Introduction to the Community Earth System Model (CESM)

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NSF

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OUTLINE

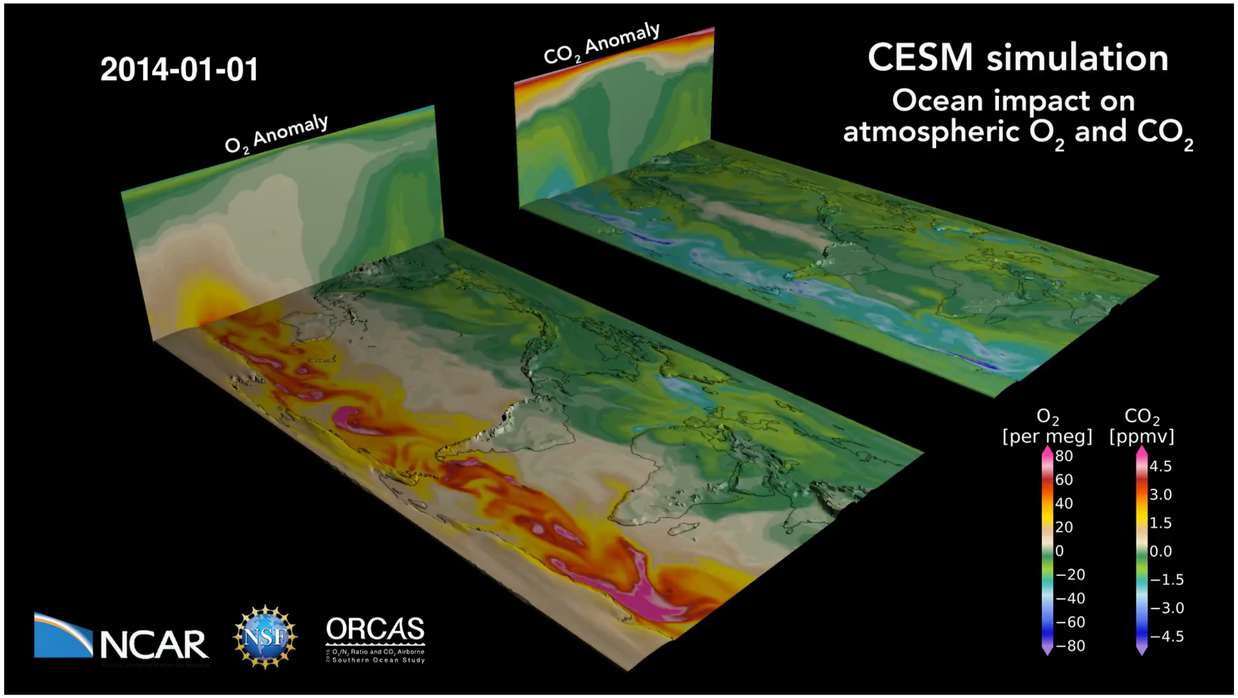
- Global earth system models
- Community Earth System Model (CESM)
- Capabilities and Applications
- Coupled Model Inter-Comparison Project phase 6 (CMIP6)
- CESM version 2 (CESM2) highlights

Global Earth System Models

A virtual laboratory for experimentation ….

General purposes include:

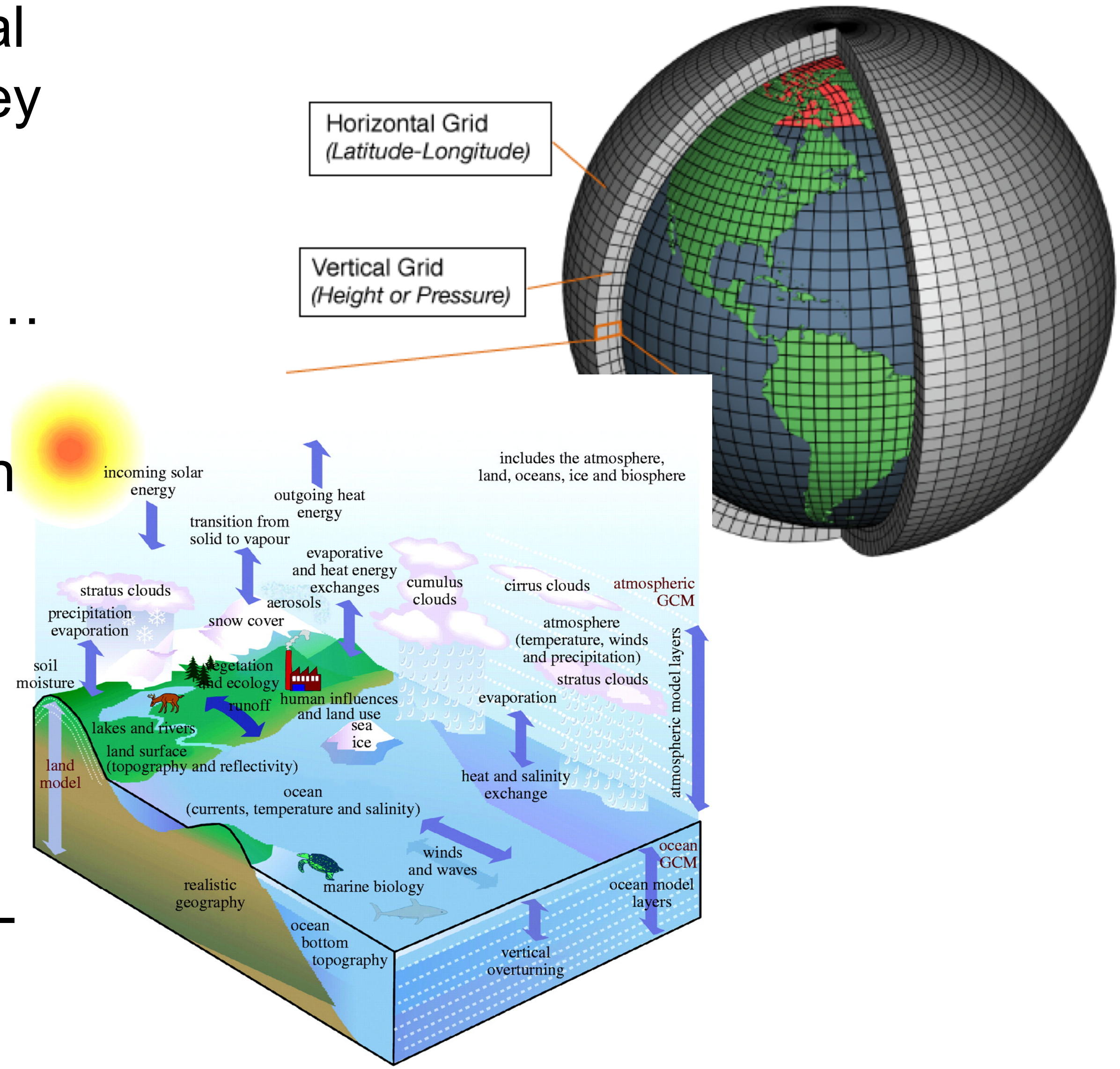
- To provide scientific understanding of observed events, climate change (historical, paleo), etc.,
- To simulate future climate change and its impacts,
- To make future predictions of weather and climate variability.



