Introduction to the Community Earth System Model (CESM)

Gokhan Danabasoglu
CESM Chief Scientist
National Center for Atmospheric Research

OUTLINE

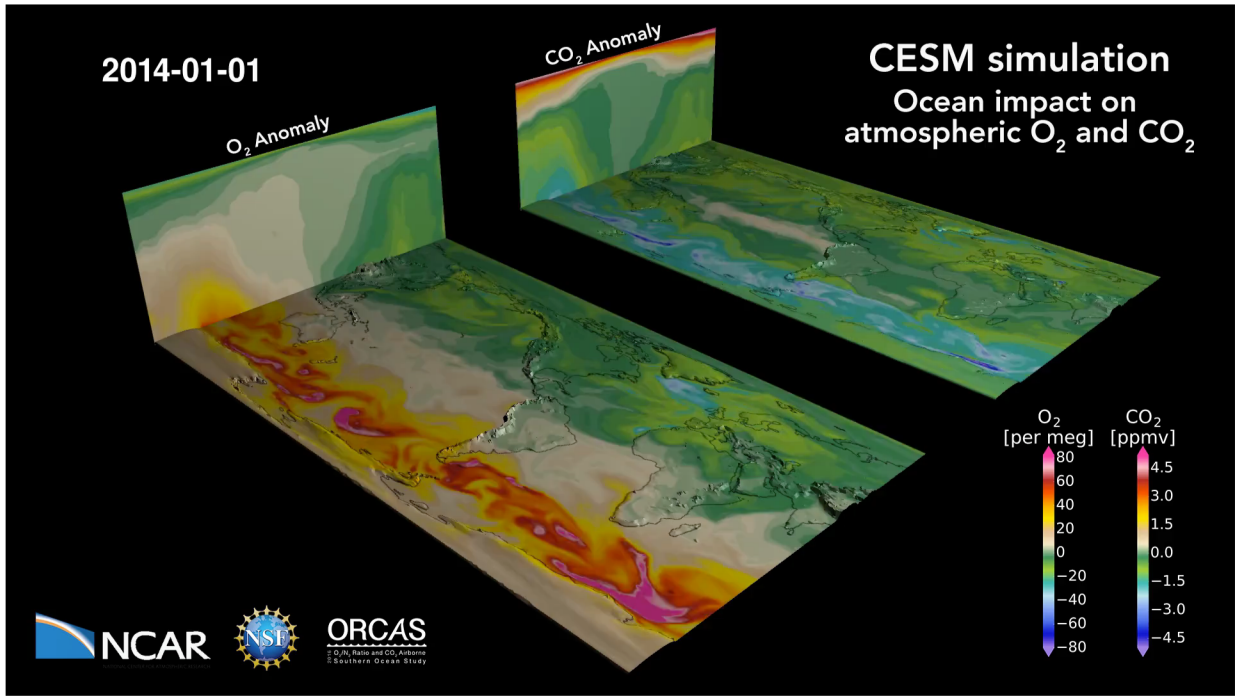
- Global earth system models
- Community Earth System Model (CESM)
- Capabilities and Applications
- CESM version 2 (CESM2) highlights
- Coupled Model Inter-Comparison Project phase 6 (CMIP6)

Global Earth System Models

A virtual laboratory for experimentation ….

General purposes include:

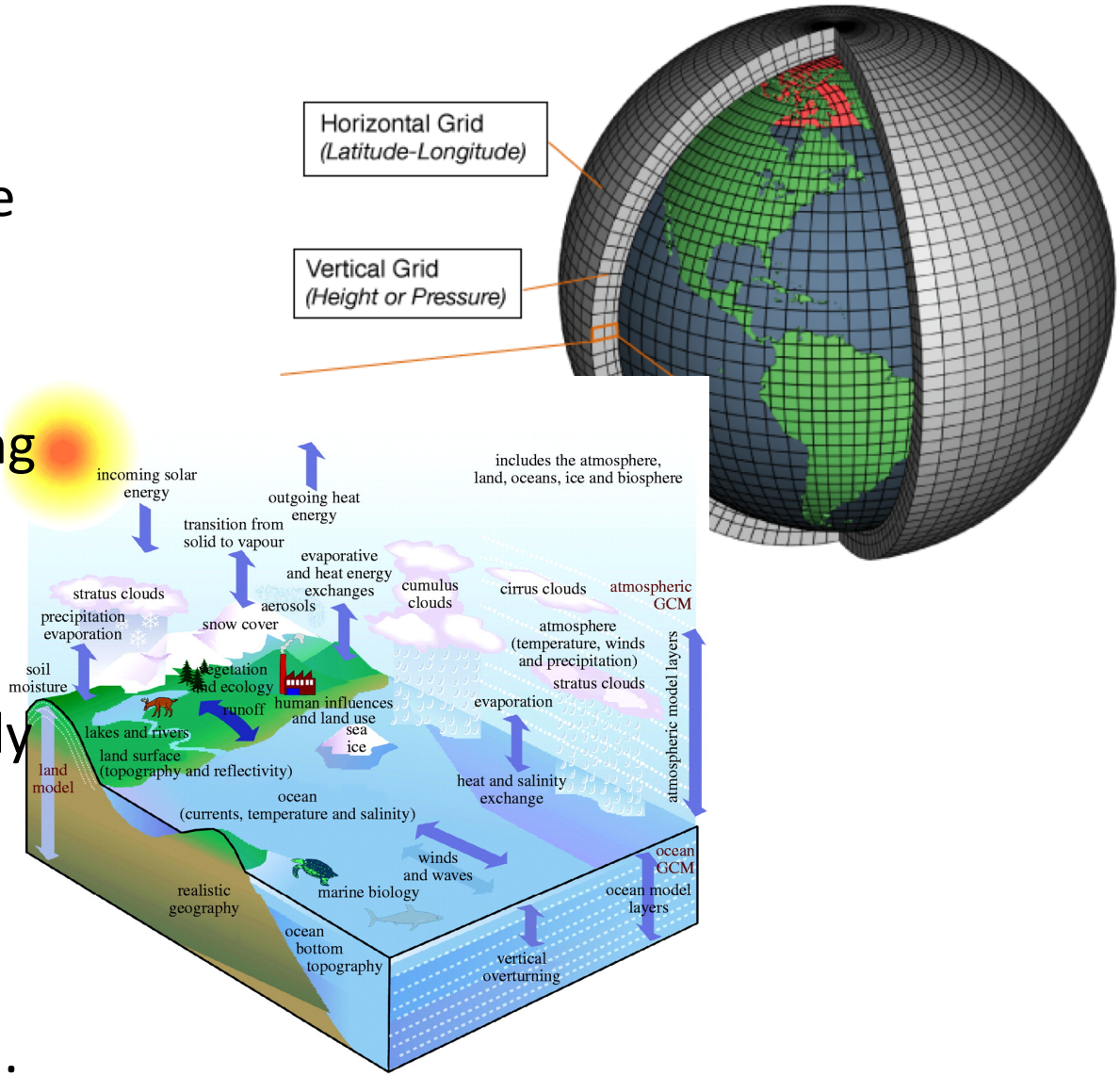
- To provide scientific understanding of observed events, climate change (historical, paleo), etc.
- To simulate future climate change and its impacts
- To make future predictions of weather and climate variability



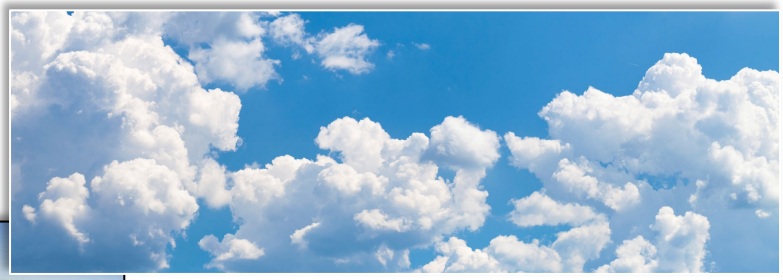
Movie from M. Long and T. Scheitlin

Global Earth System Models

- The models use physical equations to simulate key fields and processes in the atmosphere, ocean, land, and sea-ice.
- Build on our understanding of processes from observations and highly-detailed models (e.g., process models, large eddy simulations).
- Processes that remain below the grid resolution need to be parameterized.



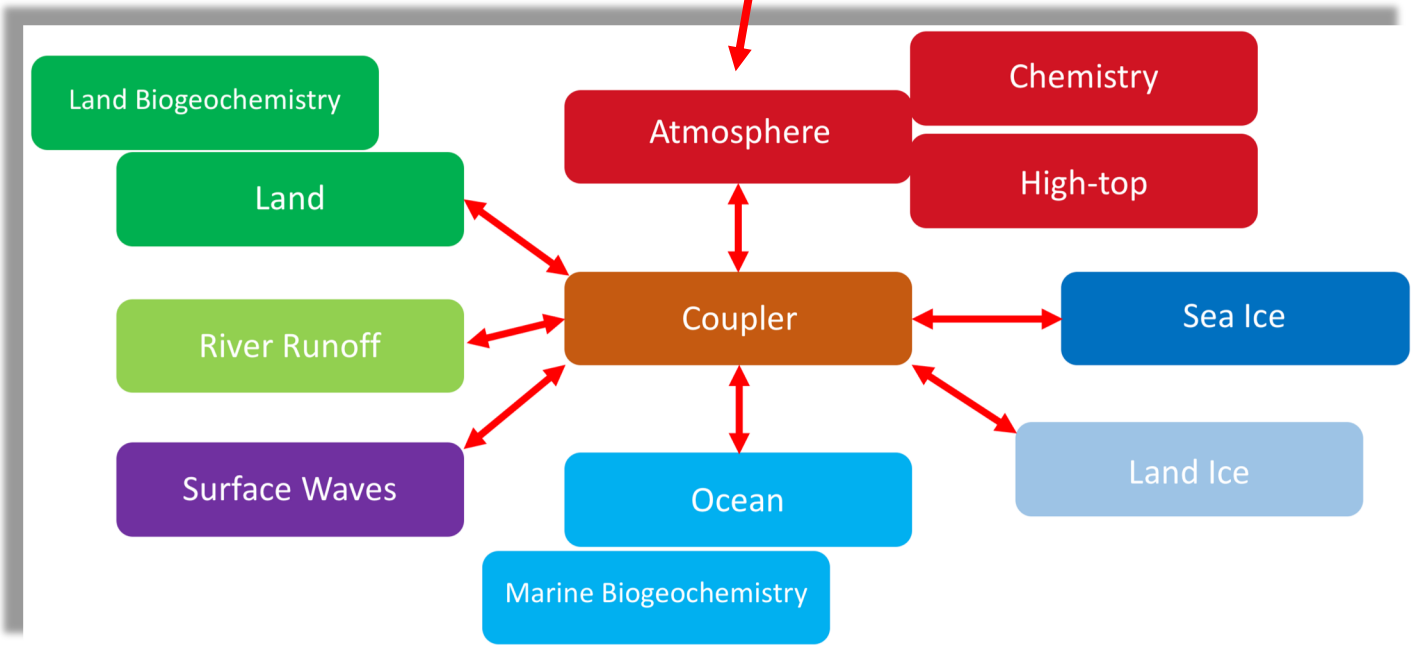
Global Earth System Models

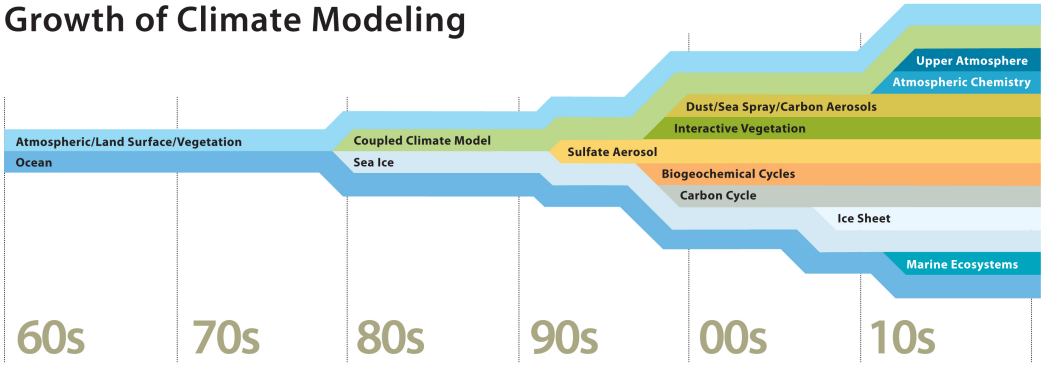


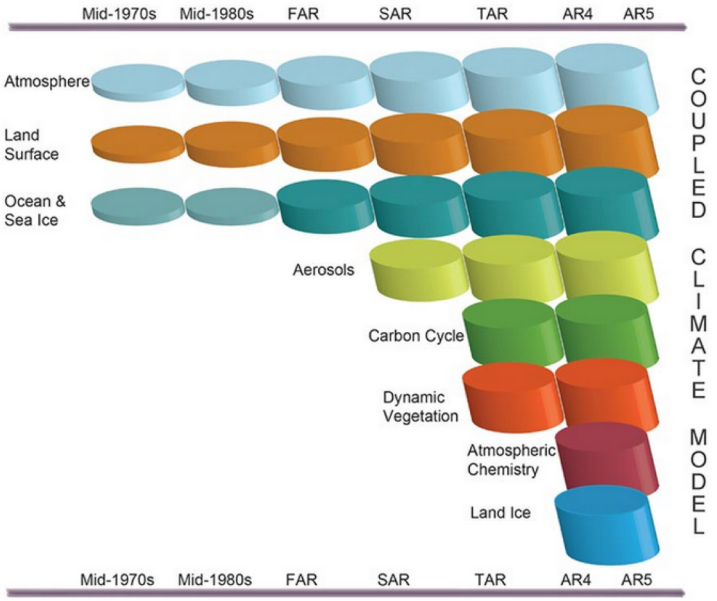
Forcings:

