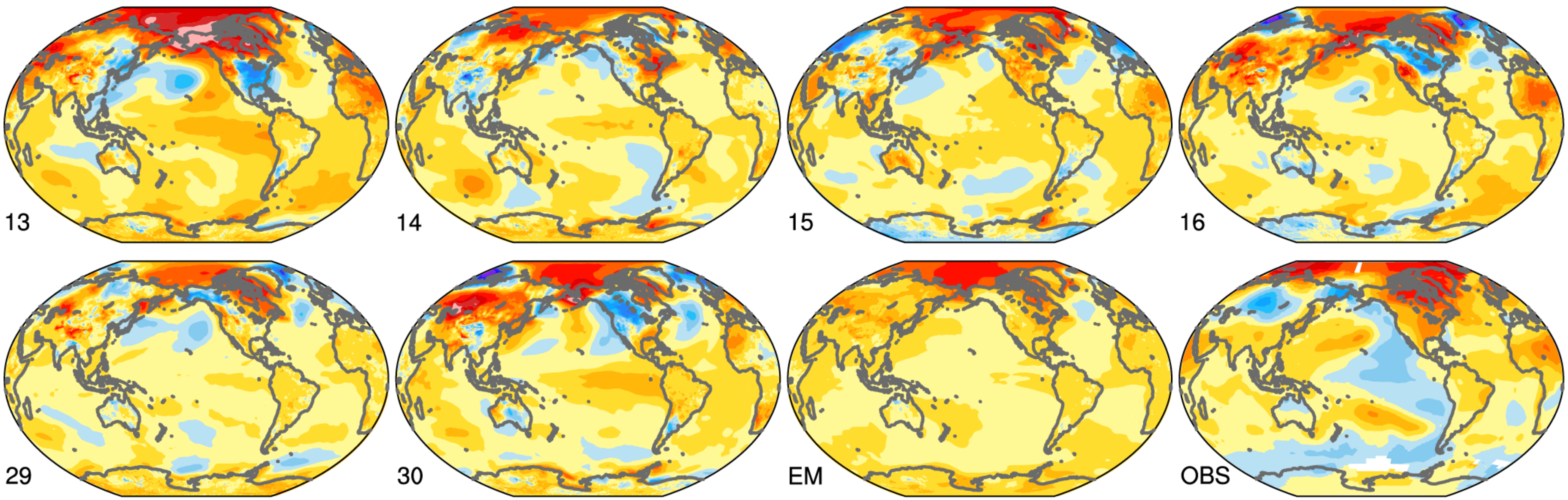


CESM1 Large-Ensemble Future Blocking

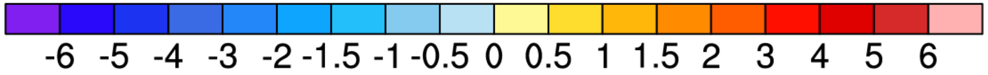
DJF – RCP8.5: 2081-2100 minus 1850 control



30 Ensemble Member versus Mean (EM)

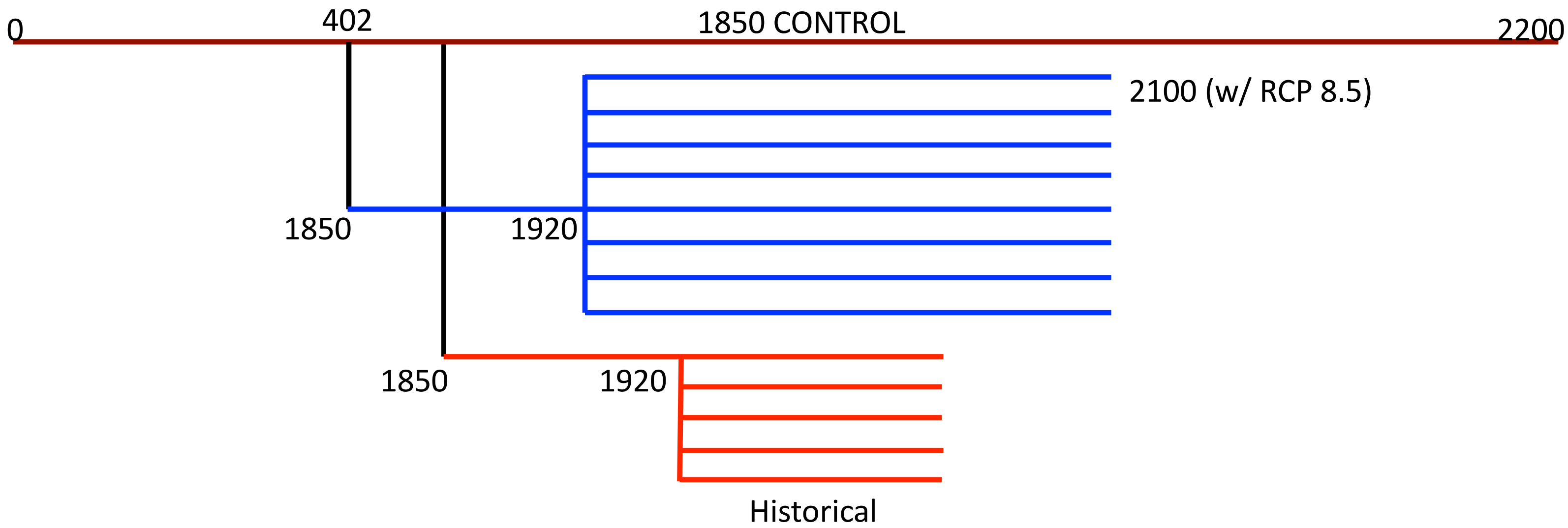


1979-2012 DJF surface air temperature trends (K/34 years)



William Large, CGD Laboratory Director
Tel: 303.497.1364 | Email: wily@ucar.edu

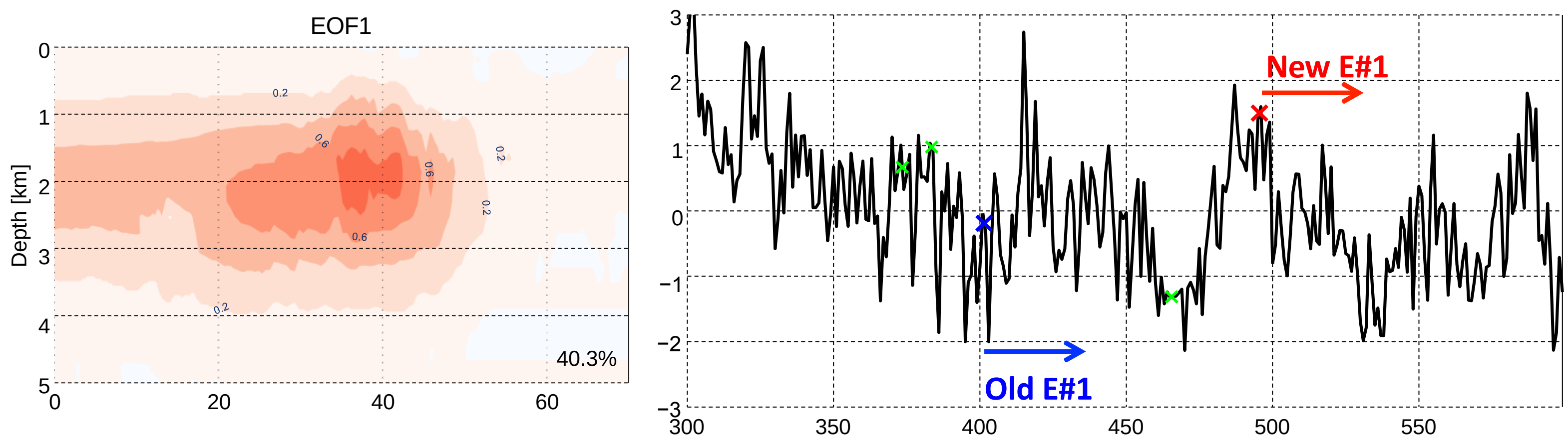
Ensemble of Ensembles: Design

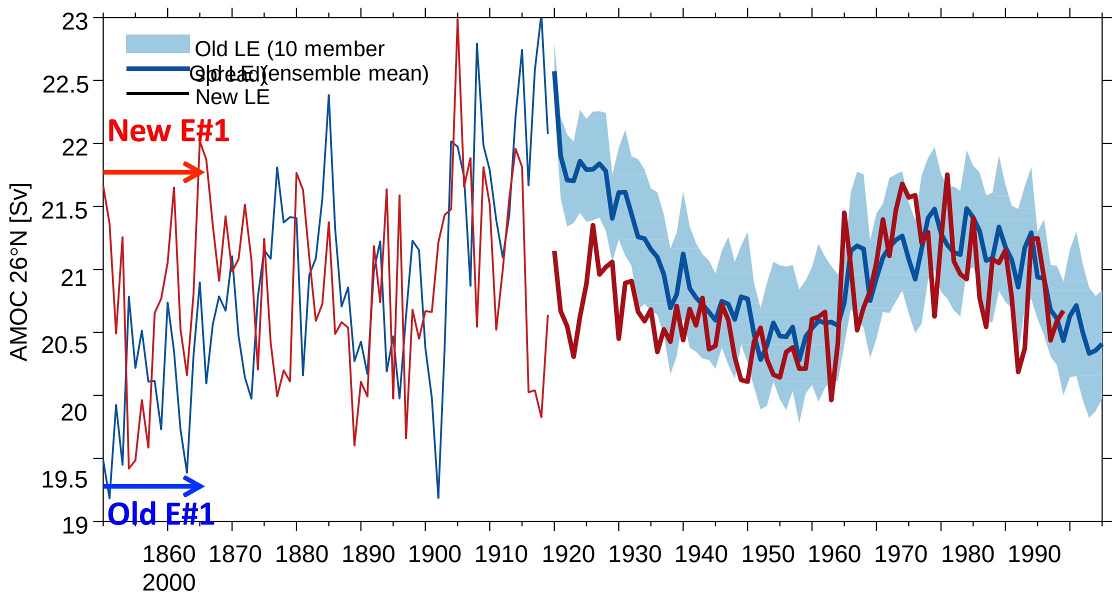


- Start from different ICs from 1850 control (496) for all components (First ensemble member)
- Generate ensemble members in 1920 as for the existing CESM-LE
- 10 members are integrated to 1999 (historic simulations only)
- Otherwise, followed the CESM-LE protocol (https://www2.cesm.ucar.edu/models/experiments/LENS/instructions)