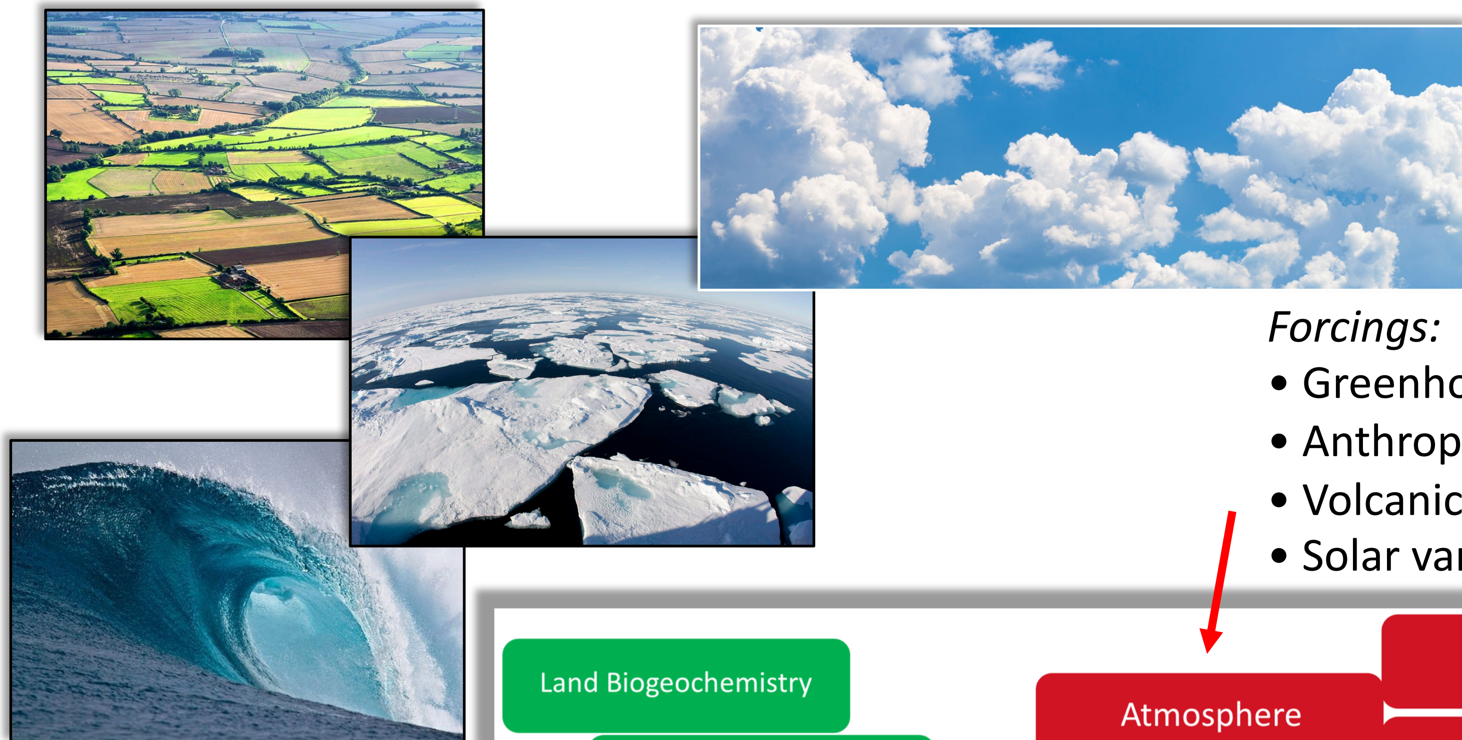
Long and Scheitlin

Global Earth System Models

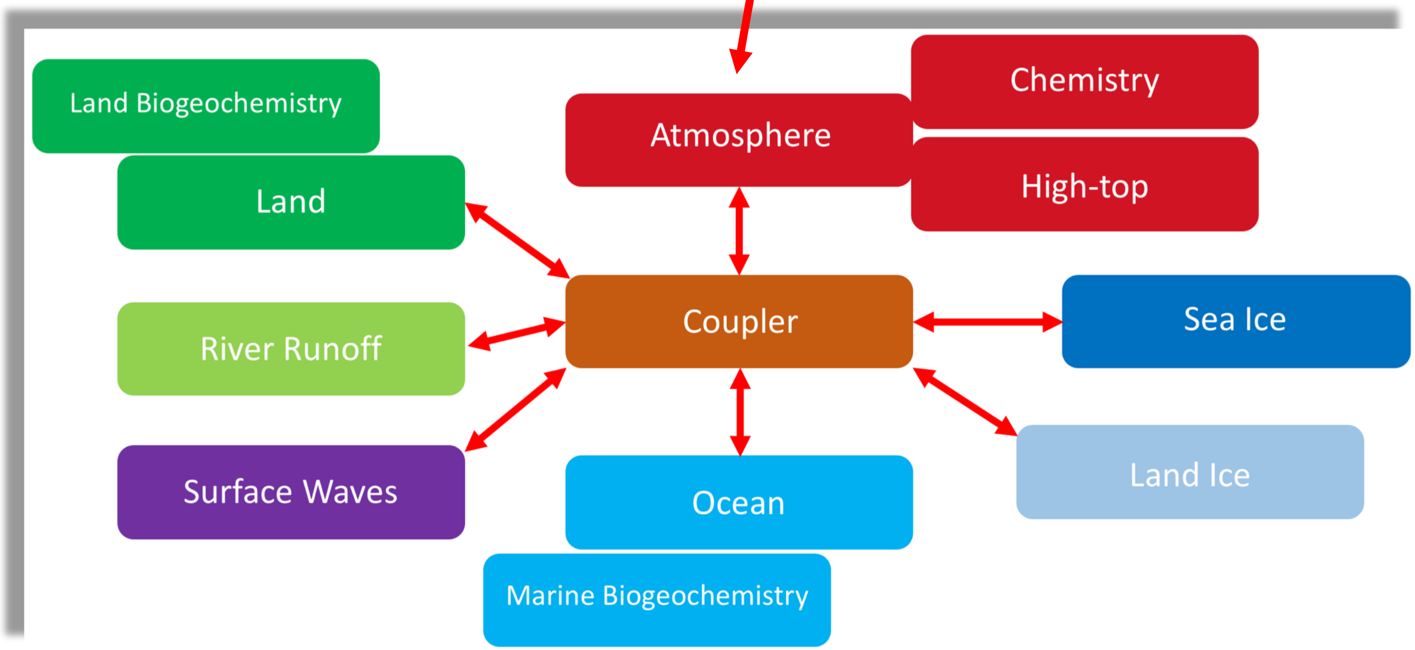
- The models use physical equations to simulate key fields and processes in the atmosphere, ocean, land, sea-ice, land-ice, …
- Processes that remain below the grid resolution need to be parameterized.
- Build on our understanding of processes from observations and highly-detailed models (e.g., process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