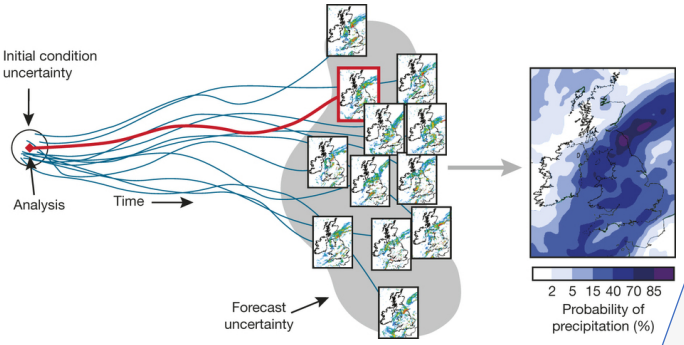
- Greenhouse gases
- Anthropogenic aerosols
- Volcanic eruptions
- Solar variability

Community Earth System Model



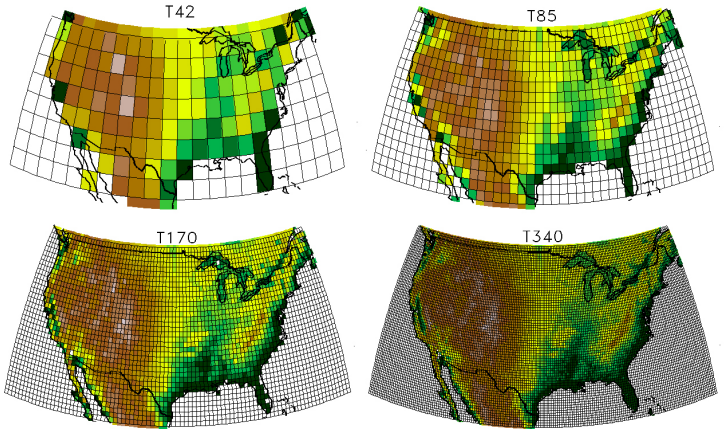

Growth of Climate Modeling
Atmospheric/Land Surface/Vegetation
Ocean
Coupled Climate Model
Sea Ice
Sulfate Aerosol
Dust/Sea Spray/Carbon Aerosols
Interactive Vegetation
Biogeochemical Cycles
Carbon Cycle
Ice Sheet
Upper Atmosphere
Atmospheric Chemistry
Marine Ecosystems
60s
70s
80s
90s
00s
10s


Mid-1970s
Mid-1980s
FAR
SAR
TAR
AR4
AR5
Atmosphere
Land Surface
Ocean & Sea Ice
Aerosols
Carbon Cycle
Dynamic Vegetation
Atmospheric Chemistry
Land Ice
COUPLED CLIMATE MODEL


Initial condition uncertainty
Analysis
Time
Forecast uncertainty

2 5 15 40 70 85
Probability of precipitation (%)

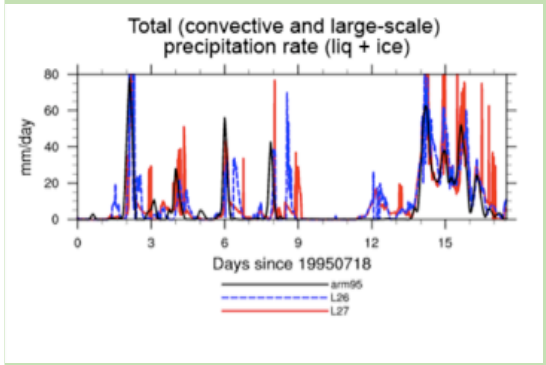
Complexity
Resolution
Resources
Ensemble size


T42
T85
T170
T340

CESM Supports a Range of Climate Science Goals Through a Single Model Code Base

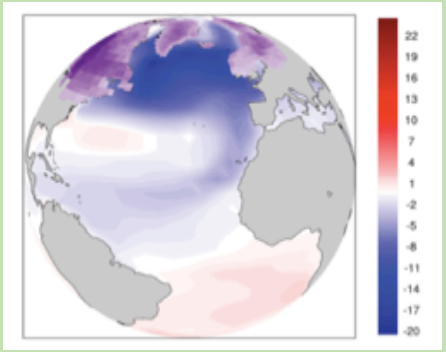
Desktop

Single column/
Coarse resolution:
Physics development



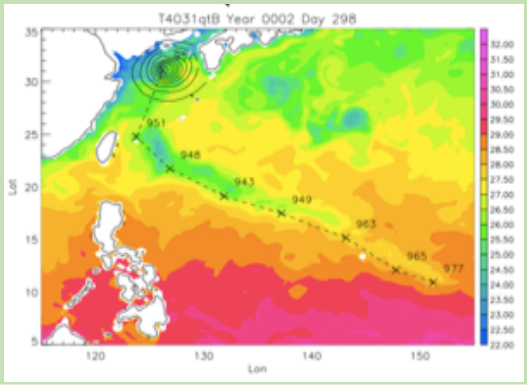
Small cluster

Lower resolution:
Paleo/Large Ensemble
University research



HPC

Higher resolution:
CMIP
Breakthrough ASD



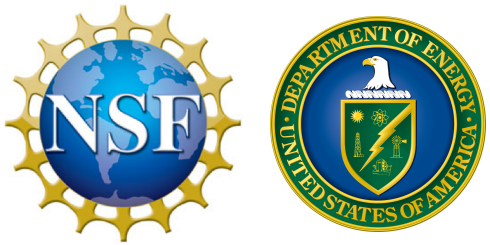
CESM Supports a Range of Climate Science Goals Through a Single Model Code Base

- All component models can be active.
- All component models can be replaced with "data models"

  Allowing, for example, ocean-only, ocean– sea-ice coupled, land-only, atmosphere-only, etc. configurations / experiments.
- Aqua planet, atmospheric dynamical cores, and slab ocean model options are available.
- Numerous options are available within components.
- Increasing number of supported component sets / configurations are provided.

CESM Project

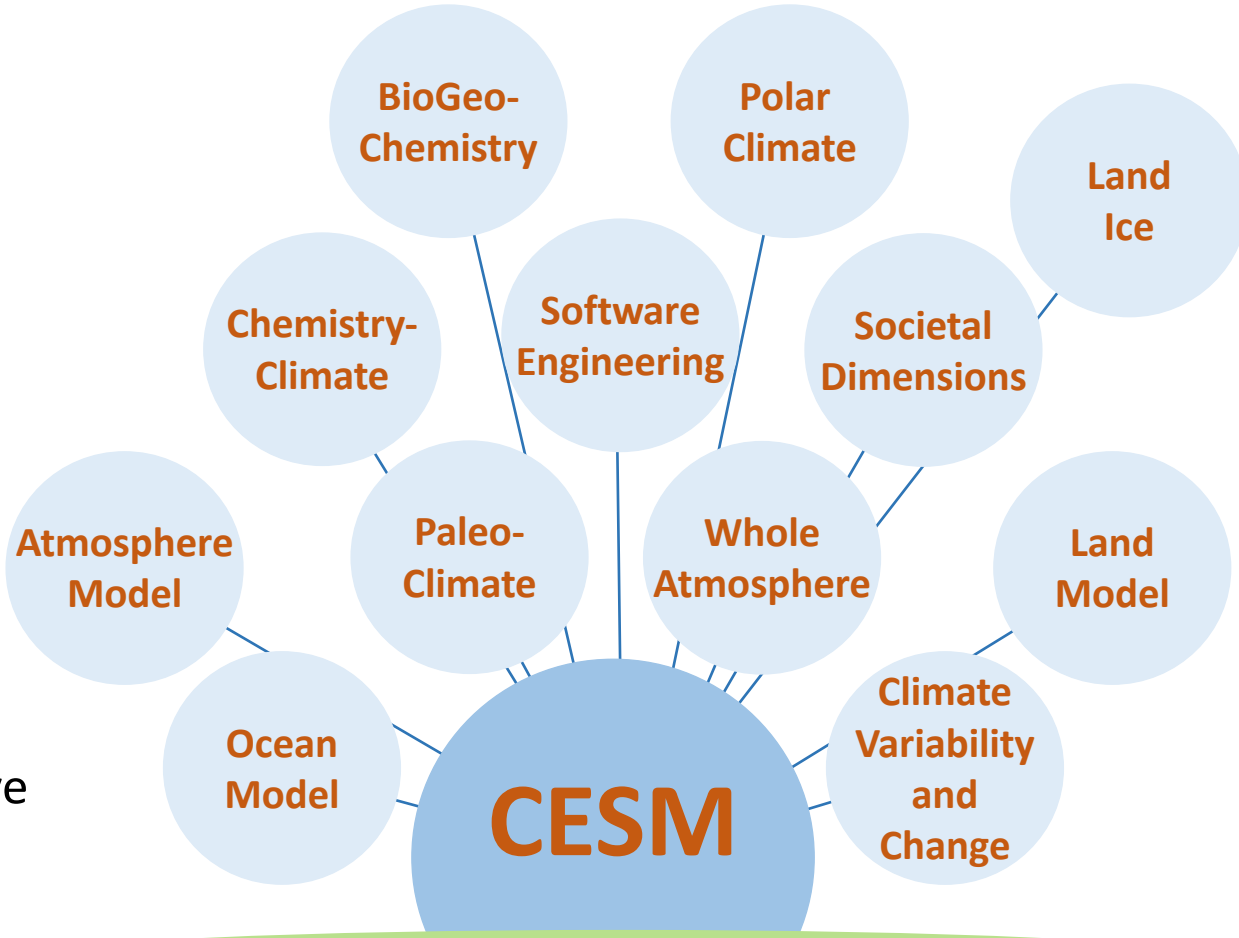
20+ years of model development and applications



Most working groups have winter/spring meetings. Annual meeting in June.