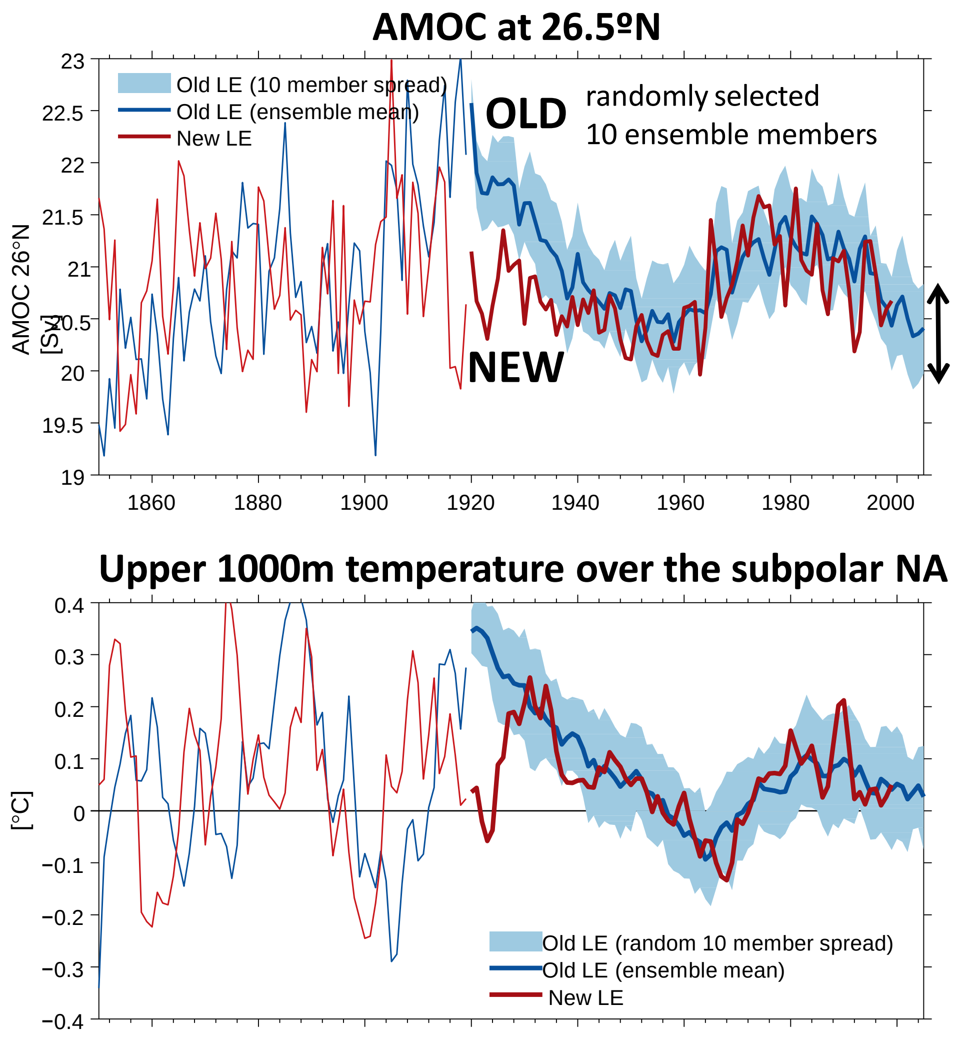
Ensemble of Ensembles: Results

AMOC EOF1 in 1850 CTRL (300–599)



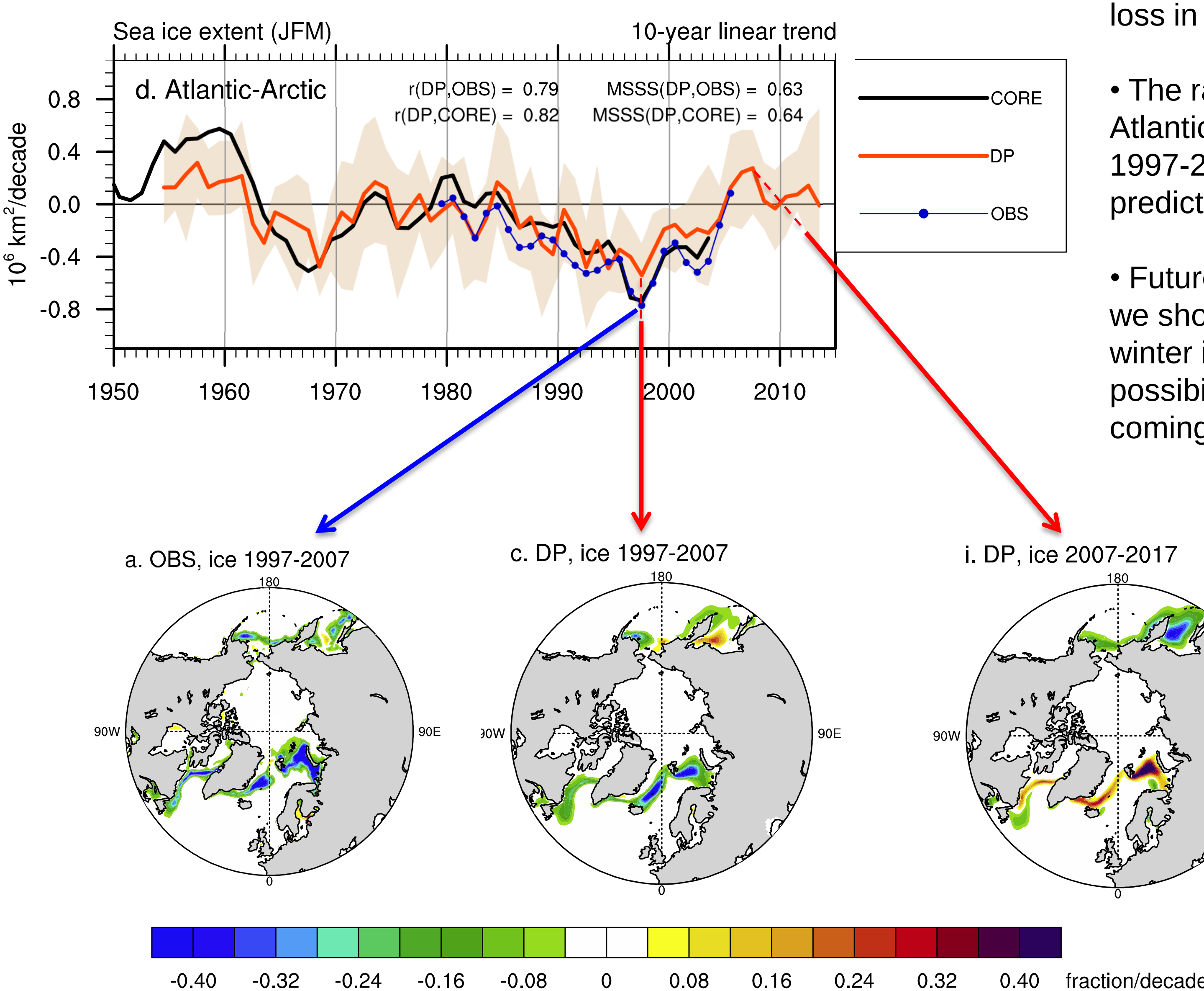


AMOC



*** Anomalies are with respect to the 1951–1980 mean**

Predicted slow-down in the rate of Atlantic (90 E to 90 W) sea ice loss

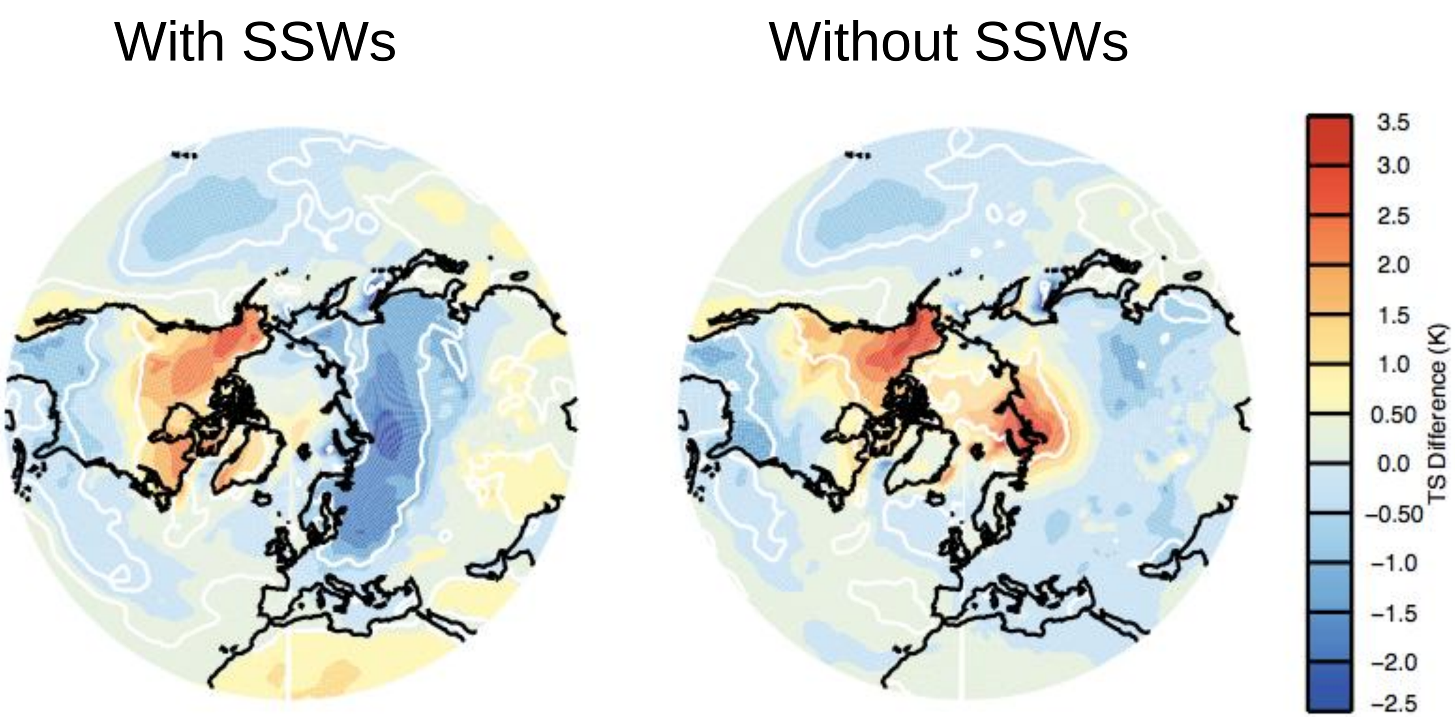


- CESM1 decadal prediction simulations can skillfully predict decadal changes in the rate of Arctic winter sea ice loss in the Atlantic sector.
- The rapid retreat of the Atlantic ice edge between 1997-2007 could have been predicted.
- Future forecasts suggest that we should expect a hiatus in winter ice loss, with a possibility of decadal growth in coming years.