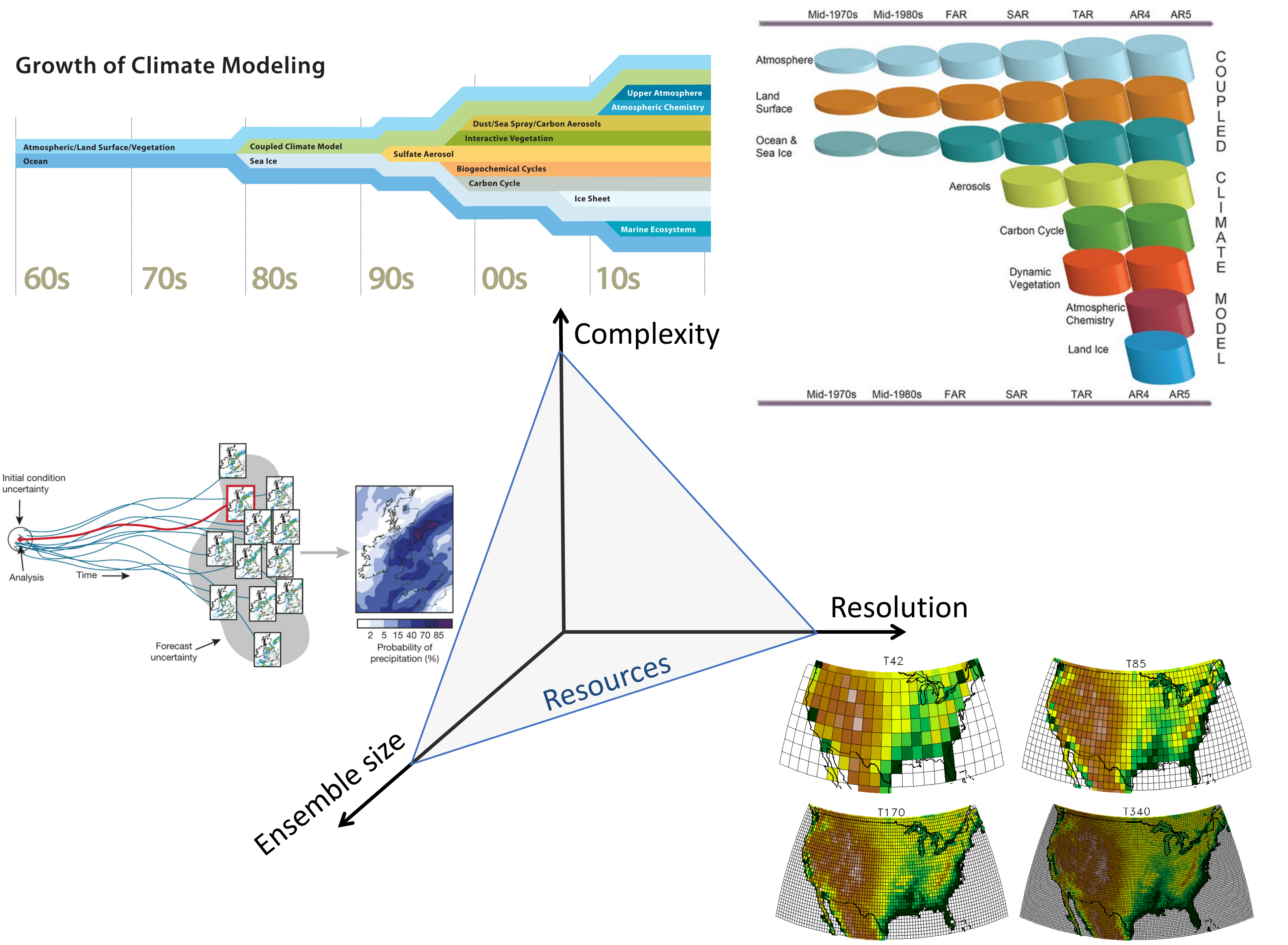
Global Earth System Models



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



Community Earth System Model



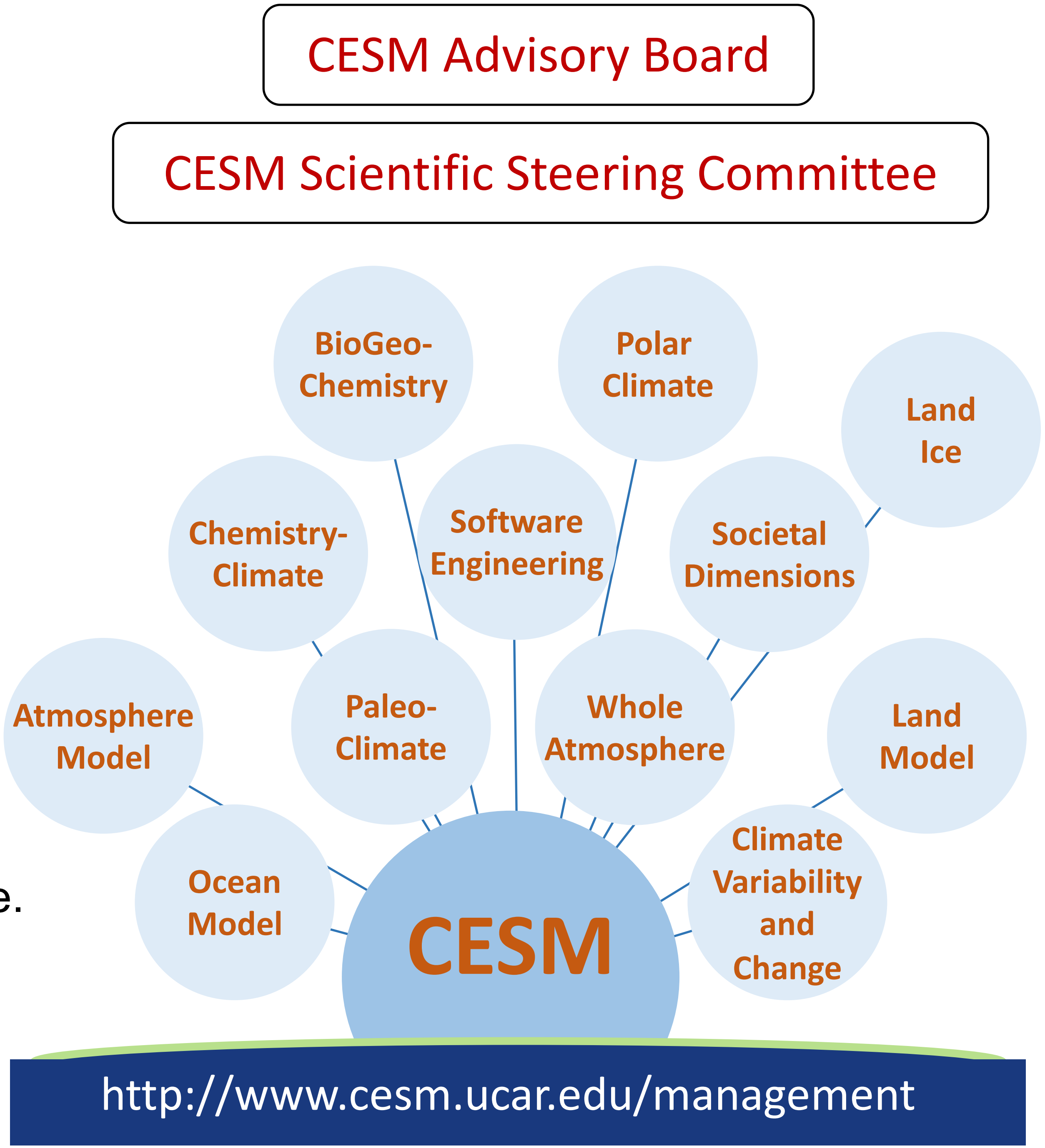
Growth of Climate Modeling
Atmospheric/Land Surface/Vegetation
Ocean
Coupled Climate Model
Sea Ice
Sulfate Aerosol
Biogeochemical Cycles
Carbon Cycle
Interactive Vegetation
Dust/Sea Spray/Carbon Aerosols
Ice Sheet
Upper Atmosphere
Atmospheric Chemistry
Marine Ecosystems
60s
70s
80s
90s
00s
10s
Mid-1970s 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
Complexity
Resolution
Resources
Ensemble size
Initial condition uncertainty
Analysis
Time
Forecast uncertainty
2 5 15 40 70 85
Probability of precipitation (%)
T42
T85
T170
T340

CESM Project

20+ years of model development and applications

Most working groups have winter/spring meetings.

Annual meeting in June.

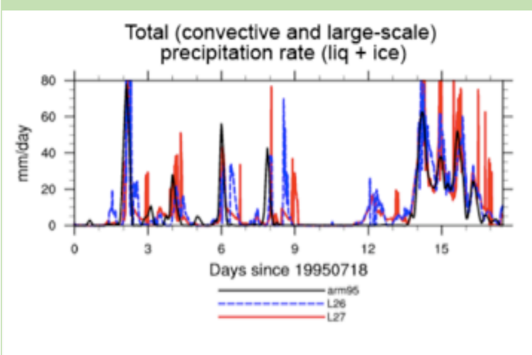


CAPABILITIES AND APPLICATIONS

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

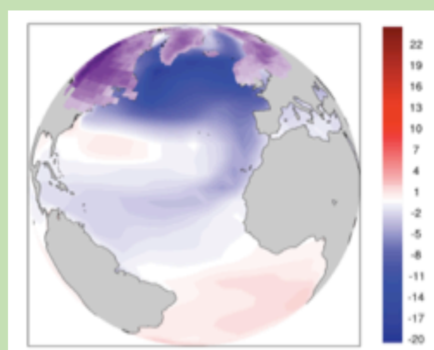
Desktop

Single column/
Coarse resolution:
Physics development



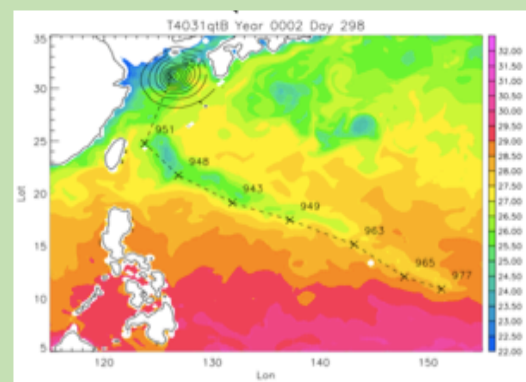
Small cluster

Lower resolution:
Paleo/Large Ensemble
University research



HPC

Higher resolution:
CMIP
Breakthrough Applications



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”