CESM Advisory Board

CESM Scientific Steering Committee

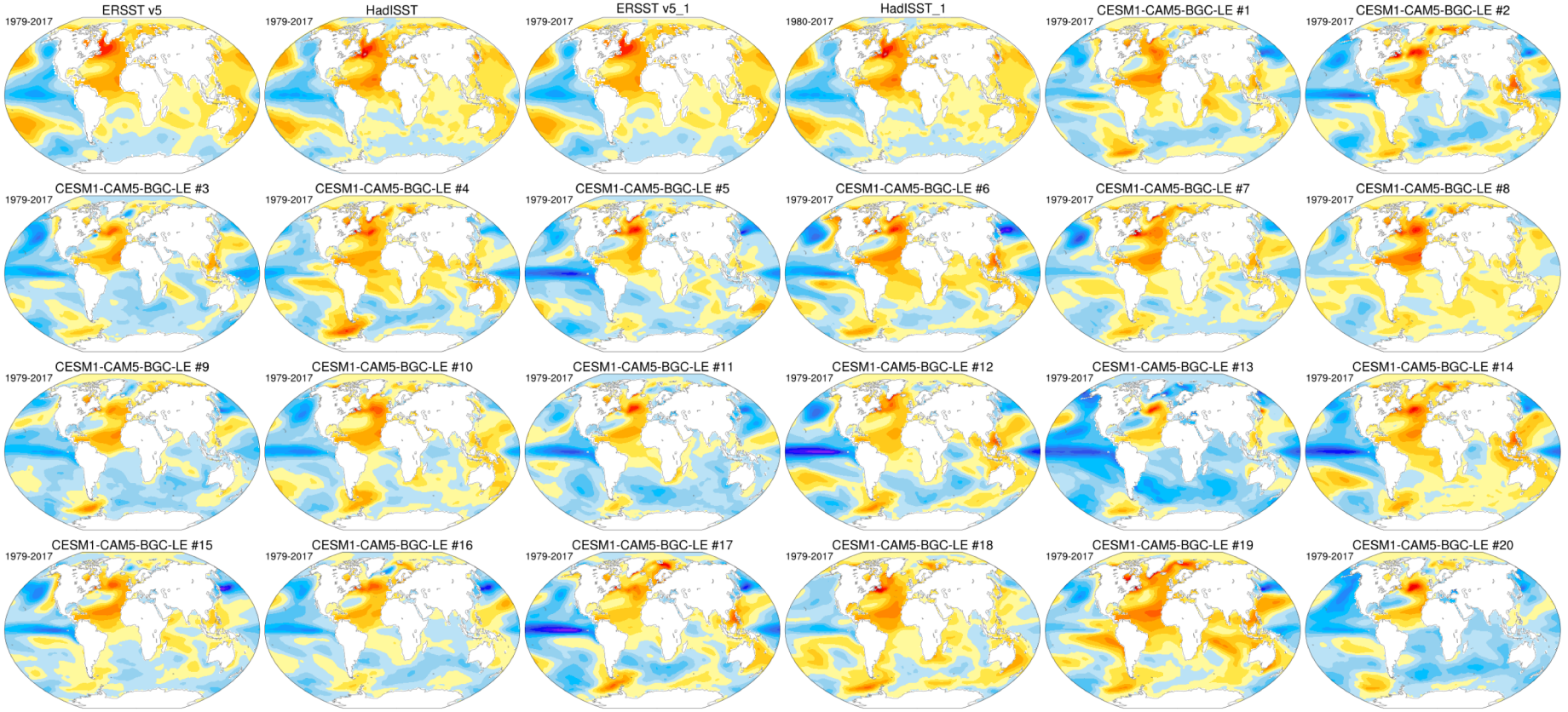


http://www.cesm.ucar.edu/management

CAPABILITIES AND APPLICATIONS

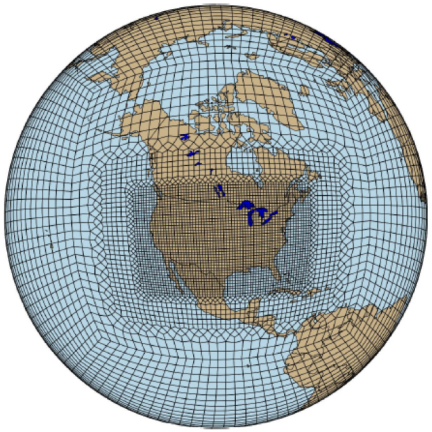
CESM Large Ensemble Simulations

Atlantic Multi-Decadal Variability (AMV)



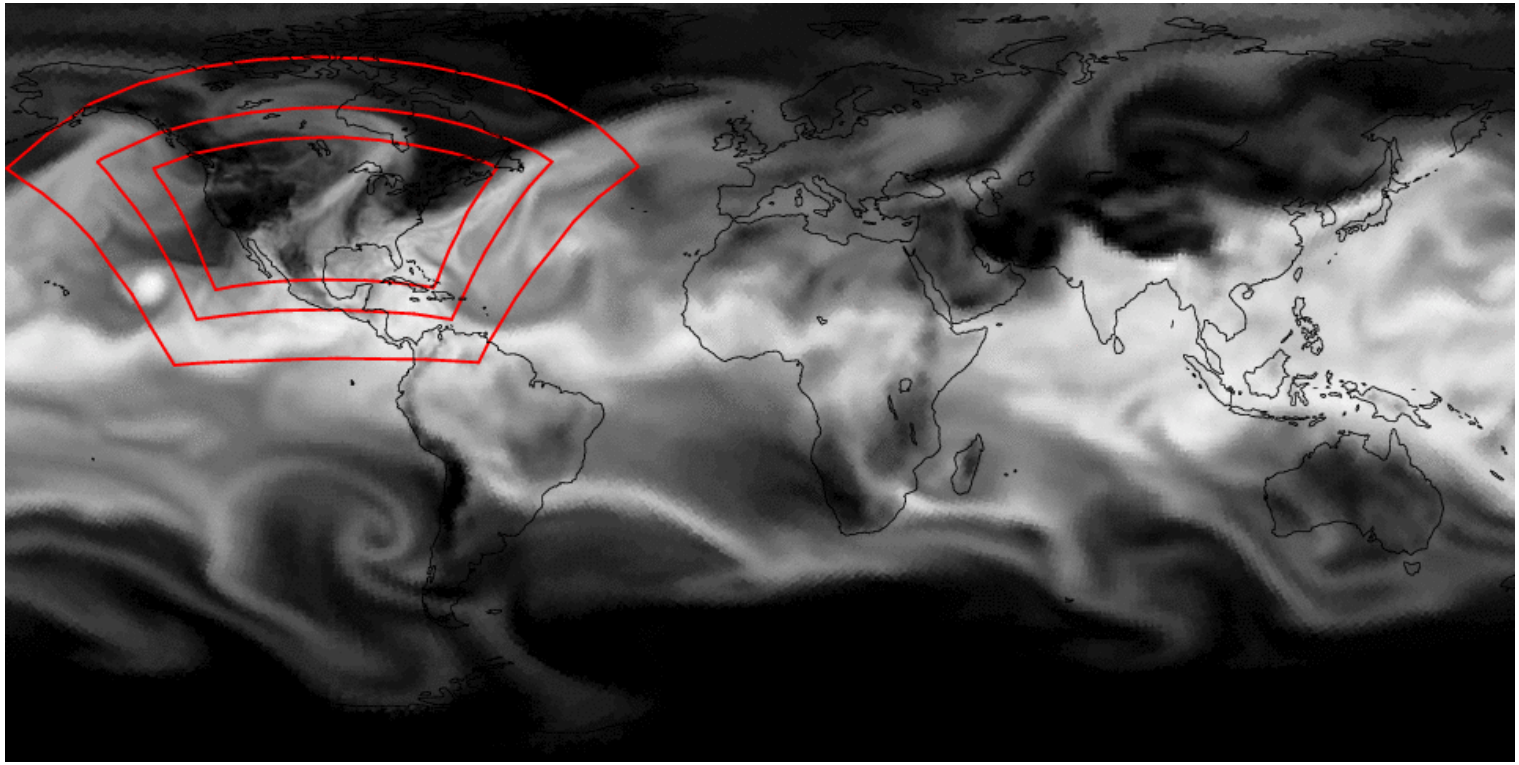
35+ members for the 1920-2080 period; same forcings; initial conditions differ only at round-off level in their atmospheric temperatures

Regional Refinement in CESM



Regional refinement in CAM6 (AMIP) with the Spectral Element (SE) dynamical core

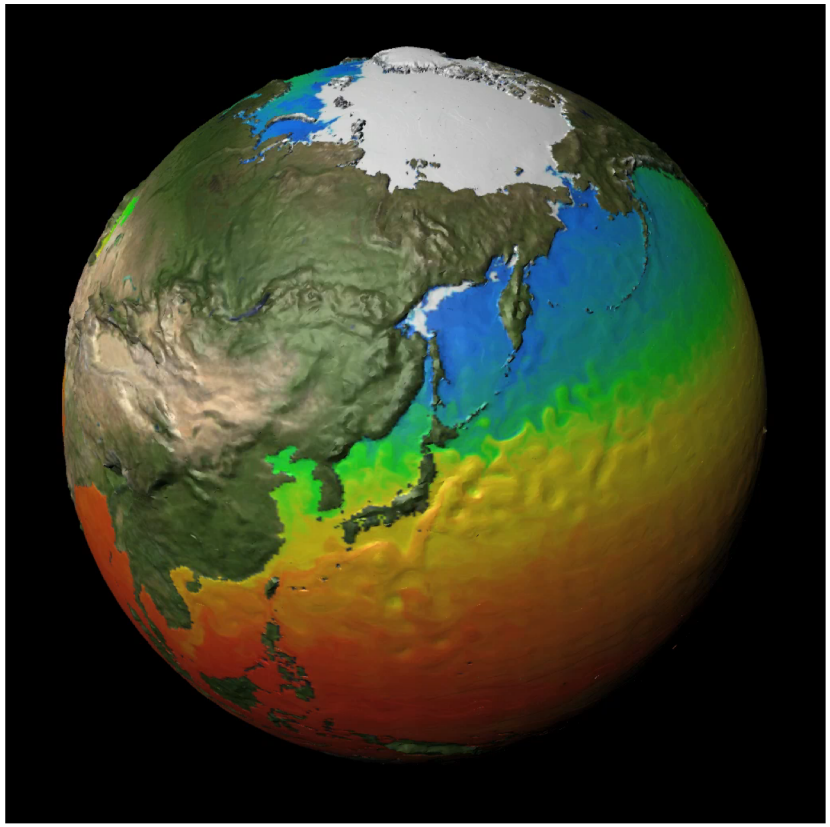
Precipitable water 23 Sept – 03 Oct 1981; 111 km -> 14 km



Colin Zarzycki and Andrew Gettelman

CESM High-Resolution Version

Based on version cesm1.3.beta17 with CAM5-SE and CLM4 at 0.25^{o} and ocean and sea-ice (CICE4) at nominal 0.1^{o} resolution



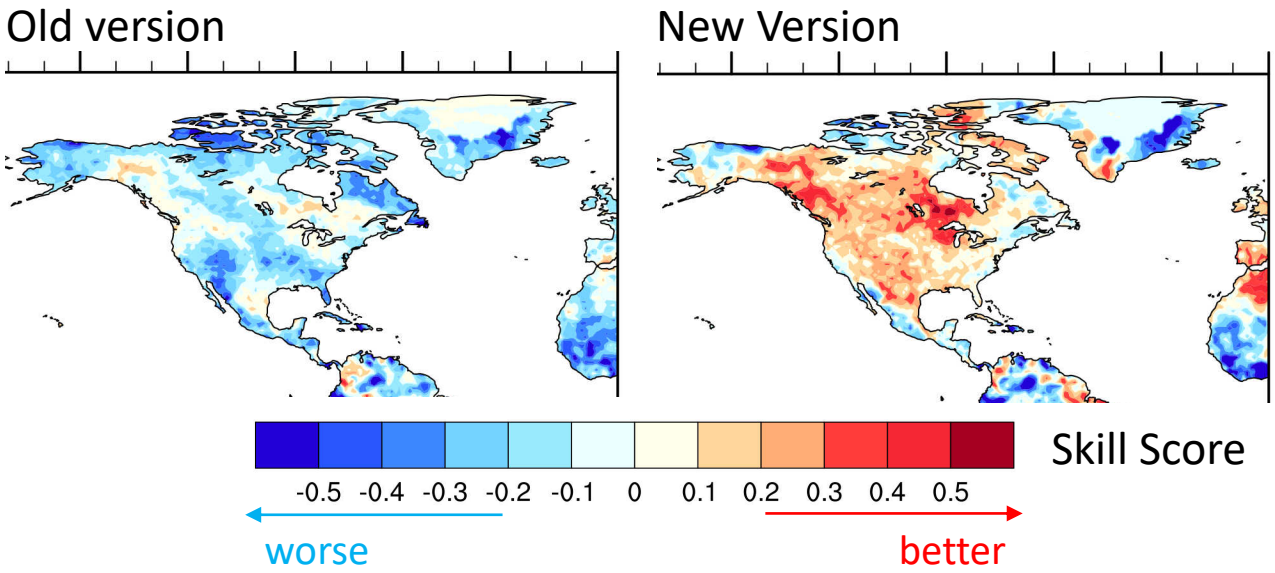
Movie from J. Small and T. Scheitlin

O(100) year present-day control simulation (ASD)

Forced ocean – sea-ice coupled simulation for the 1958-2017 period

Pre-industrial control, historical, future scenario, and climate prediction simulations

Surface Air Temperature Predictions over North America with CESM on Monthly Time Scales