Yeager et al., 2015, GRL

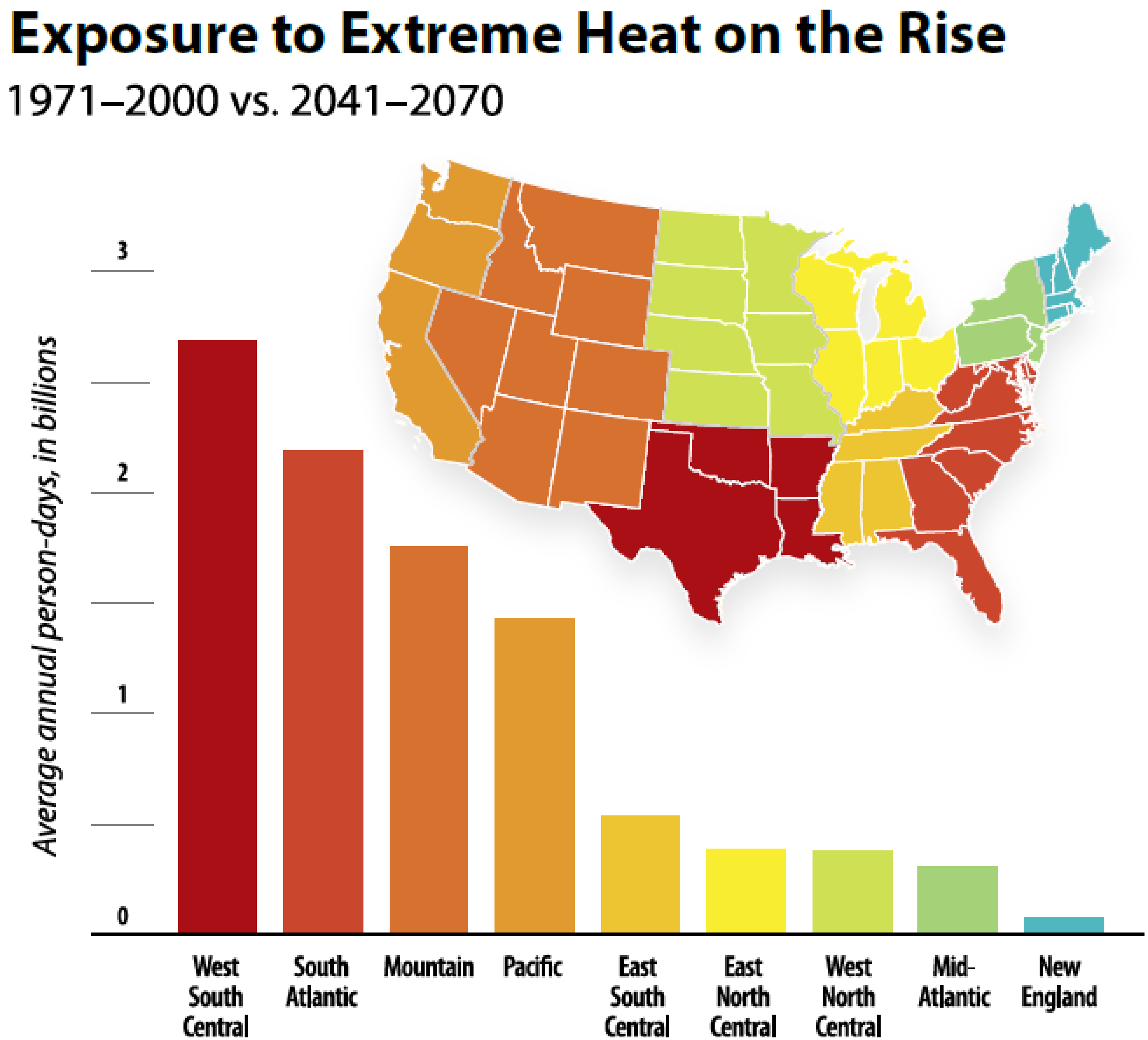
Stratosphere Impacts on El Nino Response

Jan - Mar El Nino Anomaly



Richter, Sun, Deser, Bacmeister (2015), GRL, in preparation

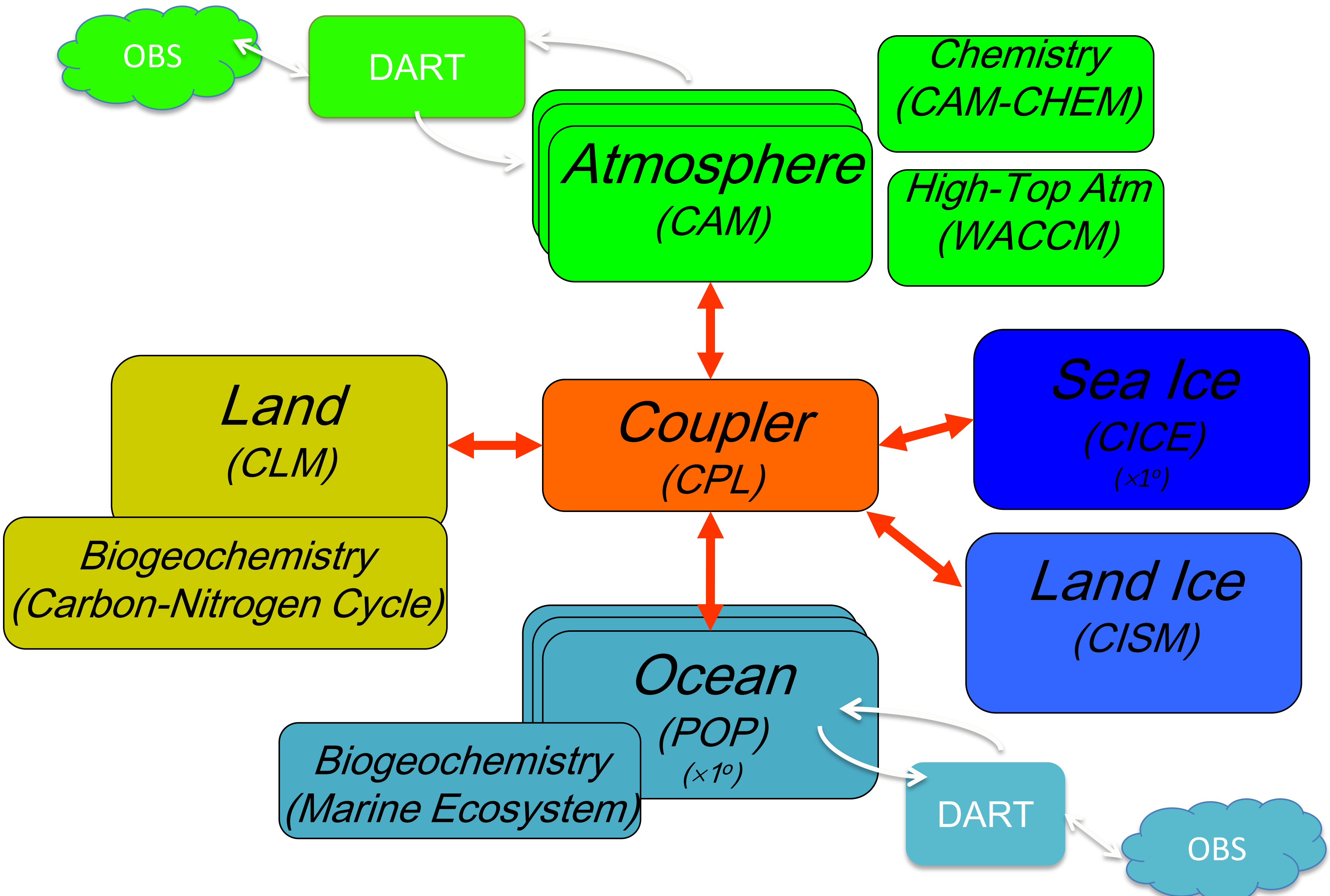
Societal Impacts of Society

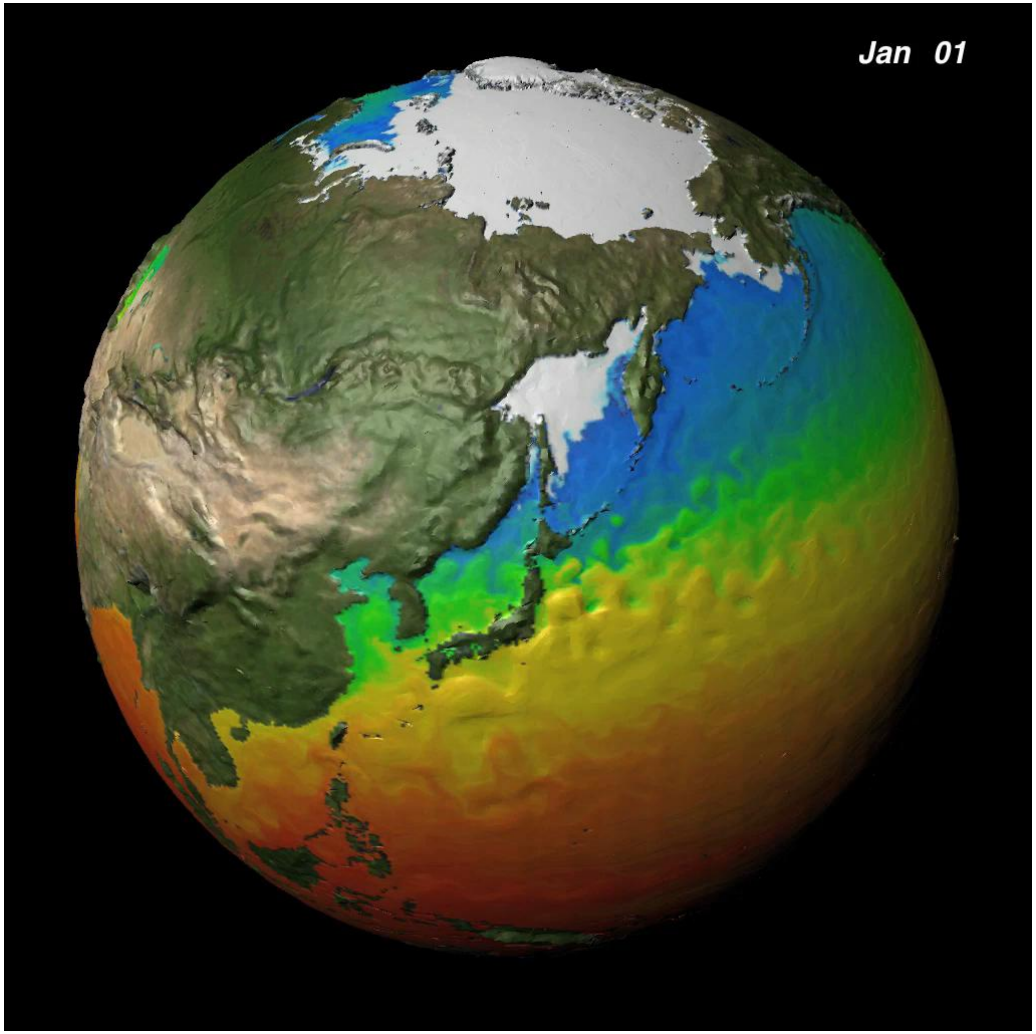


Jones, O'Neill, McDaniel, McGinnis, Mearns, Tebaldi. 2015. Nature Climate Change.