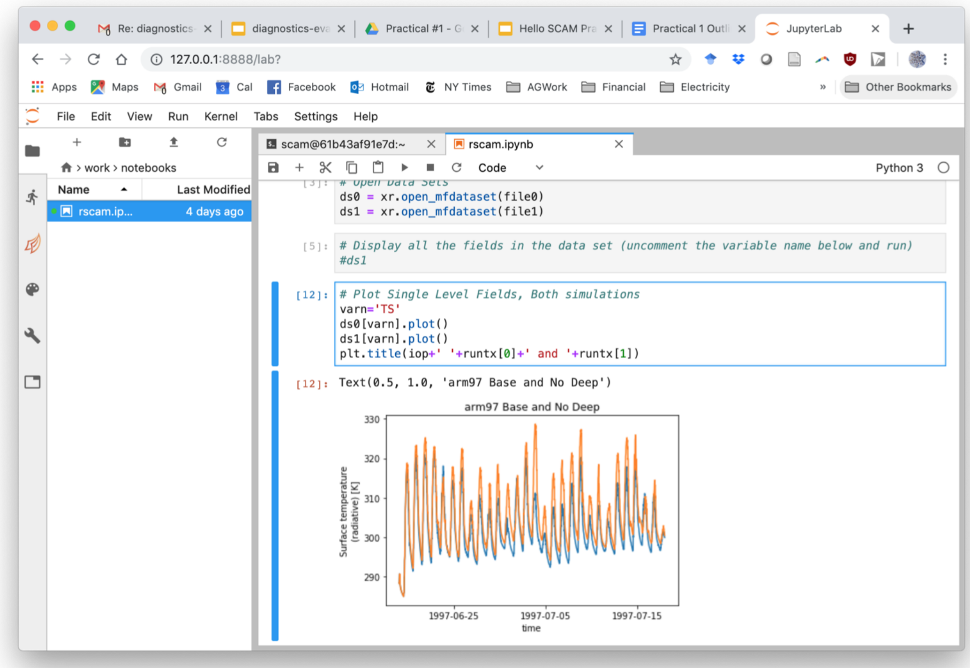
  Allowing, for example, ocean-only, ocean – sea-ice coupled, land-only, atmosphere-only, etc. configurations / experiments.

- Aqua planet, several 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.

CESM2 runs on the Cloud, but it also runs on a Laptop!

- AMWG and CISL have developed a docker container version of CESM2 configured for a Single Column Model (SCAM6)
- Runs full CESM code (including build, compile, run) with the *Jupyter Lab* Interactive Development Environment
- Used in CAM tutorial in June 2019
- Container install on Mac, Linux, & Windows

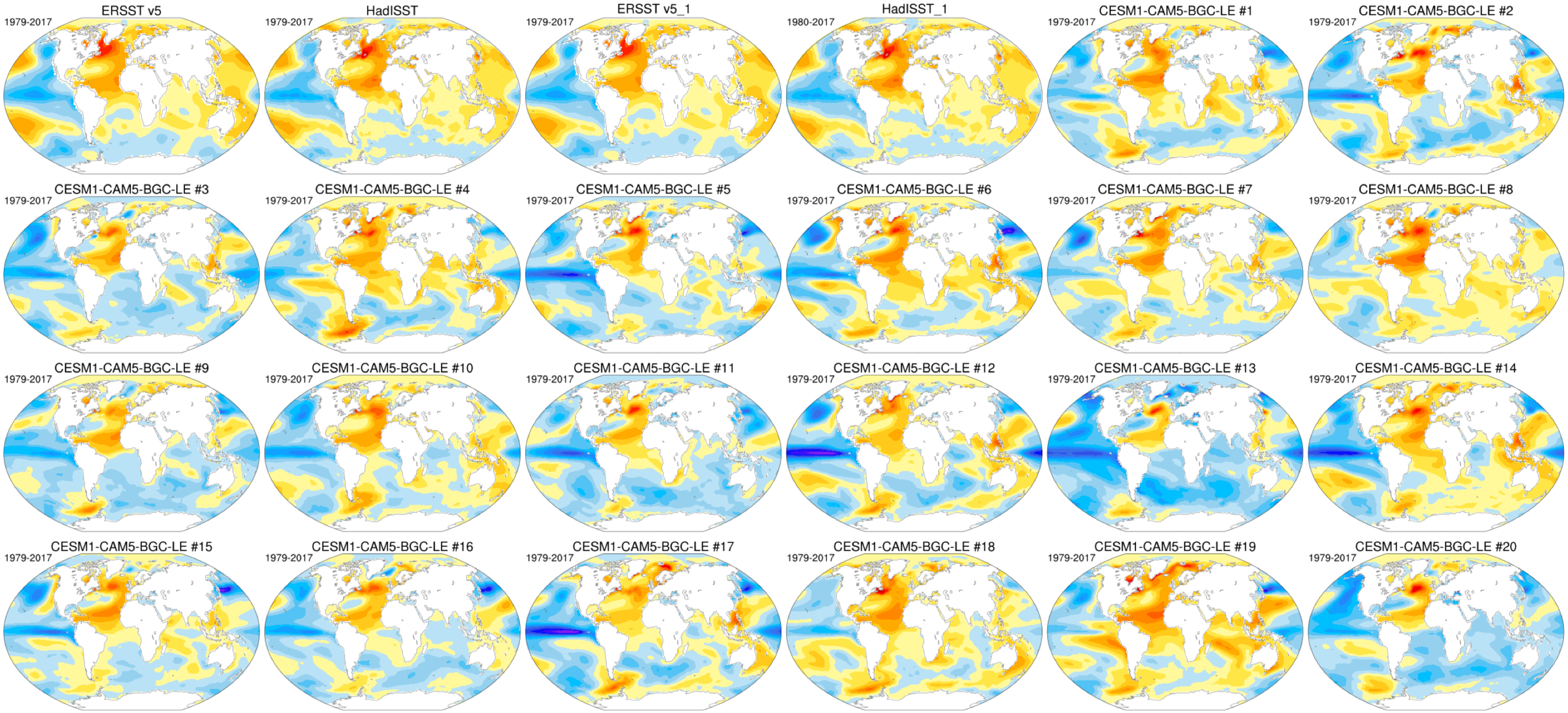
http://www.cesm.ucar.edu/models/cesm2/atmosphere/CAM6tutorial/