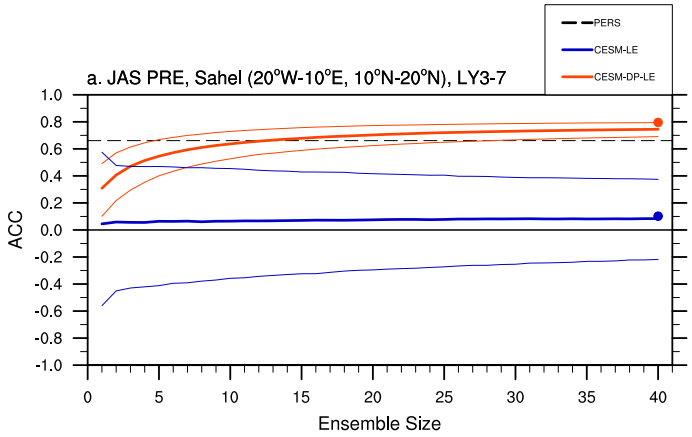
Better models and better (ocean) initial conditions lead to better surface temperature predictions over land

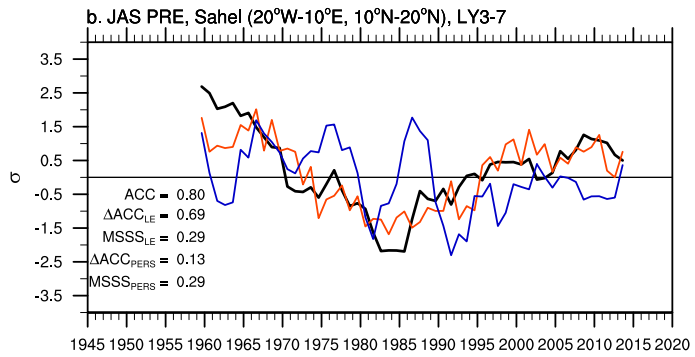
01 January starts; verifying January-means for 1982-2010

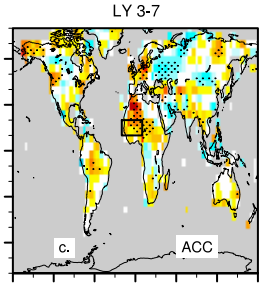
Ben Kirtman

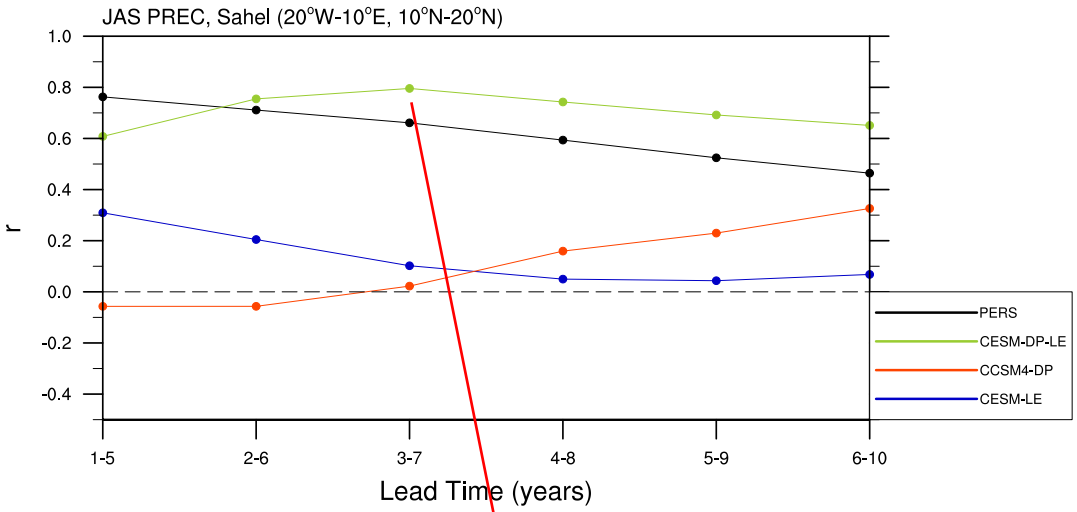
CESM Decadal Prediction Large Ensemble (CESM-DP-LE)

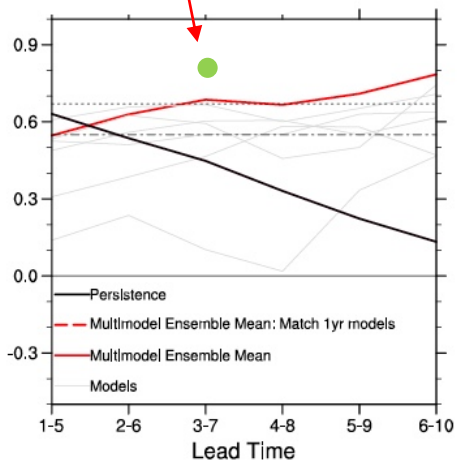
Summer Precipitation in the Sahel







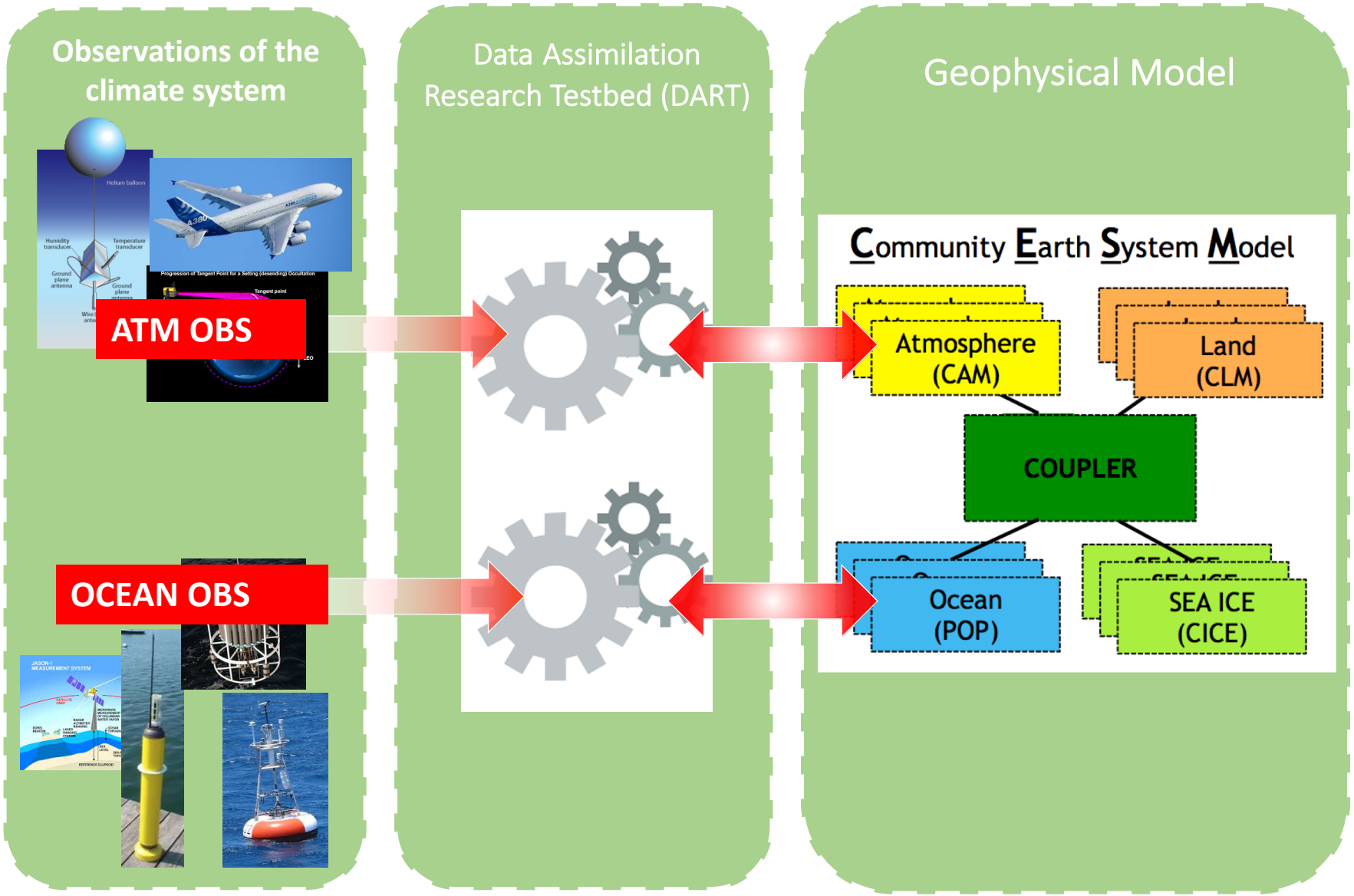




Martin & Thorncroft (2014, *GRL)*

Steve Yeager

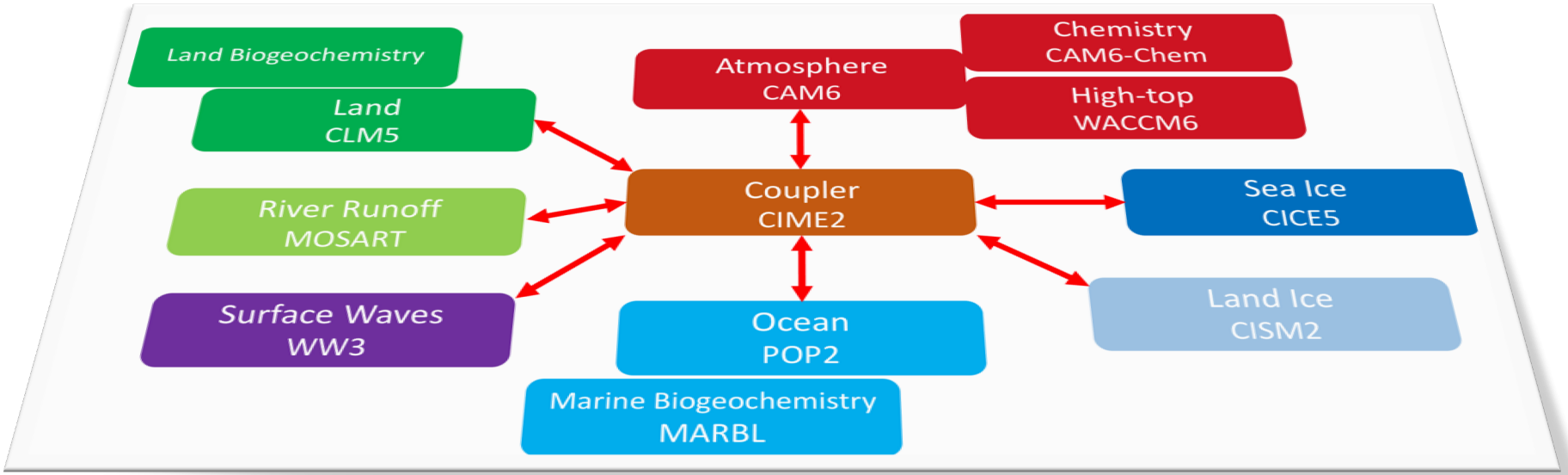
“WEAKLY” Coupled Data Assimilation: The cutting Edge



System includes coupled interactions, is “balanced” during “forecast” phase, can use most observational information.

CESM2 HIGHLIGHTS

CESM 2.0 was released to the community on 8 June 2018!