That’s All Folks !!

Community Earth System Model





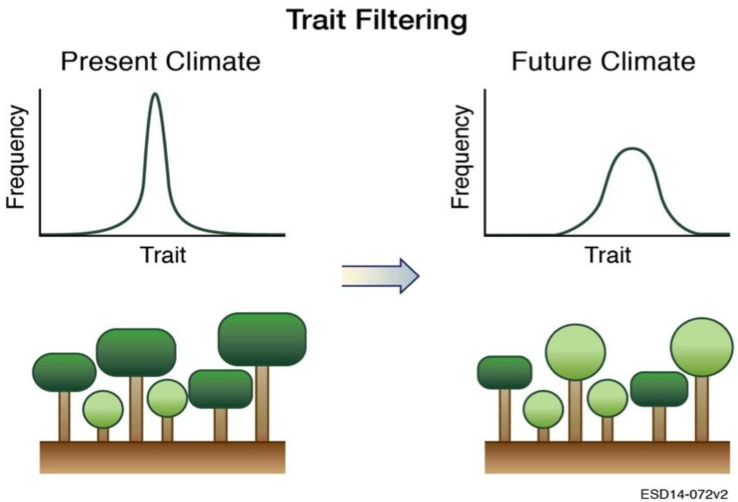
- Yellowstone-NWSC Accelerated Science Discovery Run
- Project support from DOE-BER and NSF

Highest Coupled Resolution

- Fully coupled CESM1-CAM5-SE simulations with a 25km atmosphere and 0.1^{o} ocean
- 60 years in length
- Simulation output will be available soon through the Earth System Grid
- Please contact Justin Small (jsmall@ucar.edu) if you are interested in accessing the output

Courtesy of Justin Small, Tim Scheitlin

CLM with Ecosystem Demography model

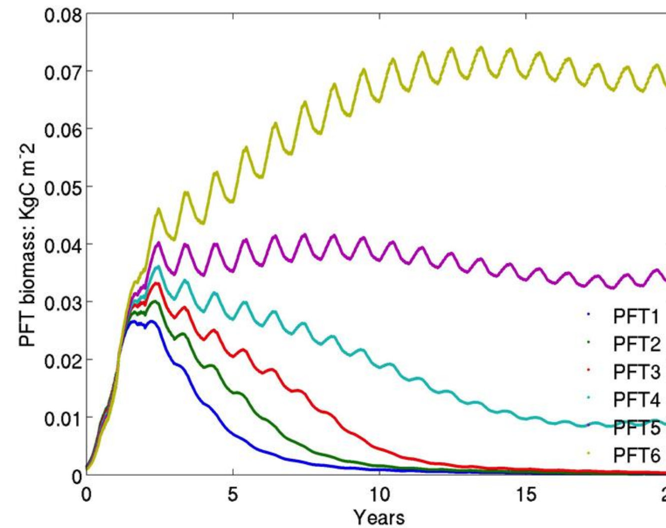


Direct competition for light

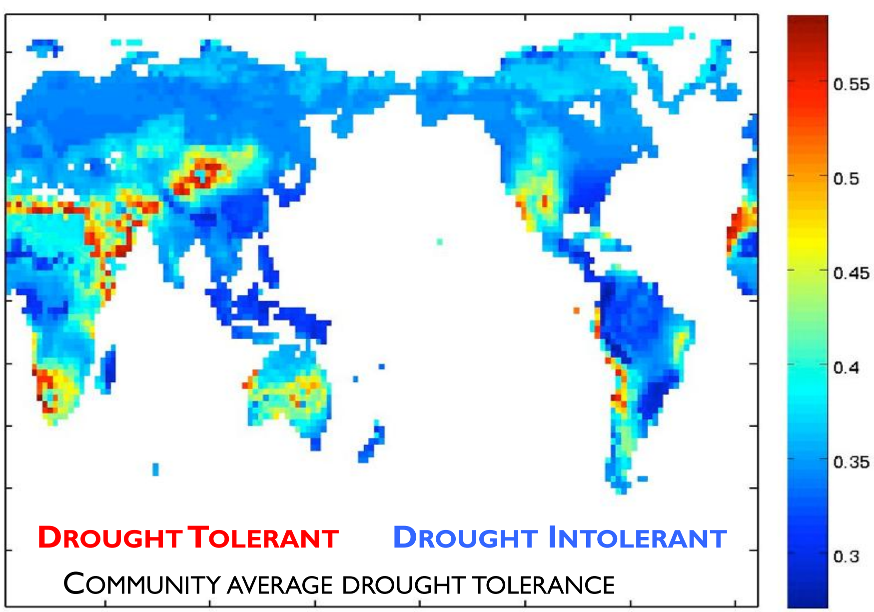
+

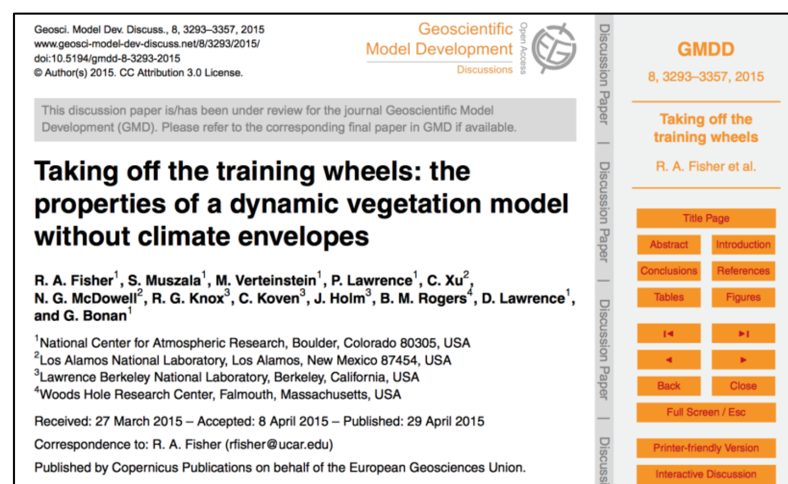
Enhanced representation of diversity

=



Emergent community structure adapted to past climate





Geosci. Model Dev. Discuss., 8, 3293–3357, 2015
www.geosci-model-dev-discuss.net/8/3293/2015/
doi:10.5194/gmdd-8-3293-2015
© Author(s) 2015. CC Attribution 3.0 License.

Geoscientific Model Development Discussions

This discussion paper is/has been under review for the journal Geoscientific Model Development (GMD). Please refer to the corresponding final paper in GMD if available.

Taking off the training wheels: the properties of a dynamic vegetation model without climate envelopes

R. A. Fisher[1], S. Muszala[1], M. Verteinstein[1], P. Lawrence[1], C. Xu[2], N. G. McDowell[2], R. G. Knox[3], C. Koven[3], J. Holm[3], B. M. Rogers[4], D. Lawrence[1], and G. Bonan[1]

[1]National Center for Atmospheric Research, Boulder, Colorado 80305, USA
[2]Los Alamos National Laboratory, Los Alamos, New Mexico 87454, USA
[3]Lawrence Berkeley National Laboratory, Berkeley, California, USA
[4]Woods Hole Research Center, Falmouth, Massachusetts, USA

Received: 27 March 2015 – Accepted: 8 April 2015 – Published: 29 April 2015

Correspondence to: R. A. Fisher (rfisher@ucar.edu)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Discussion Paper | Discussion Paper | Discussion Paper | Discussion

GMDD
8, 3293–3357, 2015

Taking off the training wheels

R. A. Fisher et al.

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

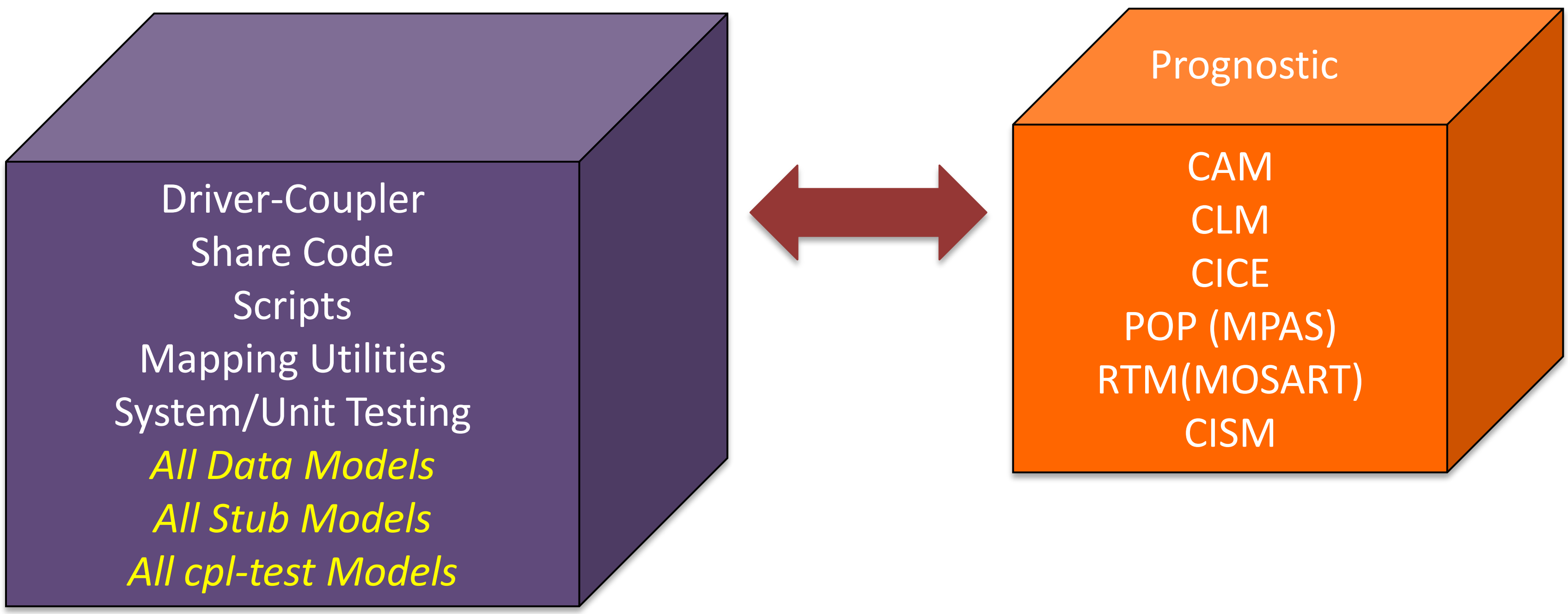
Common Infrastructure for Modeling the Earth : CIME