Gettelman, Truesdale, Dobbins, Bacmeister, Larson, and Donner

CESM Large Ensemble Simulations

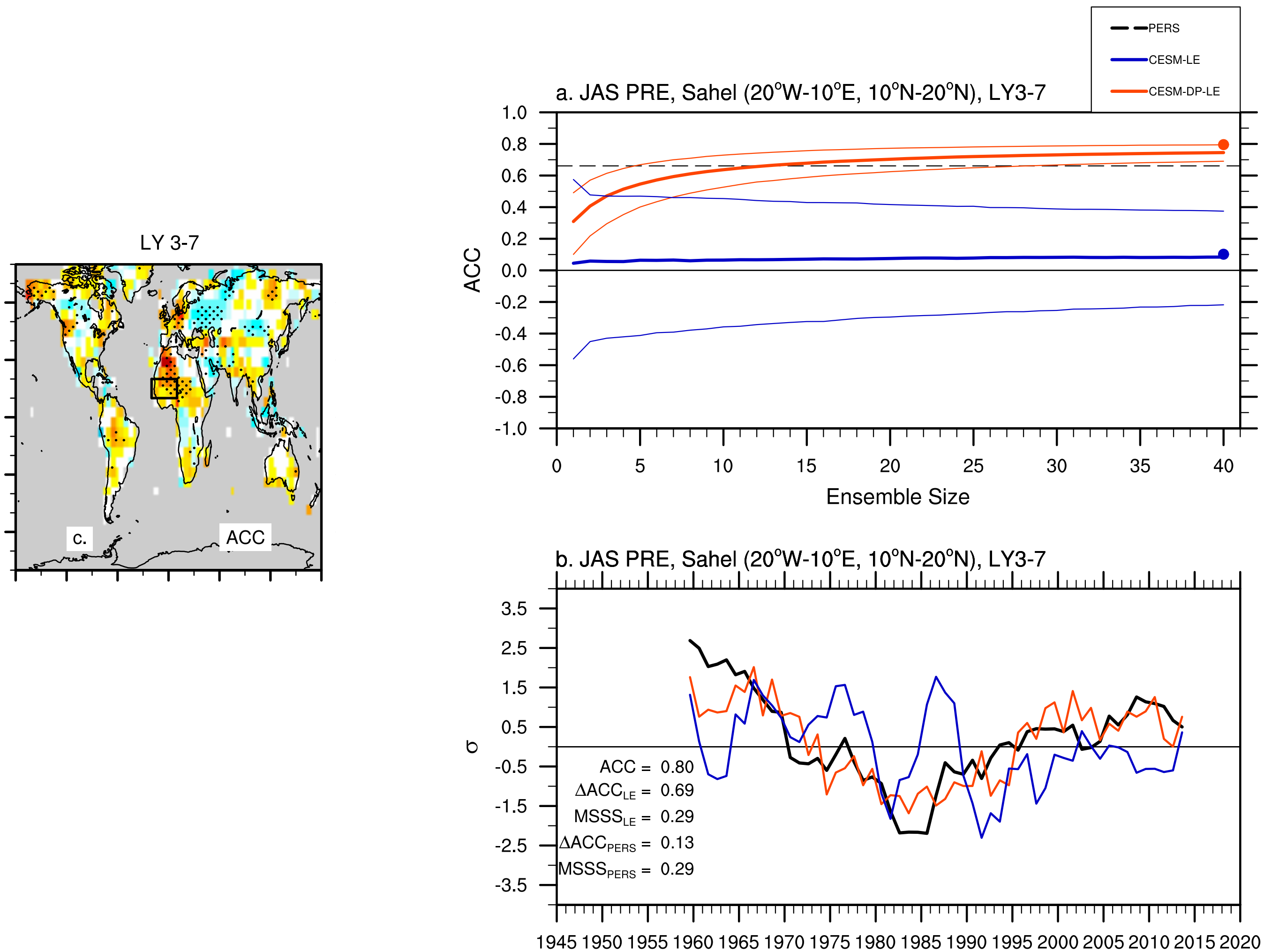
Atlantic Multi-Decadal Variability (AMV)



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

CESM Decadal Prediction Large Ensemble (CESM-DPLE)

Summer Precipitation in the Sahel



Yeager et al. (2018, BAMS)

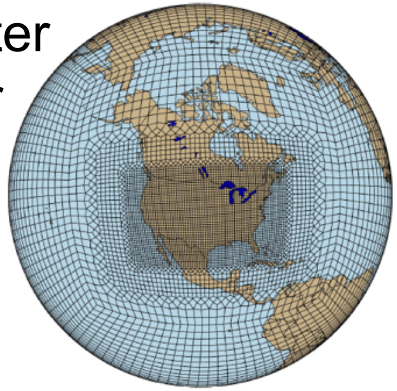
CAM6-chem with Variable Resolution

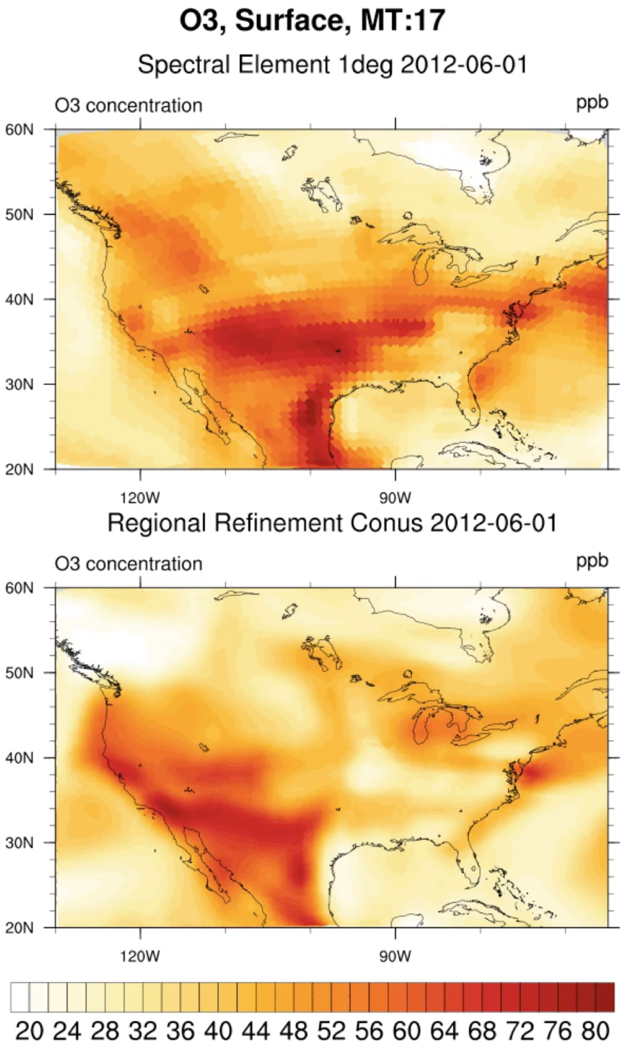
CAM6-chem with Spectral Element (SE) and regional refinement is running with ~14 km over U.S. (~1° elsewhere)

Allows regional-scale air quality modeling in the global model

Current science goals:

- Studying air quality and health impacts in U.S.
- Evaluating importance of greater chemical complexity vs. higher horizontal resolution

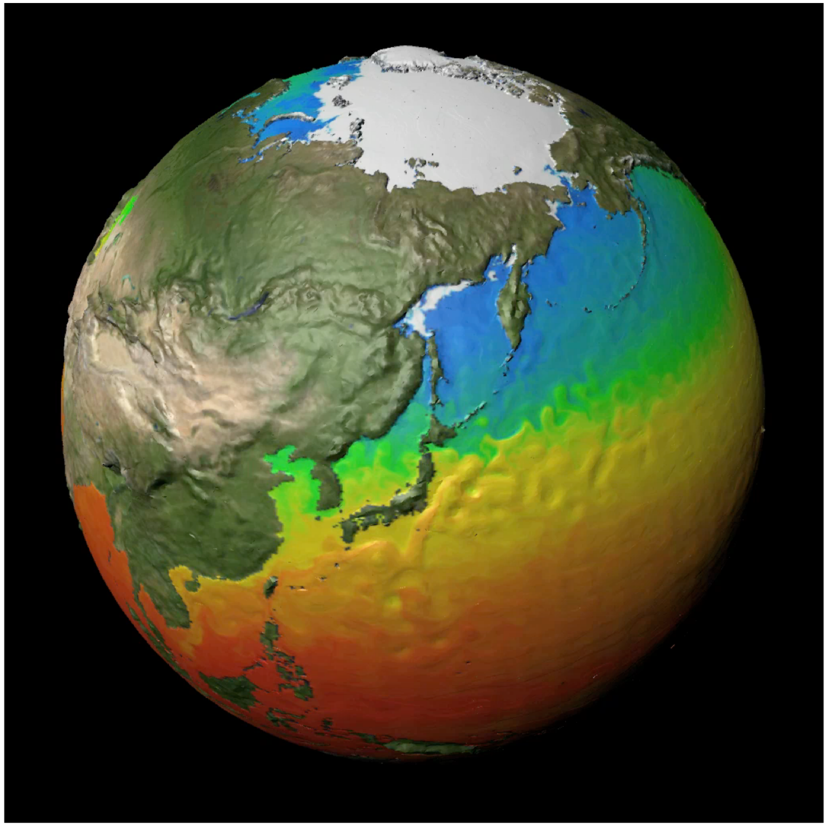




Lacey, Schwantes, Tilmes, Lauritzen, Bacmeister, Callaghan, Walters, Vitt et al.