CESM2.0 release includes:

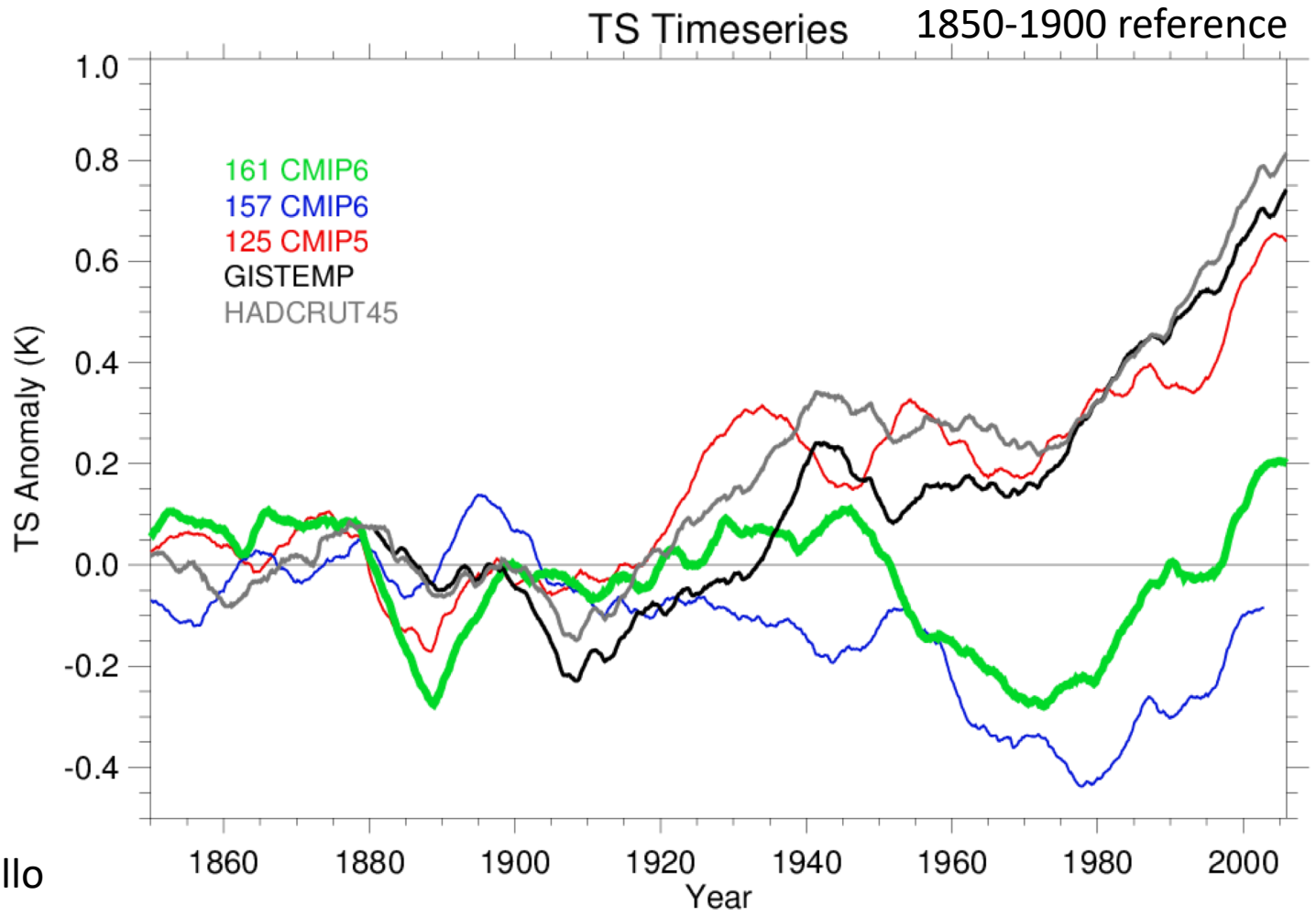
- A 300-year pre-industrial control simulation
- 2-member ensemble of historical simulations

The CESM2.0 release is not a CMIP6 release. It does not include:

- A set of *equilibrated* land and ocean BGC states and final ocean BGC parameter sets,
- Final CMIP6-related forcings from WACCM,
- Additional CMIP6-related diagnostics and component sets.

These will be made available in CESM2.1 with an anticipated release date of September / October 2018.

- Corrected CMIP6 emissions, specifically anthropogenic sulfur emissions
- Adjustments to the model representation of aerosol cloud interactions to make specific processes better match observations



John Fasullo

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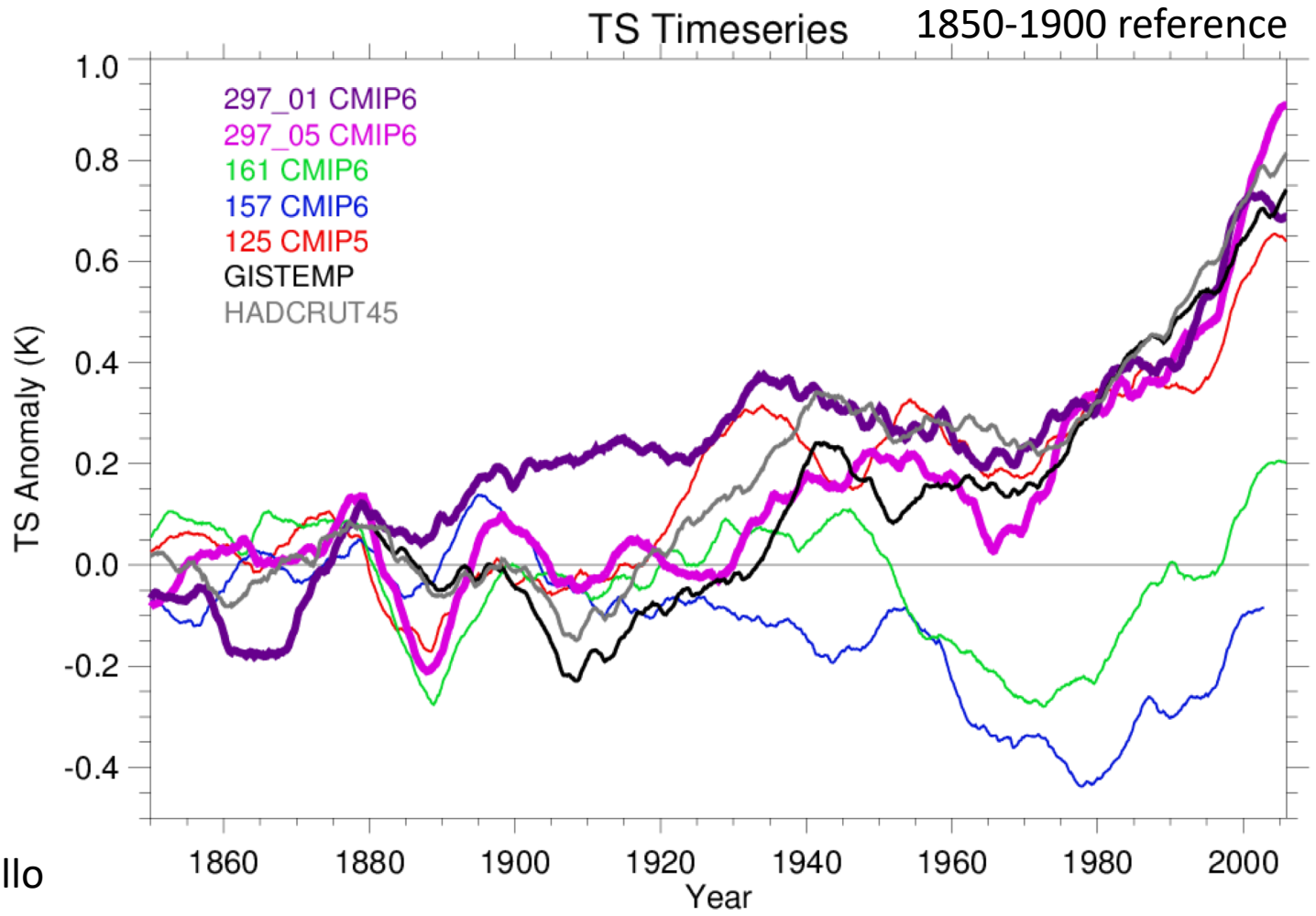
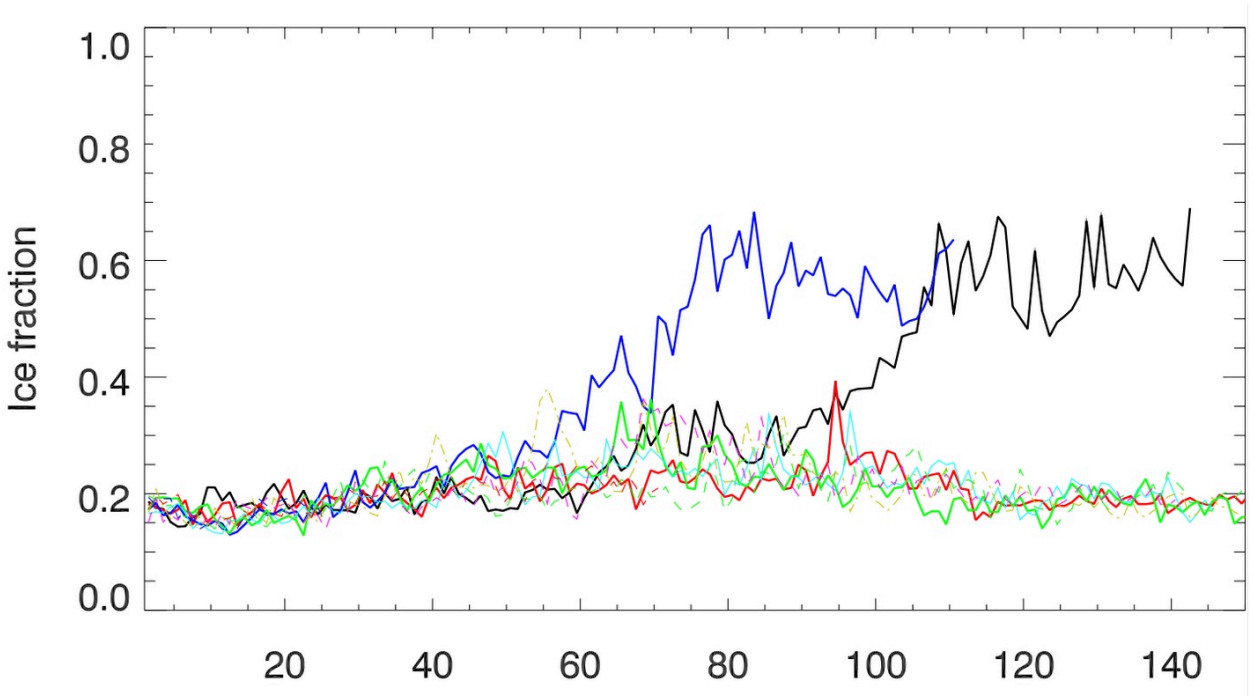
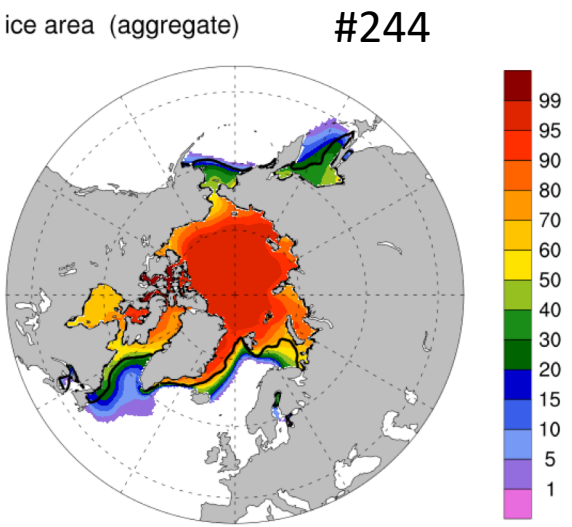
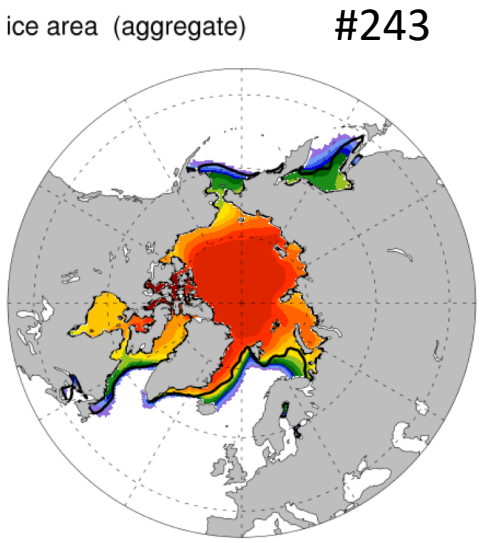