A New Paradigm – all infrastructure is ***Open Source***

IP still in place for prognostic components

All Infrastructure
PUBLIC Open Source Github
Repository -- deCESMized

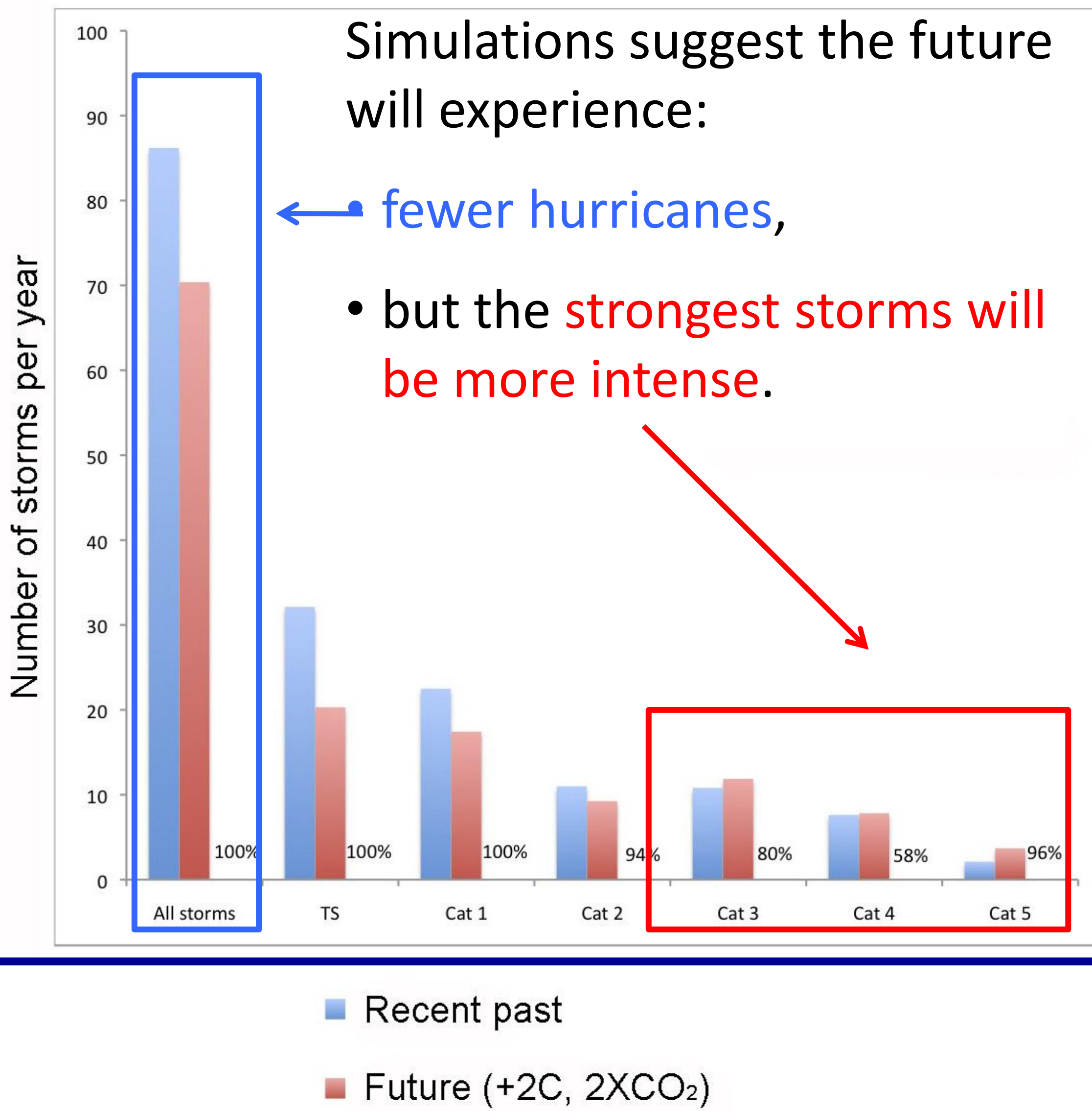
Only Prognostic Model
Components Stay in
Restricted Subversion Repository



Changes in Tropical Cyclones

Simulations suggest the future will experience:

- fewer hurricanes,
- but the strongest storms will be more intense.



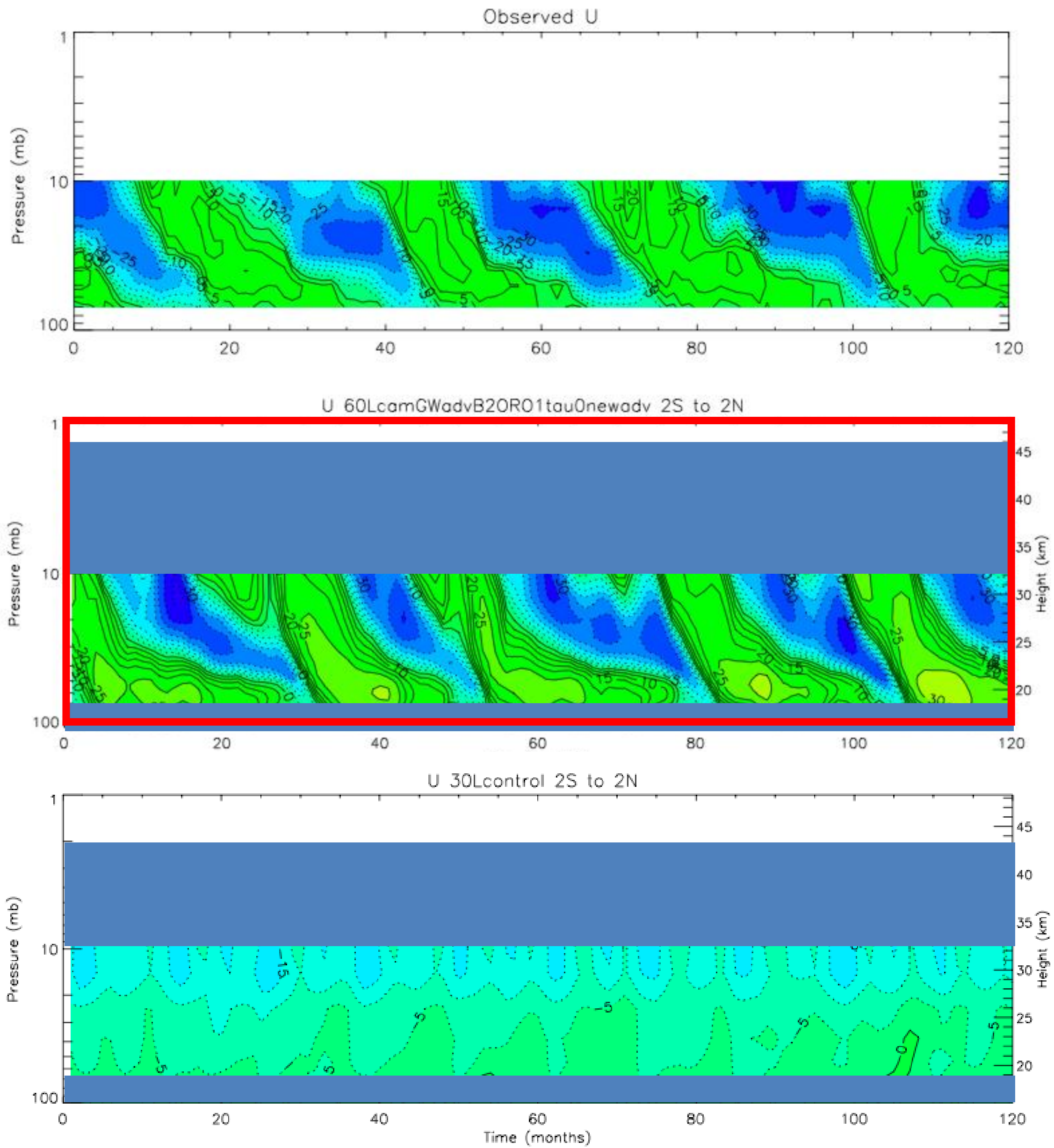
High resolution (0.25°) atmosphere simulations produce an excellent global hurricane climatology