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



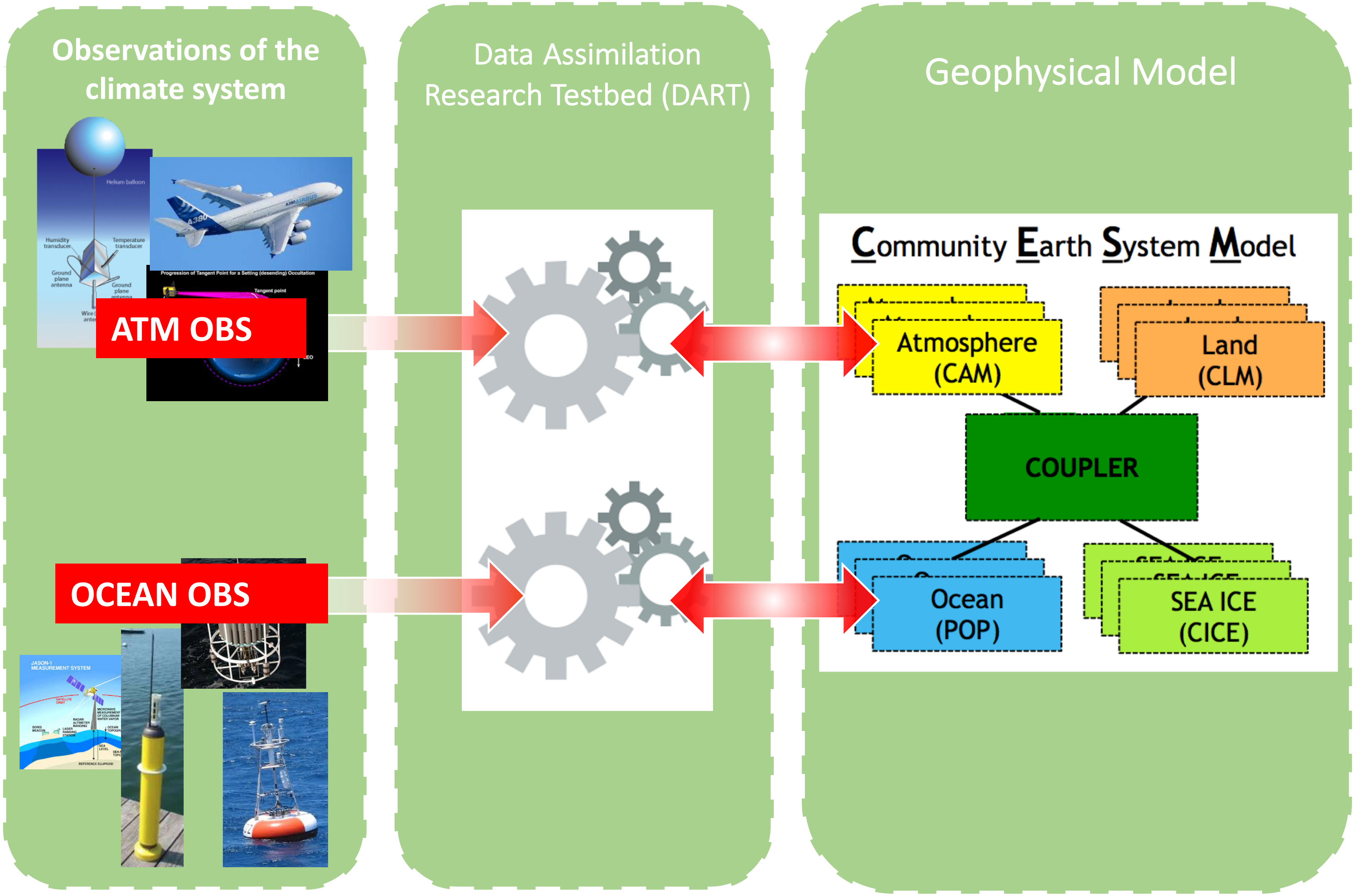
Small and Scheitlin

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

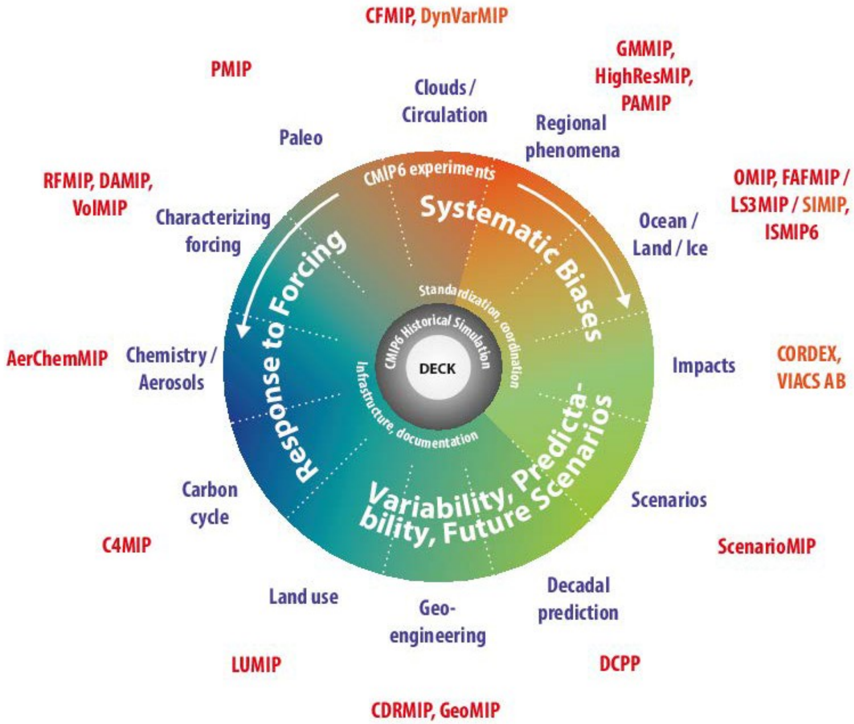
“WEAKLY” Coupled Data Assimilation: The cutting Edge



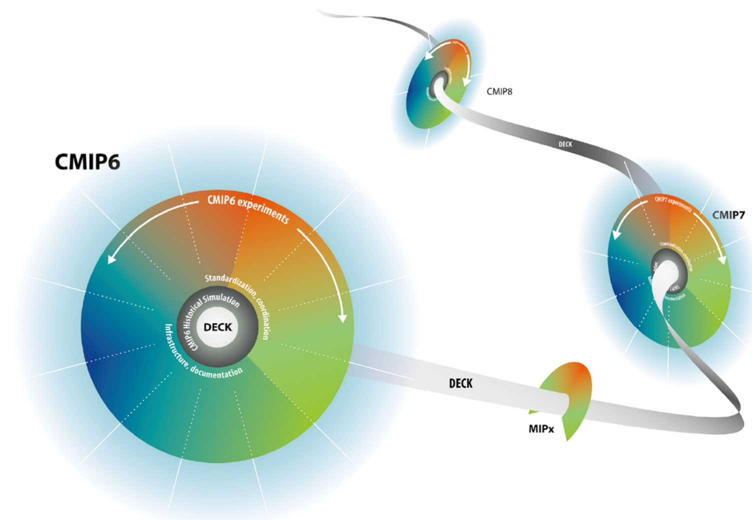
System includes coupled interactions, is “balanced” during “forecast” phase, can use most observational information.

COUPLED MODEL INTERCOMPARISON PROJECT PHASE 6 (CMIP6)

CESM2 Participation in CMIP6



Diagnostic, Evaluation, and Characterization of Klima (DECK)



- Pre-industrial control
- 1%CO2
- 4xCO2
- AMIP

Two nominal 1º model versions: CAM6 and WACCM6 atmospheric model components

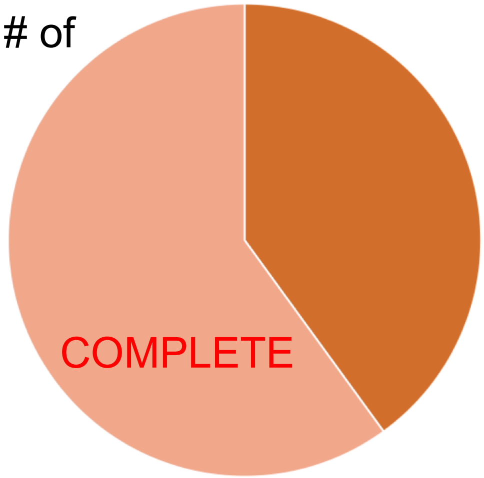
Eyring et al. (GMD, 2016)