John Fasullo

Labrador Sea Freeze



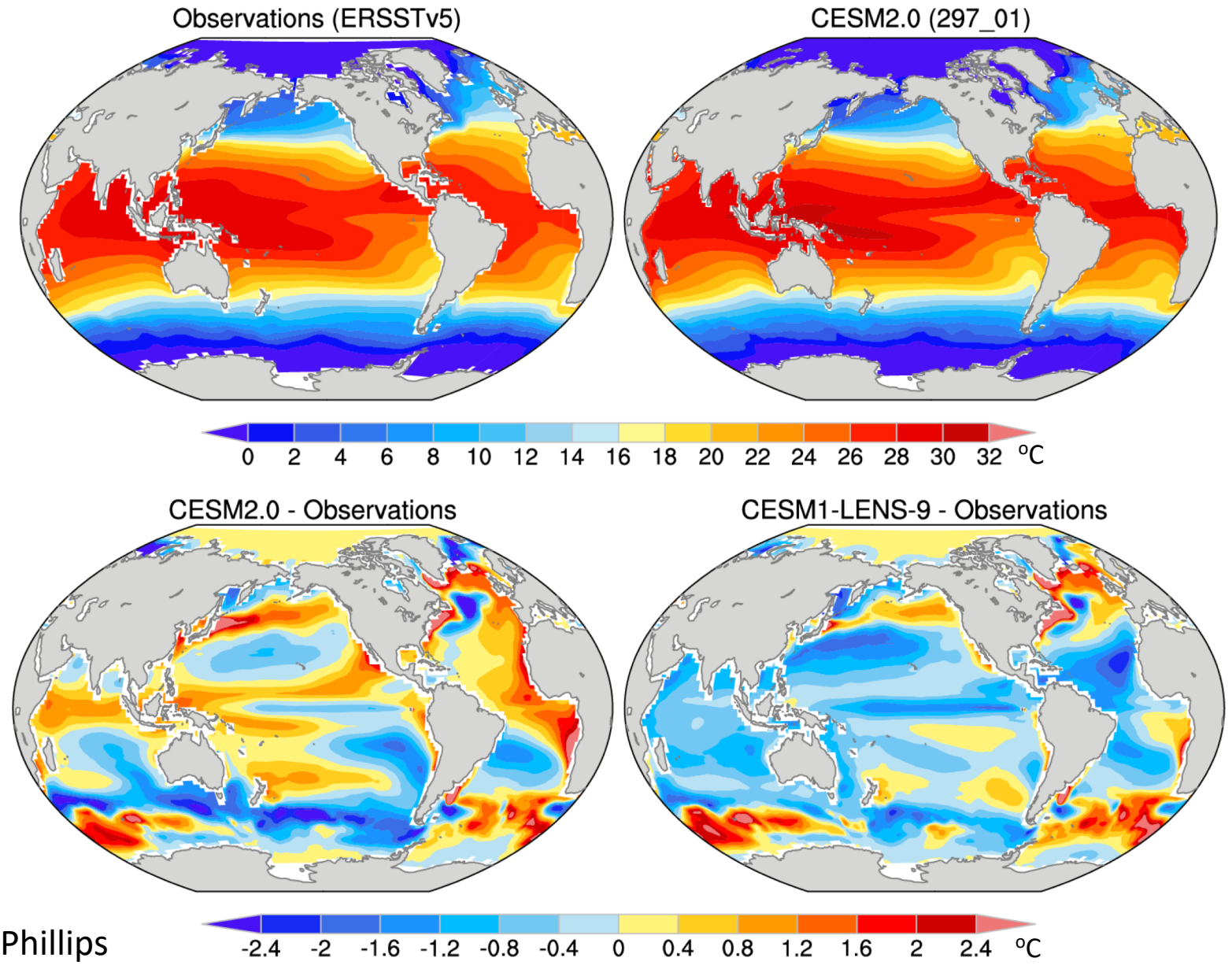




30-year average

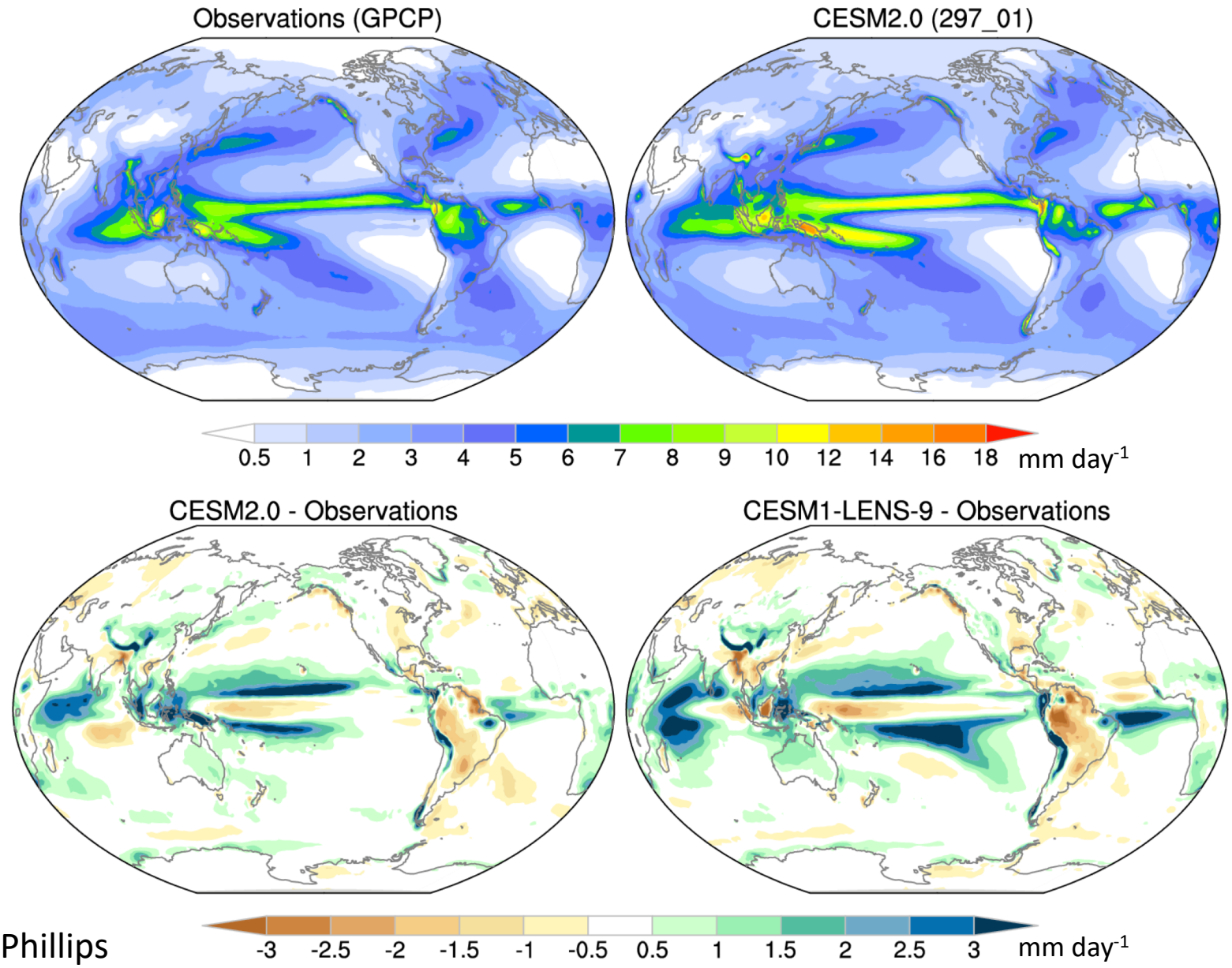
- Difficult to determine robust sources of LS freshening and cooling – no silver bullet!
- Start several pre-industrial control simulations in which ensembles are created by round-off level perturbations in the atmospheric temperature
- Designate a state after the LS transient as the pre-industrial initial conditions

Sea Surface Temperature (1979-2005)



Adam Phillips

Precipitation (1979-2005)