Courtesy of
Michael Wehner, LBNL

OBS

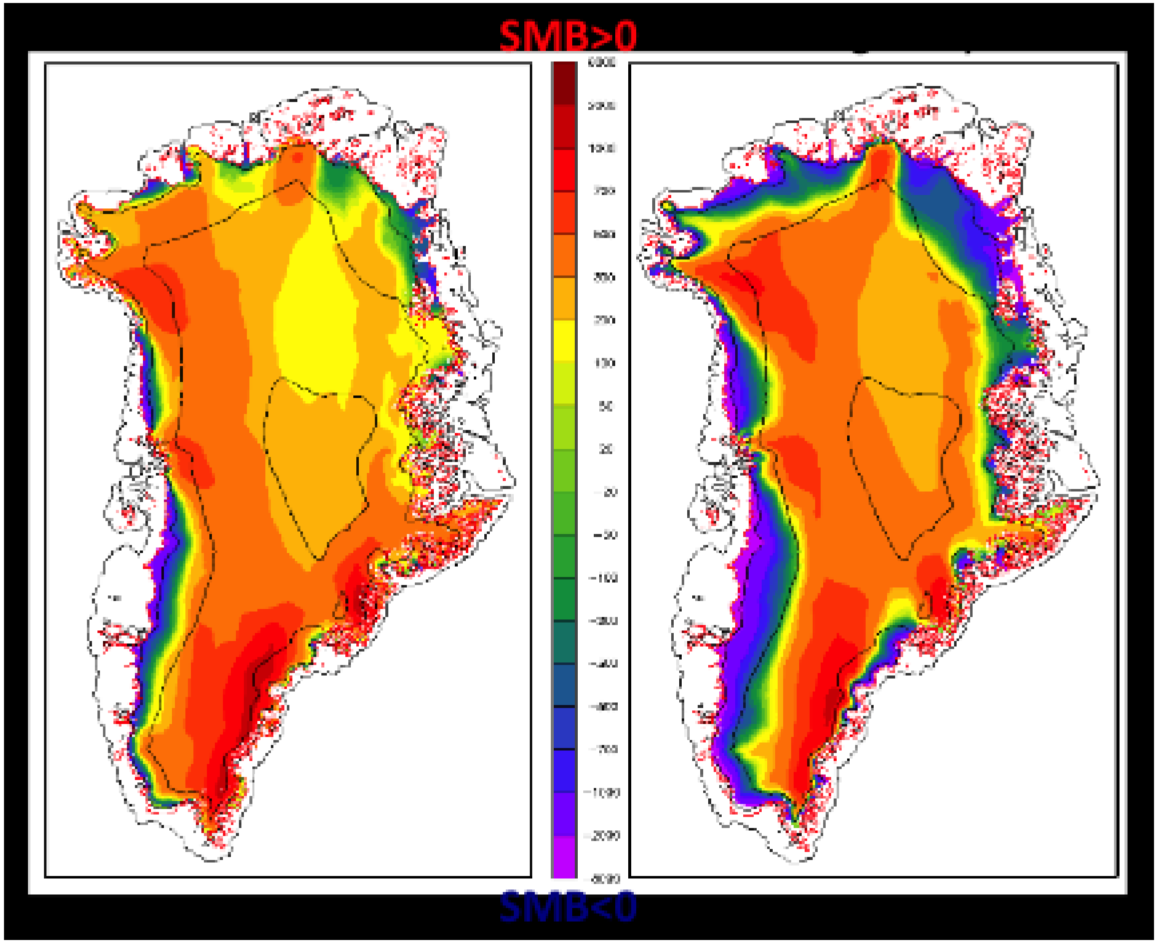
Best 60L CAM5 to date

30L control



Sea level: CESM-CISM

Average Net Surface Mass Budget



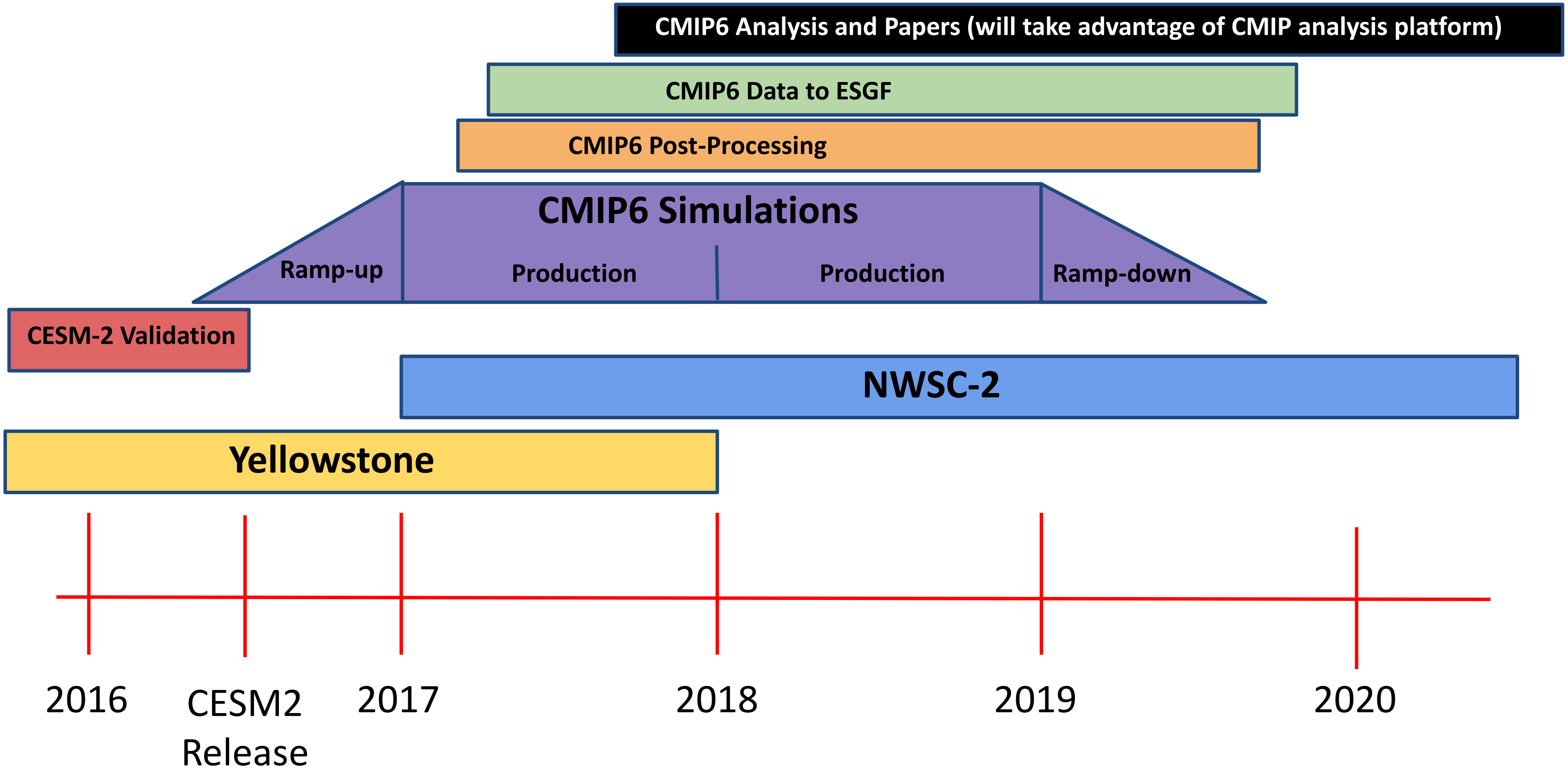
(Courtesy of Miren Vizcaino)

Present-day budgets compare well to RACMO

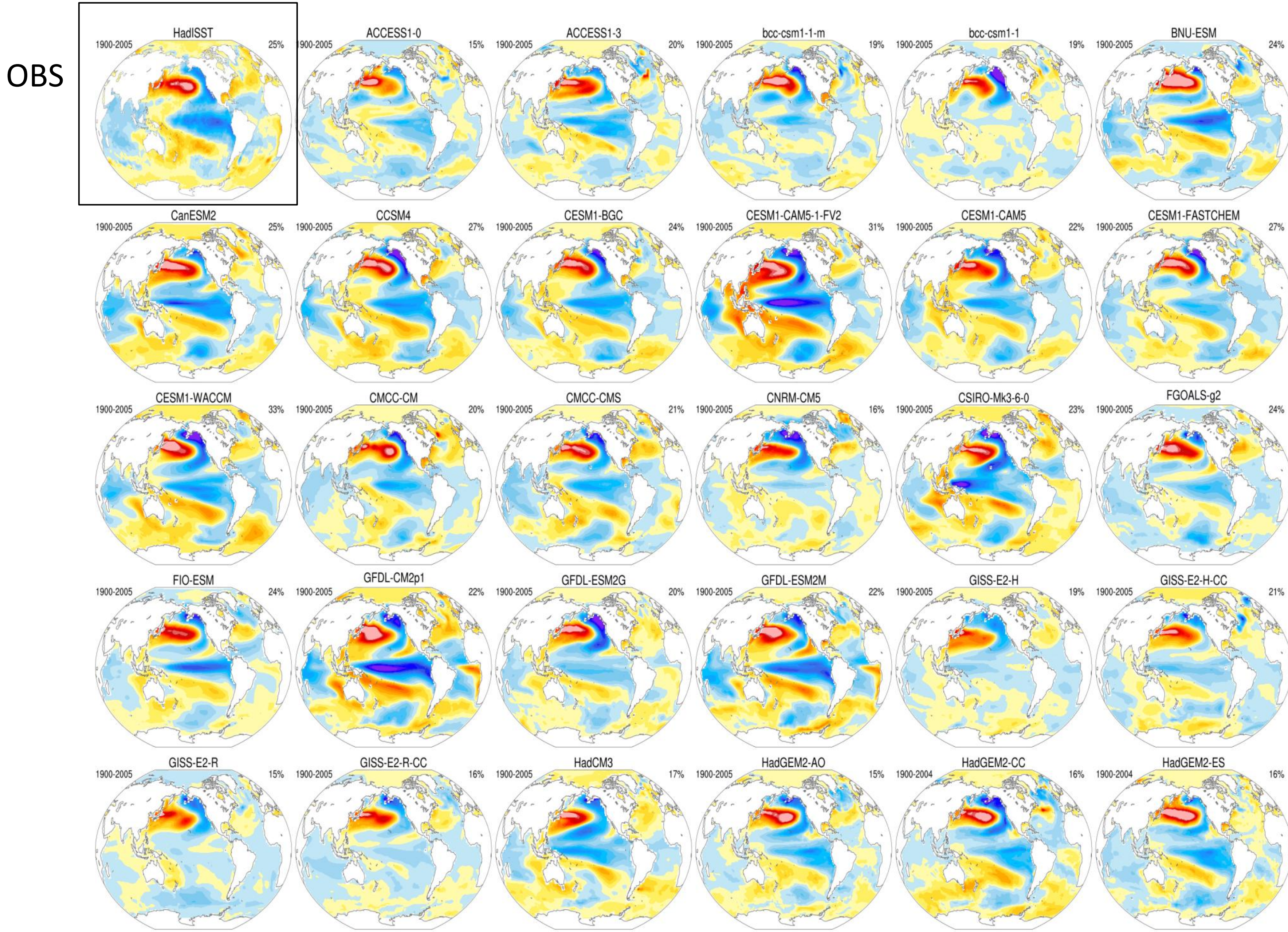
In 21st Century:

- Higher precipitation
- Larger melt
- Ablation area increases from 9% to 28% of ice sheet
- Equilibrium line ~500 m higher
- SMB increases over 2000m