MIP Tier1 Simulations

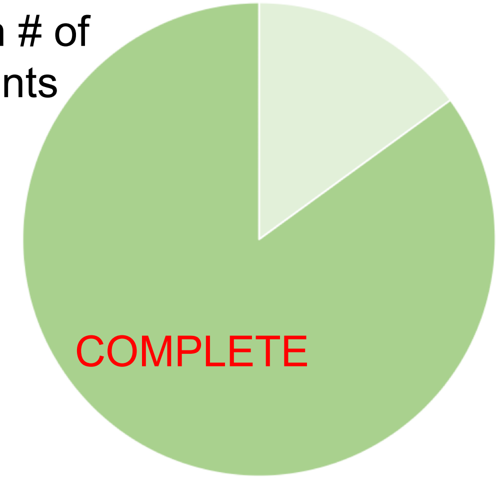
DECK & Historical Simulations

Experiment	w/ CAM6	w/ WACCM6
PI control	1200 years	500 years
1%CO2	1 member	1 member
4xCO2	1 member	1 member
AMIP	3 members	3 members
20C historical	11 members	3 members

Based on # of cases

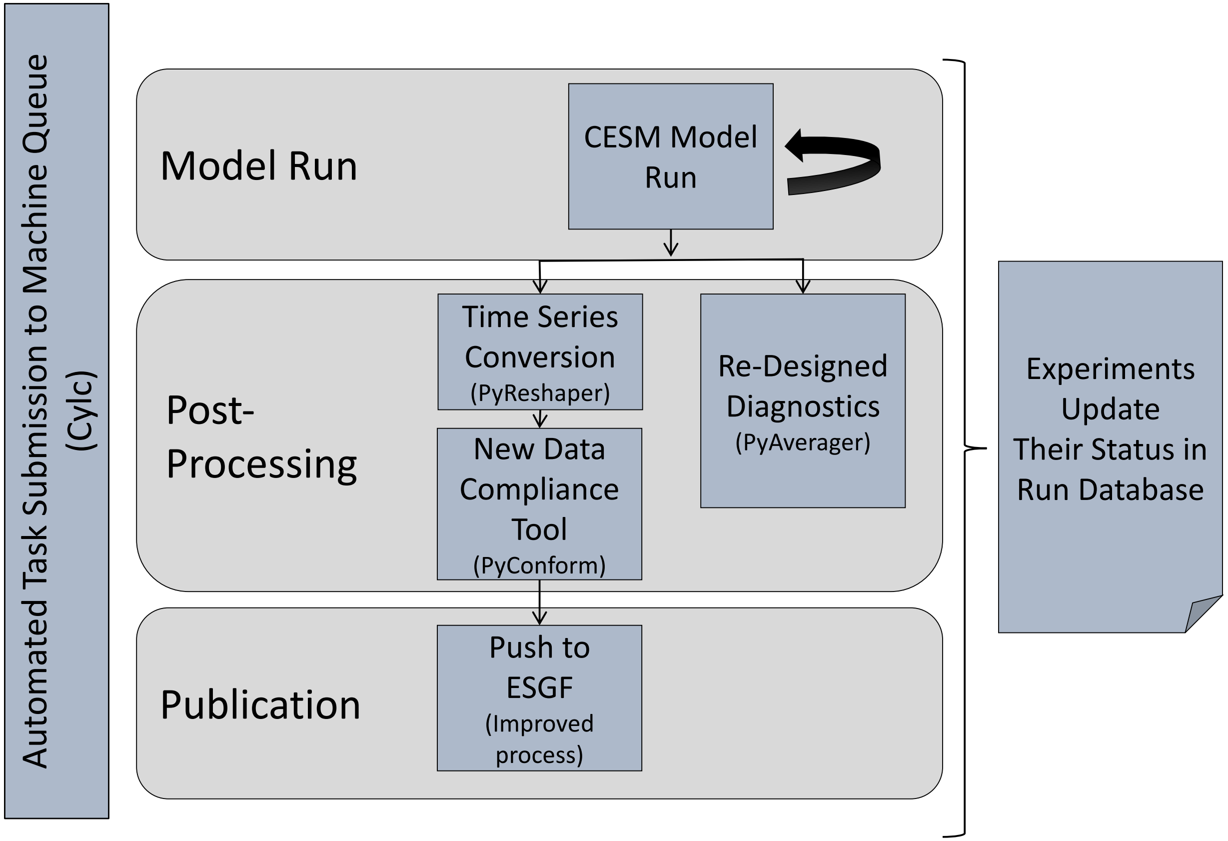


Based on # of experiments



Acknowledgment: NSF supplemental support

CESM/CMIP6 Workflow



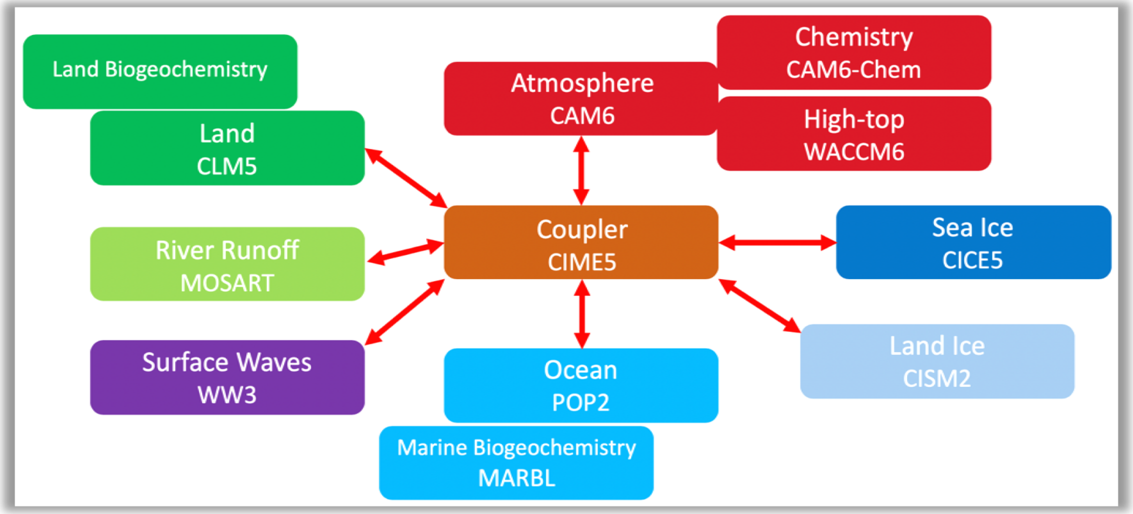
Acknowledgment: CISL…. Mickelson, Nienhouse, User Services Section;
Also Strand and Bertini