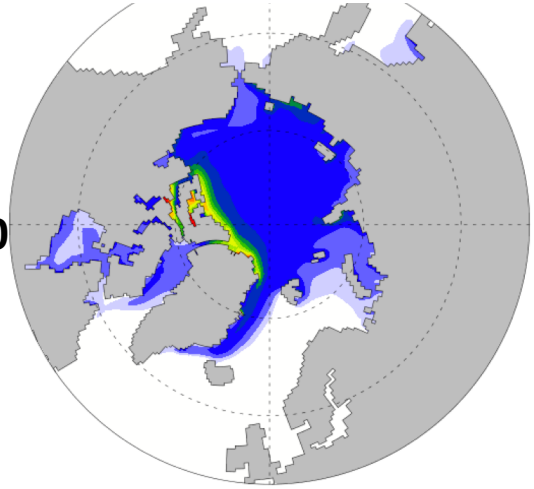


Adam Phillips

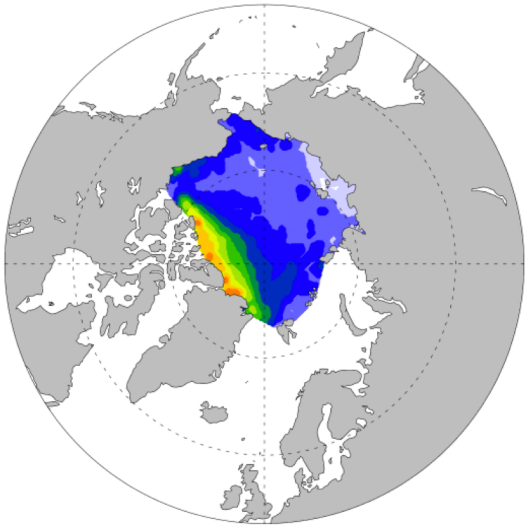
20th Century Arctic Sea Ice in CESM2.0

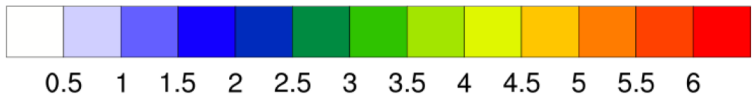
Sea Ice Thickness (m)
Feb/Mar 2001-2005

CESM2.0

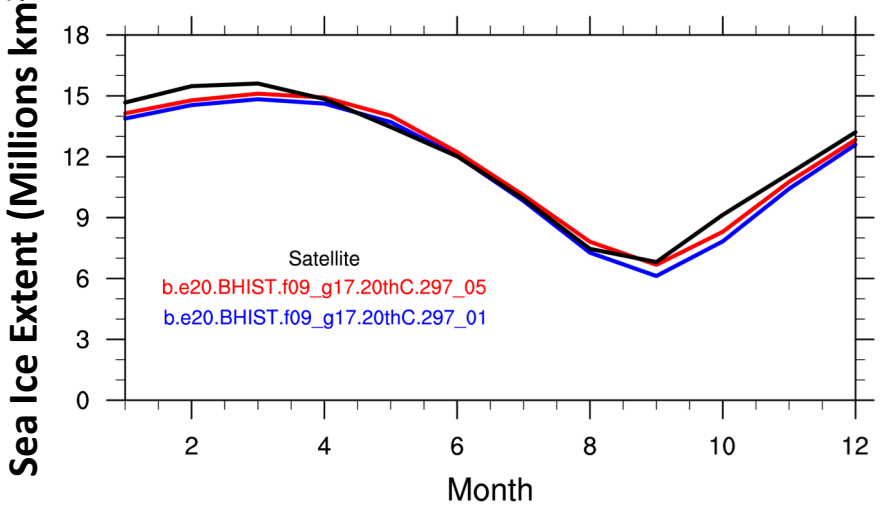


IceSat

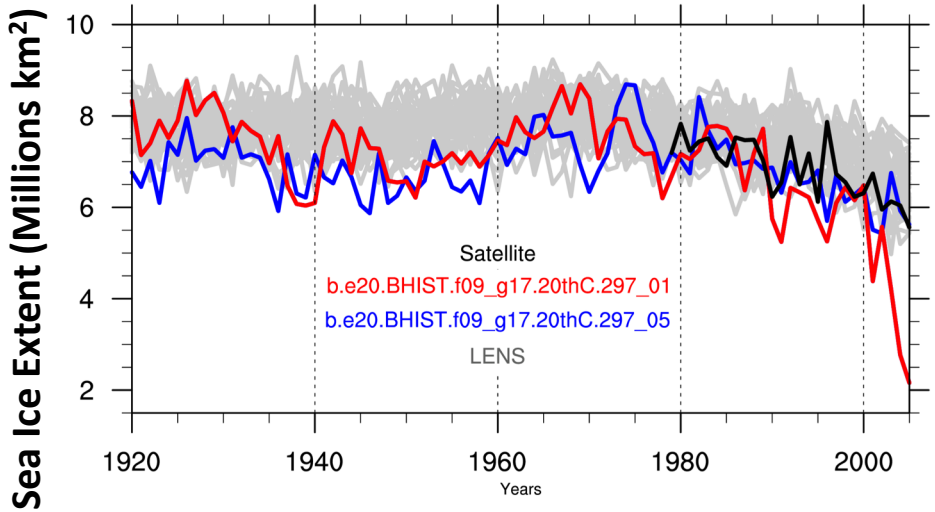




Annual Cycle Sea Ice Extent 1979-2005



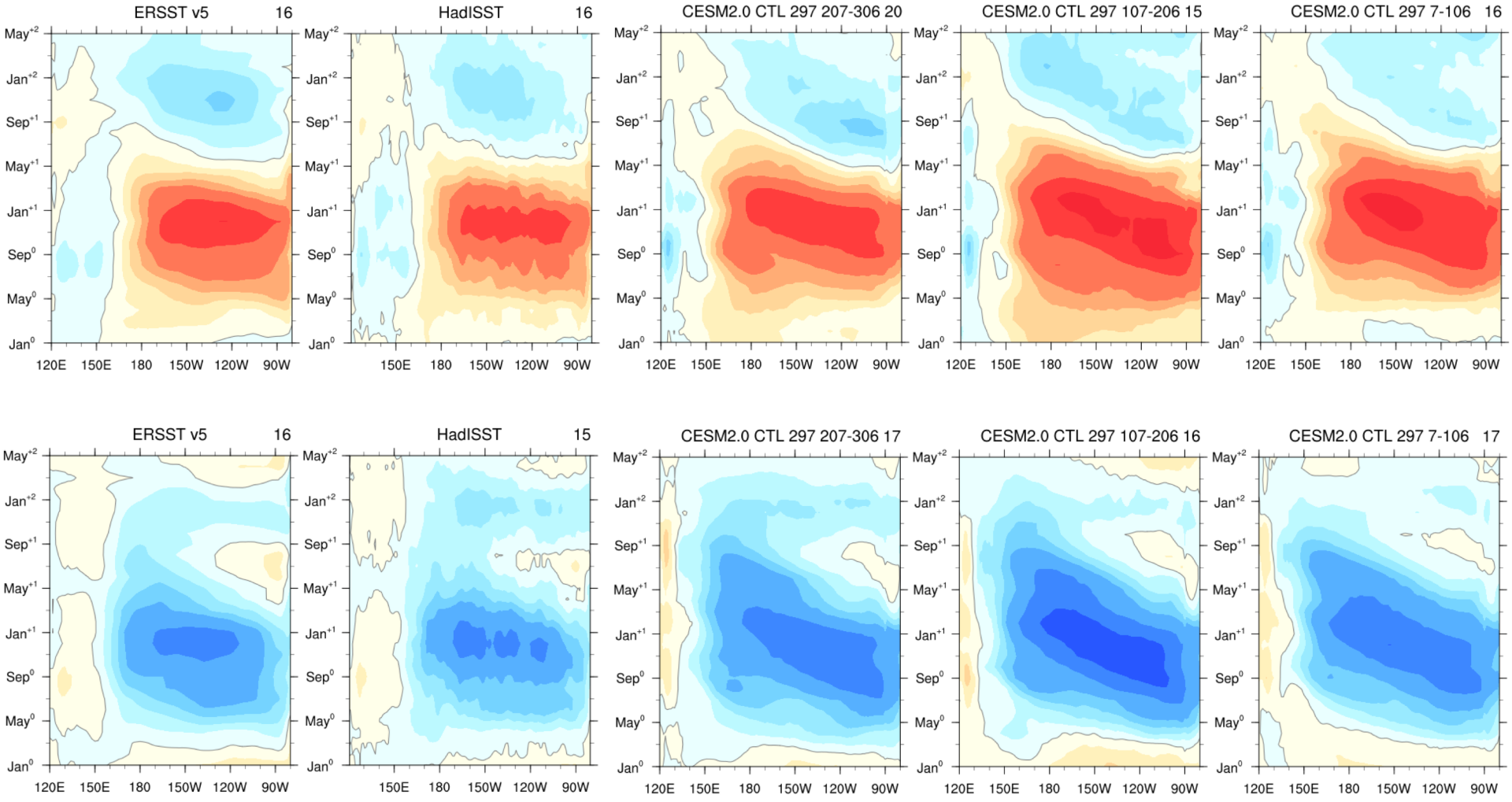
September Sea Ice Extent



Alice DuVivier

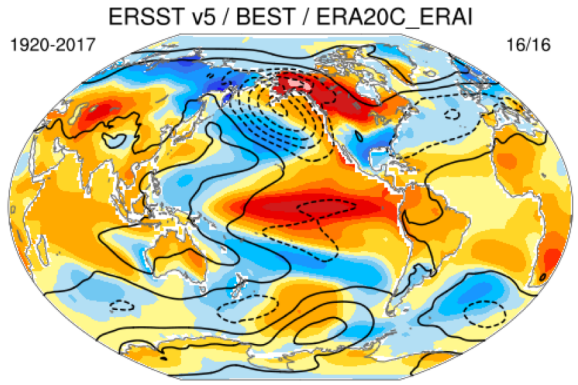
El Nino and La Nina Composites (3ºS-3ºN)

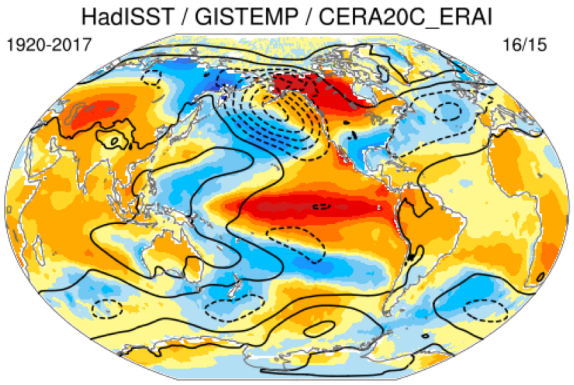
CESM2.0 PI Control

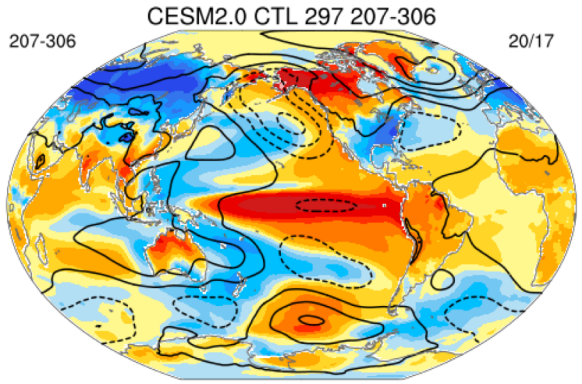


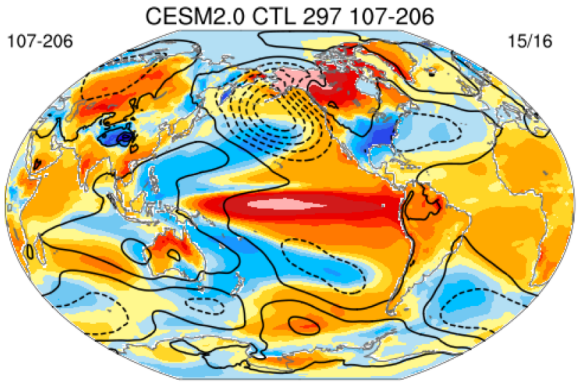
Adam Phillips

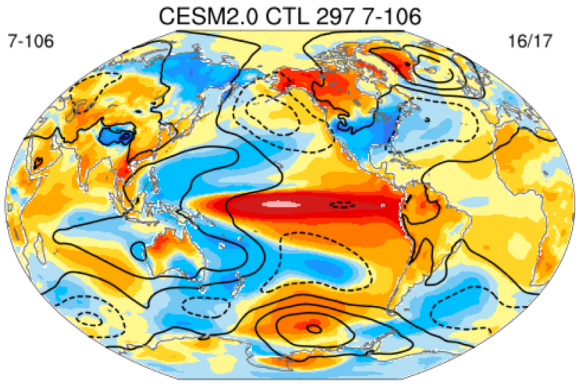
Nino3.4 Surface Temperature and Pressure Composites (DJF^{+1})

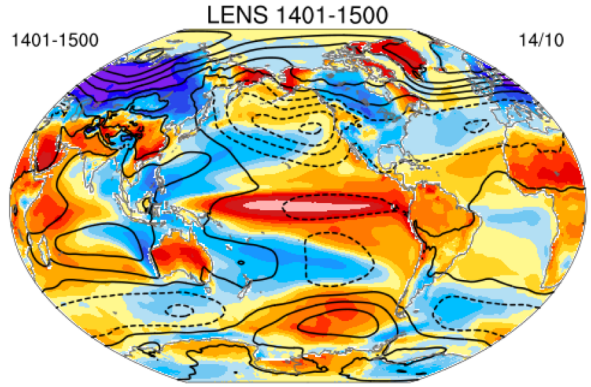


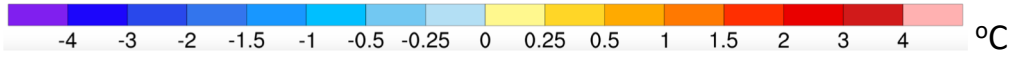








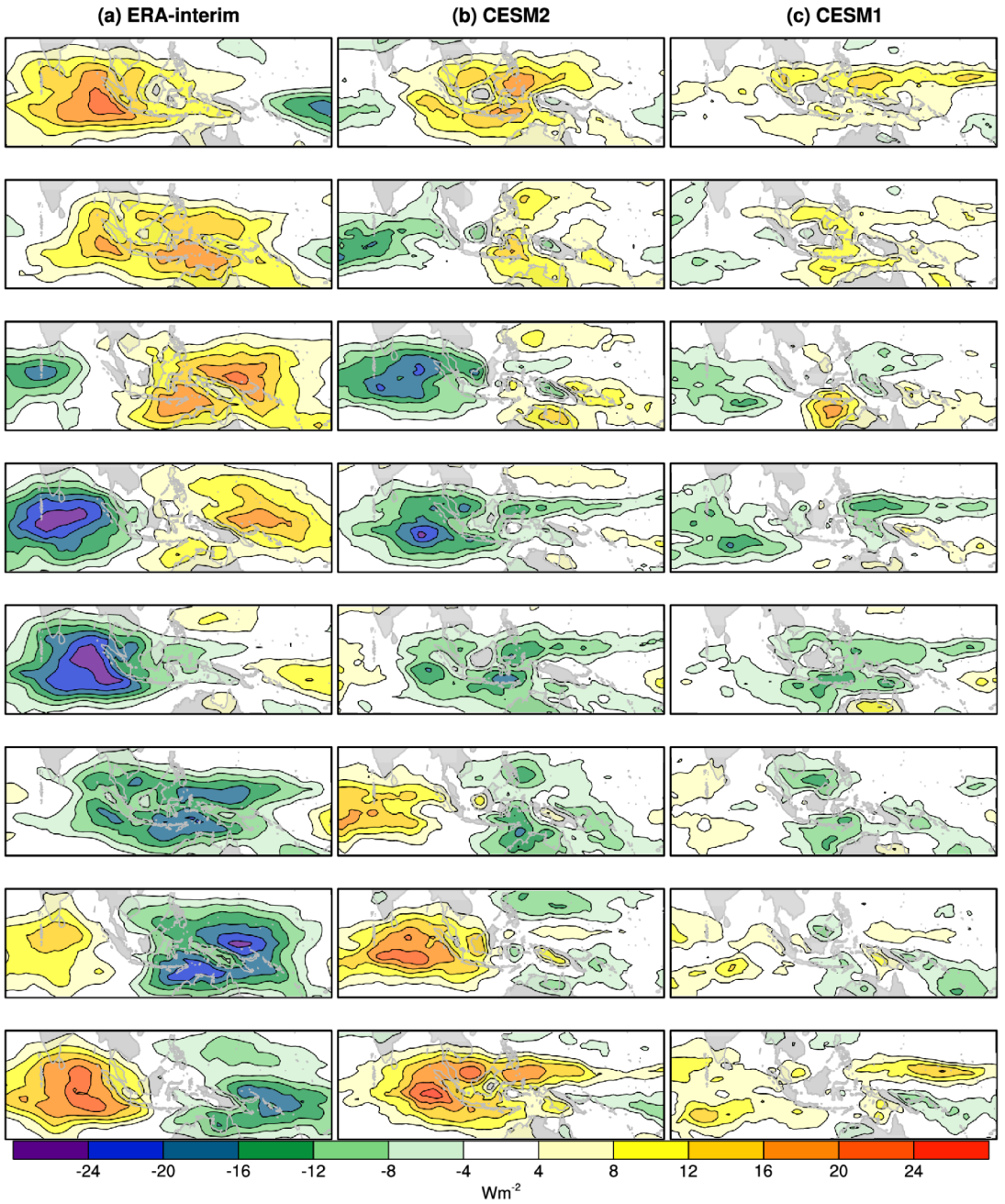




Adam Phillips

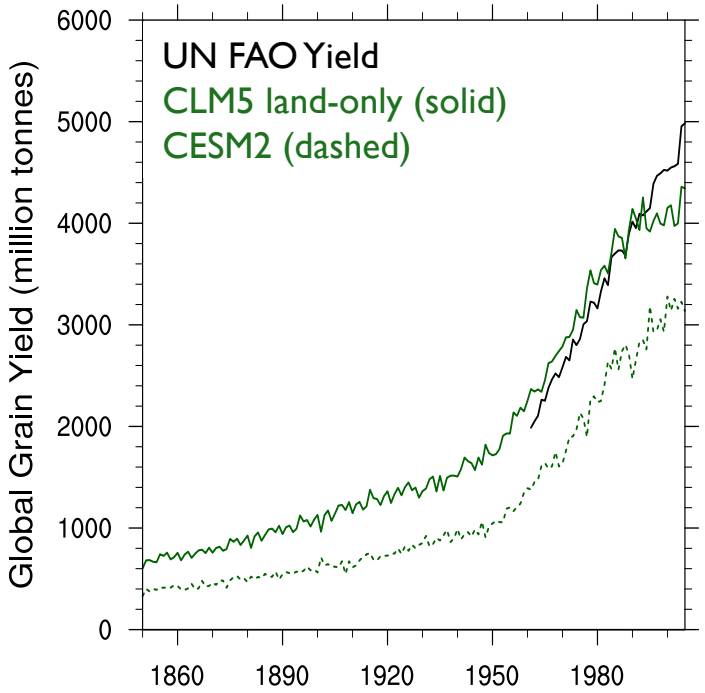
Madden – Julian Oscillation (MJO)