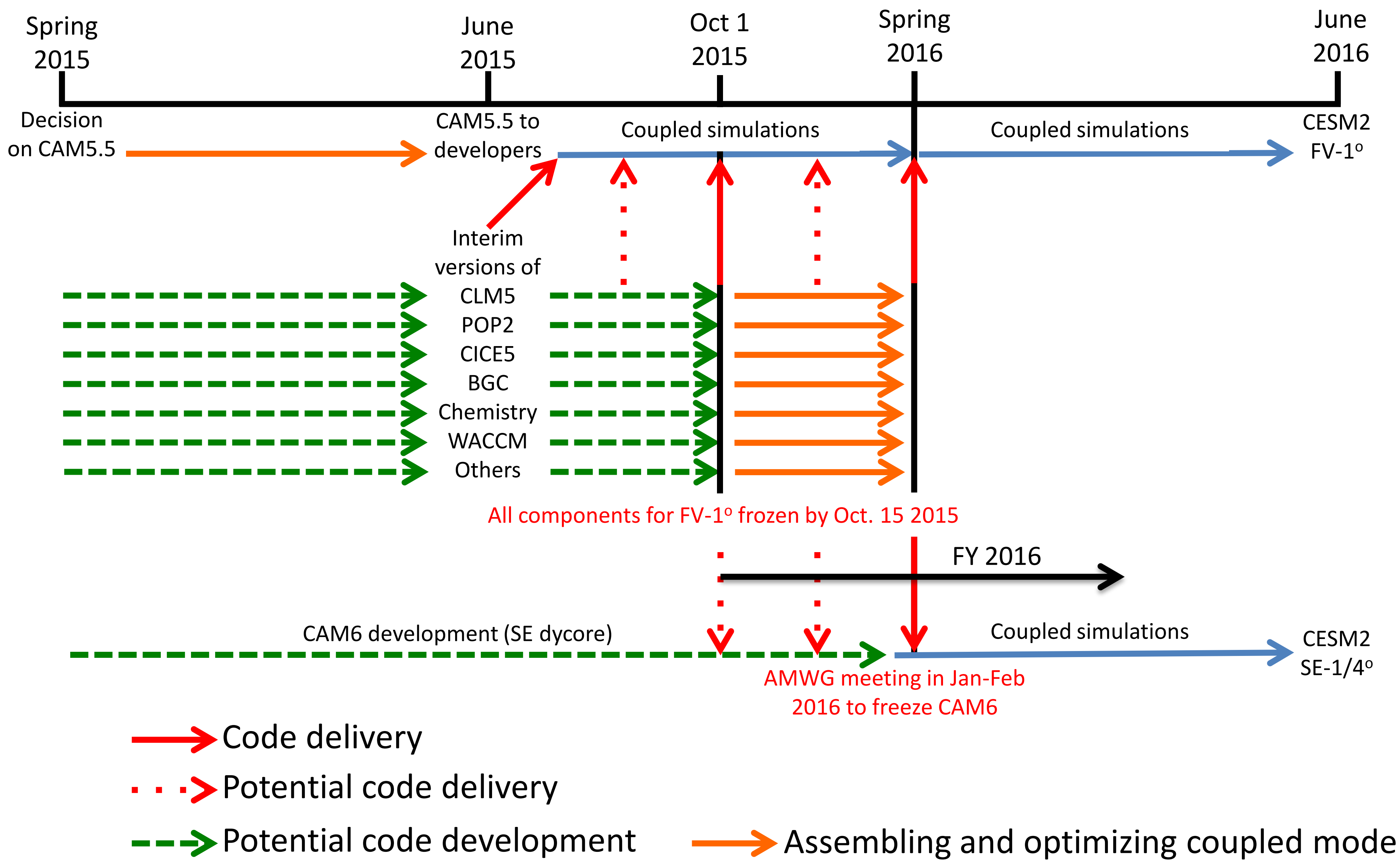
NCAR CMIP6 Planning



Pacific Decadal Oscillation CMIP5



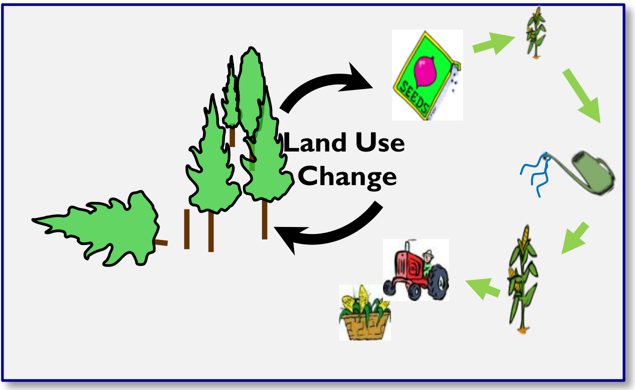
Timeline for CESM2



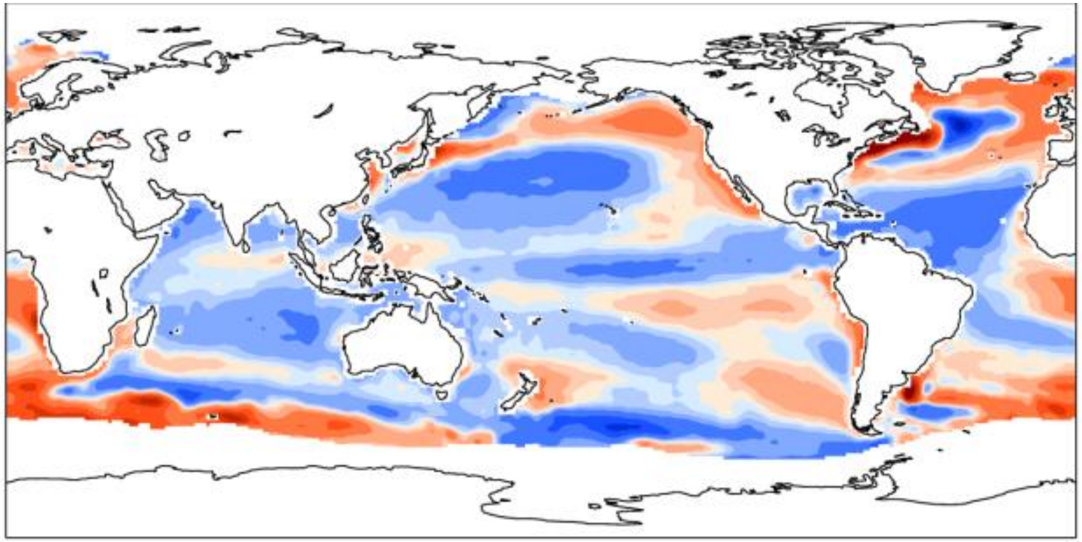
CLM versions and configurations

CLM5 to be released June 2016 (CESM2; CMIP6)

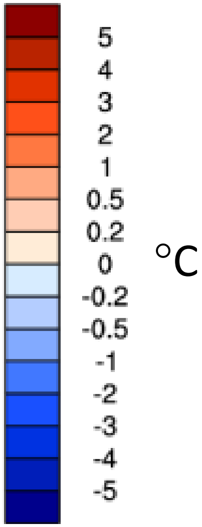
- global crop model with irrigation and fertilization (8 crop types)
- hydrology: dry surface layer, variable bedrock depth, 8.5m soil (50m ground), revised canopy interception
- snow: canopy snow updates, wind effects, firn model (12 layers)
- Model for Scale-Adaptive River Transport: hillslope → tributary → main channel
- nitrogen – flexible leaf C:N ratio, leaf N optimization, C cost for N
- ozone damage to plants
- fire trace gas and aerosol emissions
- plant hydraulics and prognostic roots
- dynamic landunits
- carbon and (water) isotope enabled
- Ecosystem Demography model



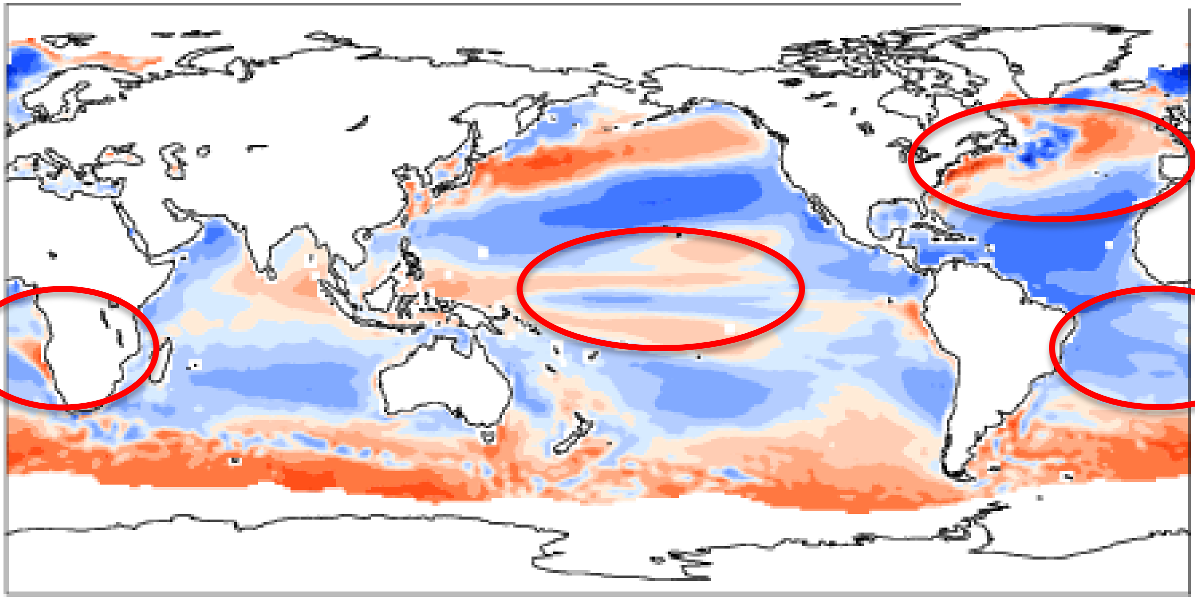
Sea Surface Temperature bias



CESM std. res.
1850 control (CAM5-FV) Re
HadSST pre-indust



CESM High-res
Re HadSST Present

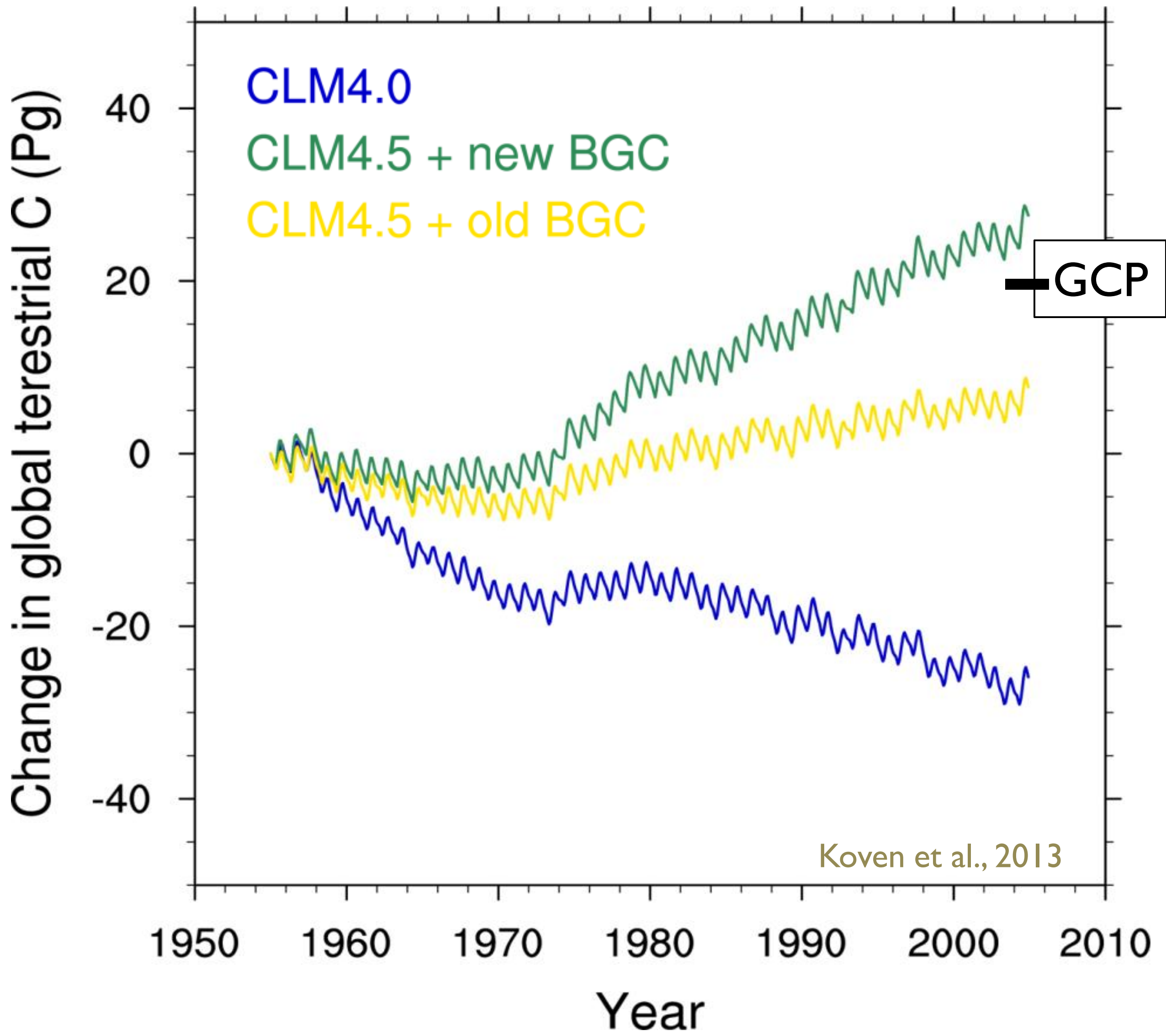


Comparison of ASD SST bias against standard resolution CESM 1850 run.
Annual Mean.

Land Model Developments (CLM4.5)

Accumulated carbon

- - land cover change,
- + CO_2 fertilization
- +/- regional climate-carbon feedbacks.

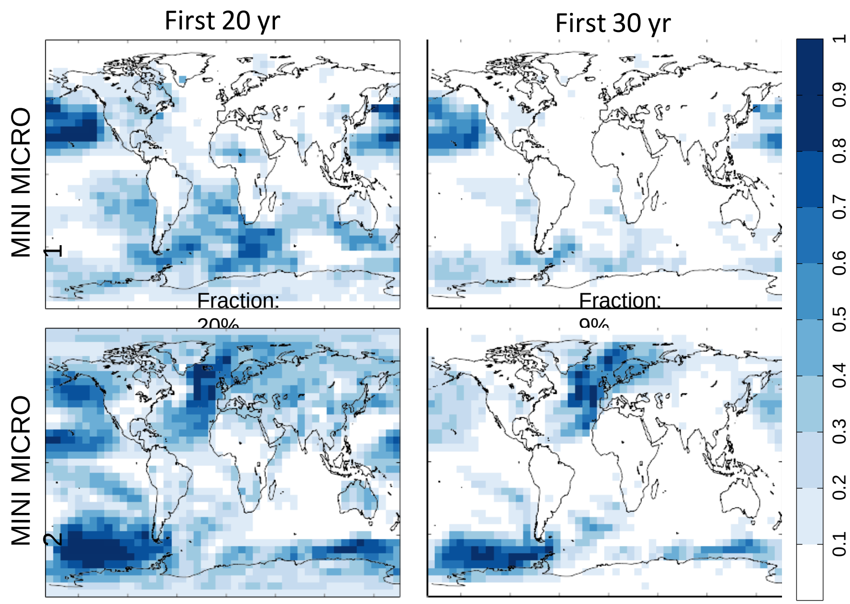


Reduce N-limitation on CO_2 fertilization.

Courtesy of Dave Lawrence

Motivation & Goal

Probability of a cooling trend



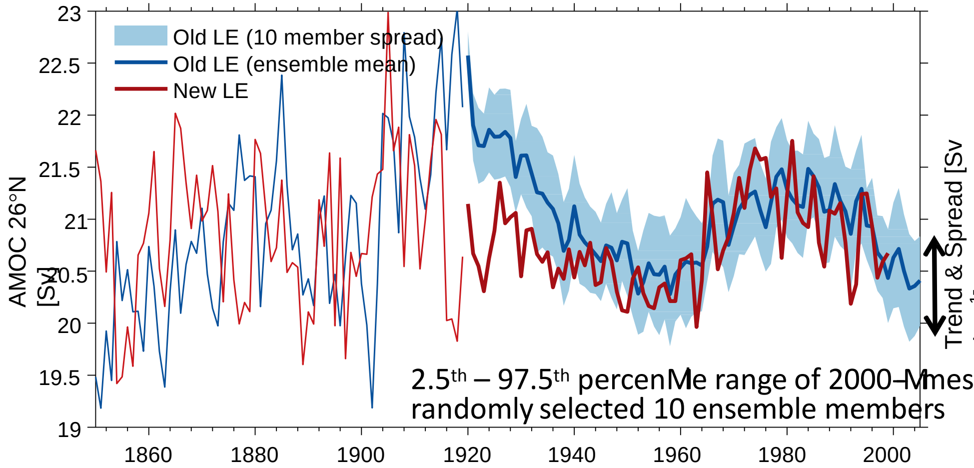
* Each 1% CO_2 increase simulation started with different ocean initial conditions and 50 ensemble members are generated by perturbing SST

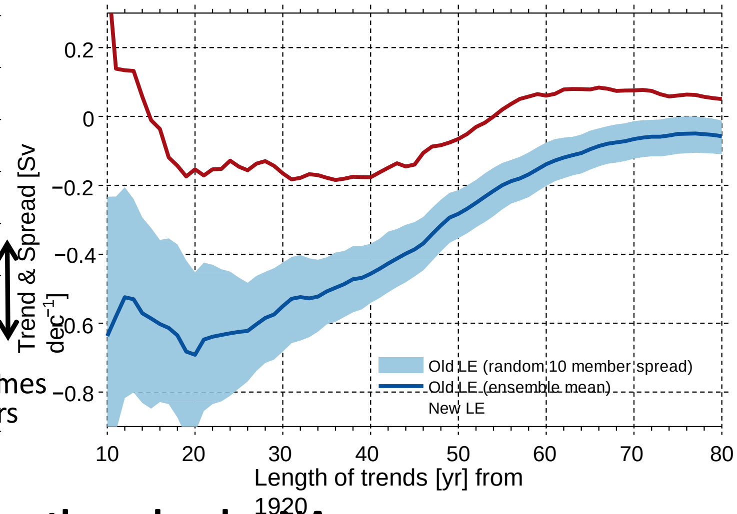
Hawkins et al., submitted to Clim. Dyn.

- The ocean has a relatively long "memory" (~decadal time scales)
- Spread and uncertainty of internal variability are expected to be different when considering different ocean initial conditions (ICs)
- **To sample internal variability arising due to different ocean initial states!**

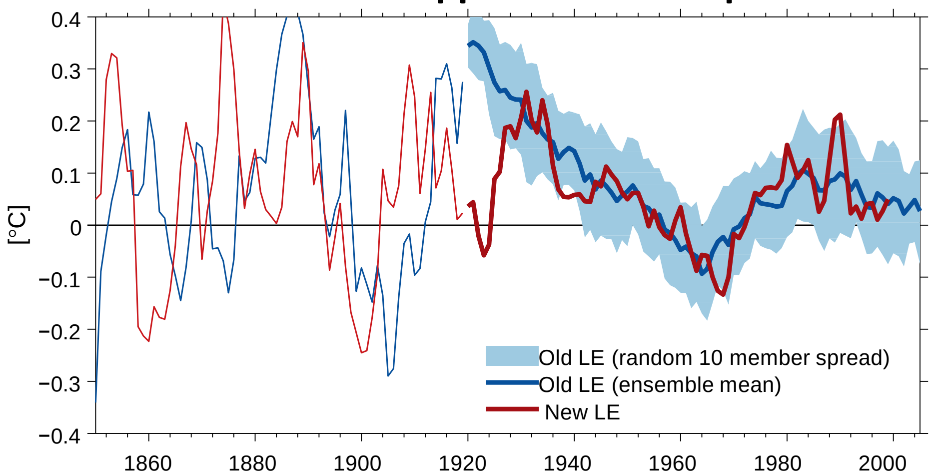
AMOC

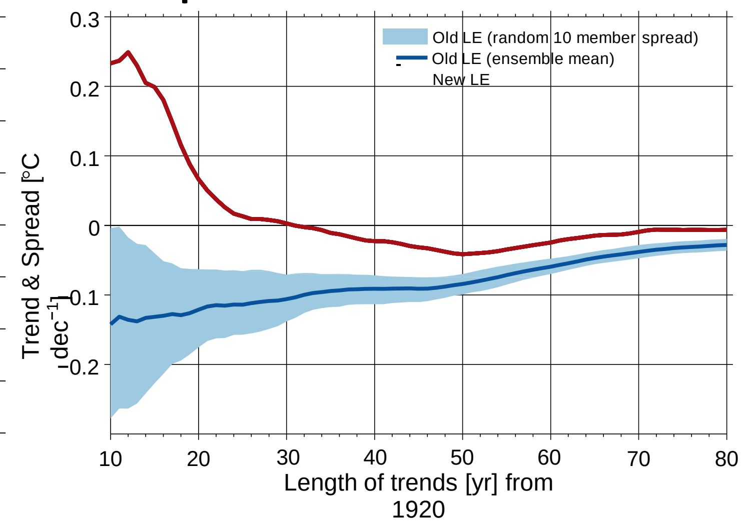
AMOC at 26.5ºN





Upper 1000m temperature over the subpolar NA





*** Anomalies are with respect to the 1951–1980 mean**