DJF Composites of Outgoing Longwave Radiation Anomalies



Rich Neale

Global grain yields in CLM5: Coupled versus Land-only

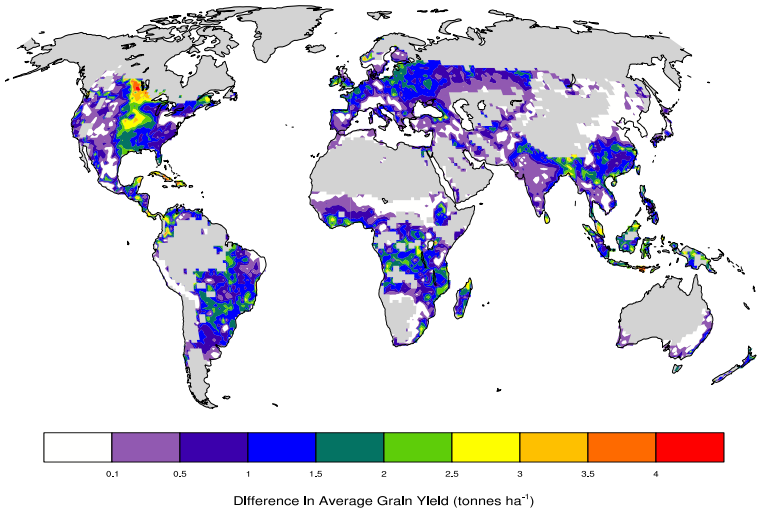


CLM5 crop yield reasonably matches FAO yields

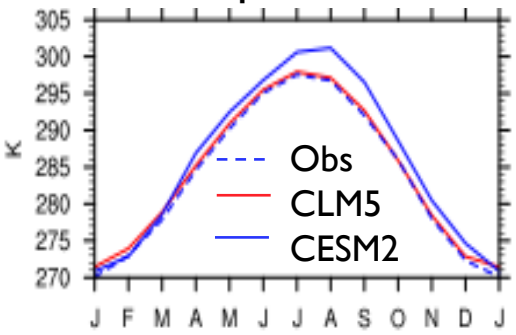
Low bias in yield in coupled CESM2

Too warm and dry in summer in Midwest US in CESM2

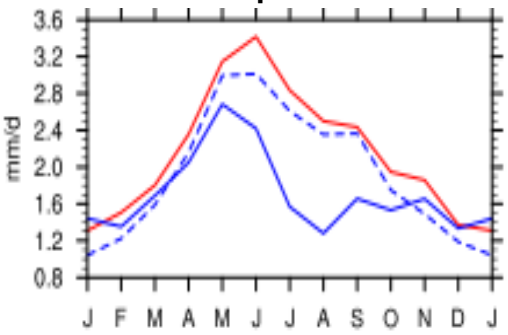
Grain yield
CLM5 (land-only) – CESM2



Temperature

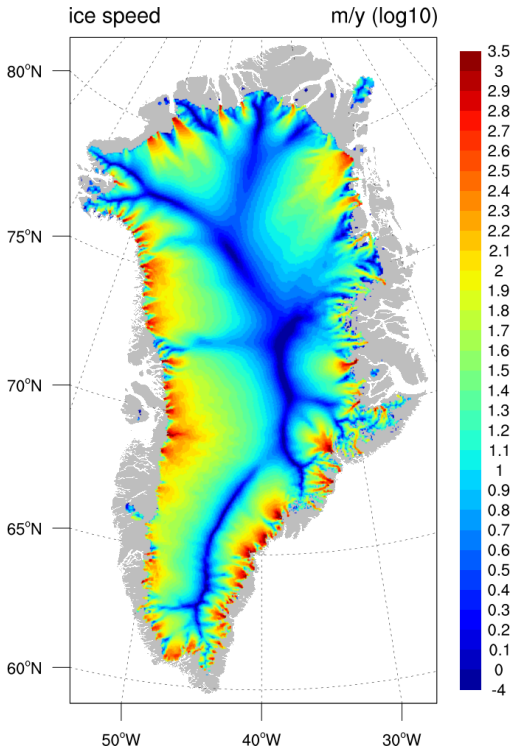


Precipitation



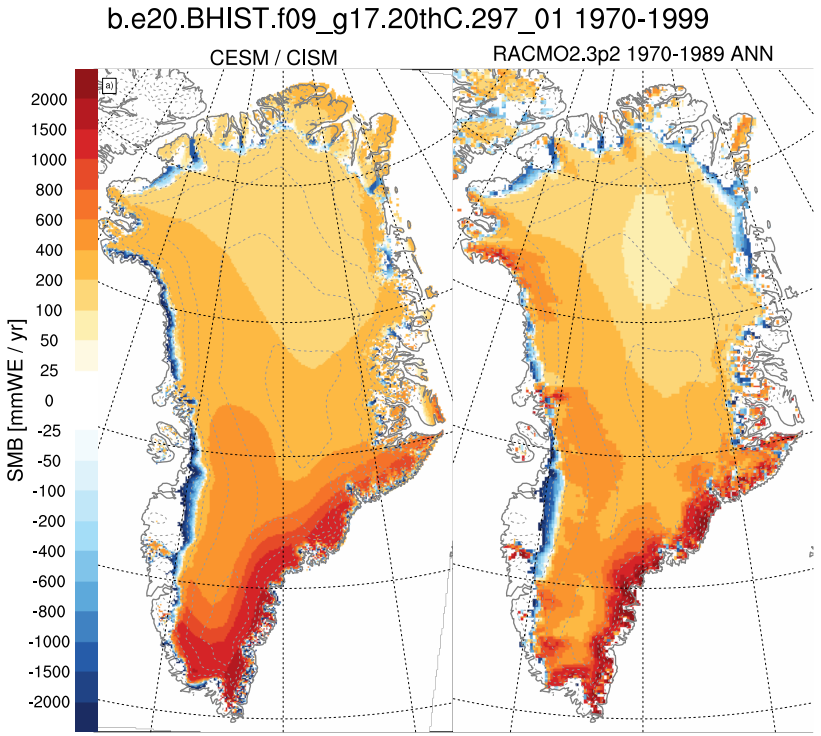
Lombardozzi et al., in prep

Ice Sheet Dynamics and Surface Mass Balance



Left: Greenland surface ice speed from CISM2.1.

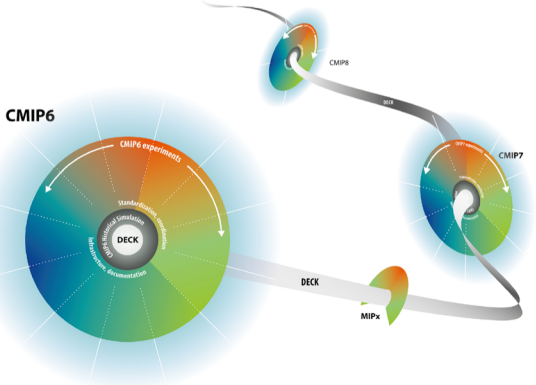
Right: Simulated Greenland SMB from CESM/CISM (left panel) and RACMO2 regional model (right panel). **Red** = net accumulation, **blue** = net ablation.



- CESM2.0 includes version 2.1 of the Community Ice Sheet model (CISM), with efficient higher-order dynamics and improved physics (basal sliding, iceberg calving)
- The surface climate of ice sheets has improved, giving a more realistic surface mass balance for both Greenland and Antarctica.
  - Deep firn model in CLM for realistic refreezing and densification; drag parameterization in CAM for more accurate surface winds; reduced bias in high-latitude longwave cloud forcing

William Lipscomb & Jan Lenaerts

COUPLED MODEL INTERCOMPARISON PROJECT PHASE 6 (CMIP6)



CMIP DECK Simulations

Experiment short name	CMIP6 label	Experiment description	Forcing methods	Start year	End year	Minimum no. years per simulation	Major purpose
DECK experiments							
AMIP	*amip*	Observed SSTs and SICs prescribed	All; CO_2 concentration prescribed	1979	2014	36	Evaluation, variability
Pre-industrial control	*piControl* or *esm-piControl*	Coupled atmosphere–ocean pre-industrial control	CO_2 concentration prescribed or calculated	n/a	n/a	500	Evaluation, unforced variability
Abrupt quadrupling of CO_2 concentration	*abrupt-4×CO2*	CO_2 abruptly quadrupled and then held constant	CO_2 concentration prescribed	n/a	n/a	150	Climate sensitivity, feedback, fast responses
1 % yr^{-1} CO_2 concentration increase	*1pctCO2*	CO_2 prescribed to increase at 1 % yr^{-1}	CO_2 concentration prescribed	n/a	n/a	150	Climate sensitivity, feedback, idealized benchmark
CMIP6 historical simulation							
Past ~1.5 centuries	*historical* or *esm-hist*	Simulation of the recent past	All; CO_2 concentration prescribed or calculated	1850	2014	165	Evaluation

Eyring et al. (2016,*GMD*)

CMIP6: MIPs Participation

MIP acronym	MIP name	Name of primary sponsor(s)
AerChemMIP	Aerosols and Chemistry Model Intercomparison Project	Lamarque/Emmons/Liu (Wyoming)
C4MIP	Coupled Climate Carbon Cycle Model Intercomparison Project	Lindsay
CDRMIP	Carbon Dioxide Removal Model Intercomparison Project	D. Lawrence/Lindsay
CFMIP	Cloud Feedback Model Intercomparison Project	Medeiros/Kay (CU)/Klein (LLNL)
DAMIP	Detection and Attribution Model Intercomparison Project	Tebaldi/Arblaster
DCPP	Decadal Climate Prediction Project	Danabasoglu/Meehl
GeoMIP	Geoengineering Model Intercomparison Project	Tilmes/Mills
GMMIP	Global Monsoons Model Intercomparison Project	Fasullo/Kinter (COLA)
HighResMIP	High Resolution Model Intercomparison Project	Neale/Bacmeister
ISMIP6	Ice Sheet Model Intercomparison Project for CMIP6	Lipscomb/Otto-Bliesner
LS3MIP	Land Surface, Snow and Soil Moisture	D. Lawrence
LUMIP	Land-Use Model Intercomparison Project	D. Lawrence/P. Lawrence
OMIP	Ocean Model Intercomparison Project	Danabasoglu/Lindsay
PAMIP	Polar Amplification Model Intercomparison Project	Deser/Philips
PMIP	Palaeoclimate Modelling Intercomparison Project	Otto-Bliesner
RFMIP	Radiative Forcing Model Intercomparison Project	Gettelman/Neale
ScenarioMIP	Scenario Model Intercomparison Project	Meehl/O'Neill/P. Lawrence
VolMIP	Volcanic Forcings Model Intercomparison Project	Mills/Otto-Bliesner
Data only		
CORDEX	Coordinated Regional Climate Downscaling Experiment	Mearns/Gutowski
DynVar	Dynamics and Variability of the Stratosphere-Troposphere System	Marsh
SIMIP	Sea-Ice Model Intercomparison Project	Bailey/Holland/Jahn (CU)/Hunke (LANL)
VIAAB	VIA Advisory Board for CMIP6	Mearns/O'Neill

Target completion time frame for the simulations: Summer 2019

Welcome to NCAR!

Questions & Comments?