CESM2 *Incremental* Releases

CESM2.1.0 on 10 December 2018

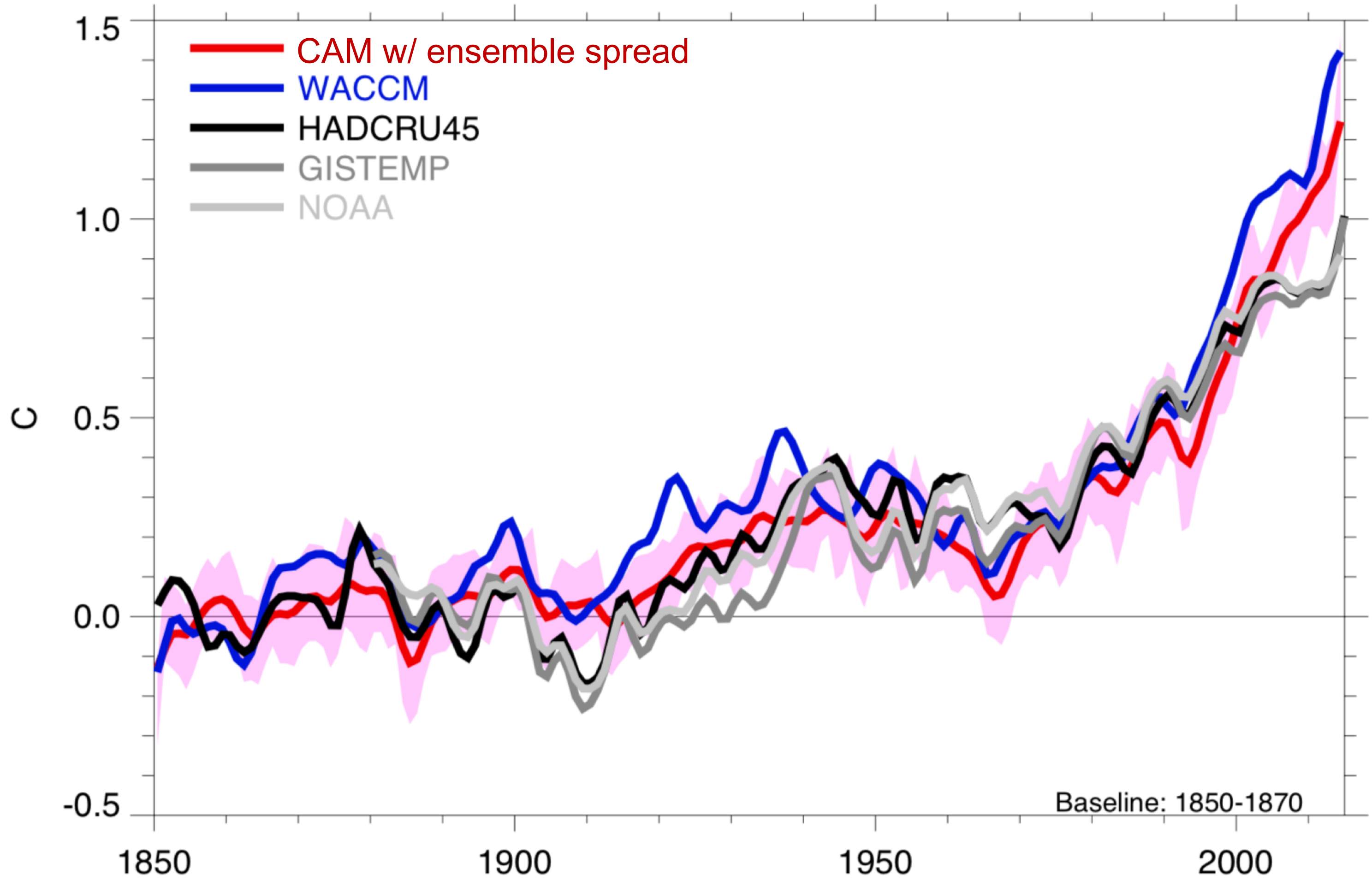
CESM2.1.1 on 10 June 2019

- CESM2.1.1 further expands the available set of out-of-the-box configurations of CESM2 for readily performing all of the DECK, historical, and several MIP Tier 1 simulations.
- It also contains functional release of component sets that use 2º CAM6 and WACCM6 versions.



CESM2 HIGHLIGHTS

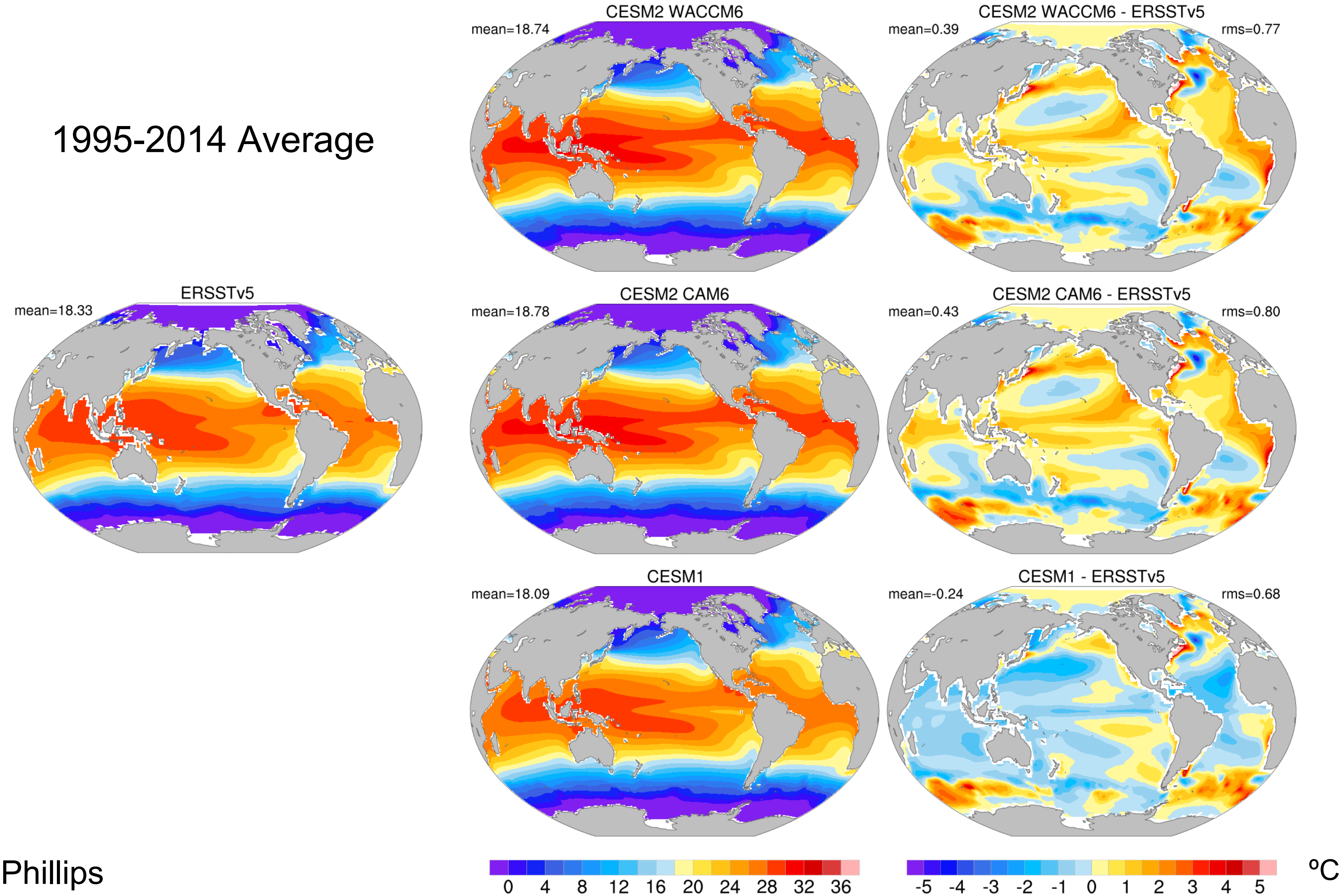
Global-Mean Surface Temperature Time Series



Fasullo

Sea Surface Temperature (SST)

1995-2014 Average



Phillips

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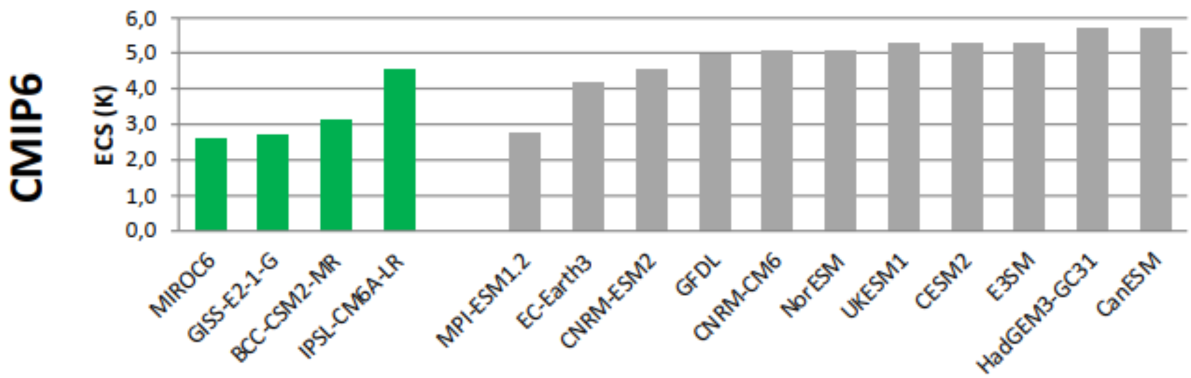
Equilibrium Climate Sensitivity (2 x CO2)

Nominal 1º resolution with a Slab Ocean Model (SOM)

CCSM3:	2.9ºC
CCSM4 (CAM4):	3.2ºC
CESM1 (CAM5):	4.1ºC
CESM2.0:	5.3ºC

Our investigations suggest that the increased ECS in CESM2 has arisen from a combination of relatively small changes to cloud microphysics and boundary layer parameters that were introduced during the development process. In particular, the major physics developments such as CLUBB are not themselves responsible for the increased ECS.

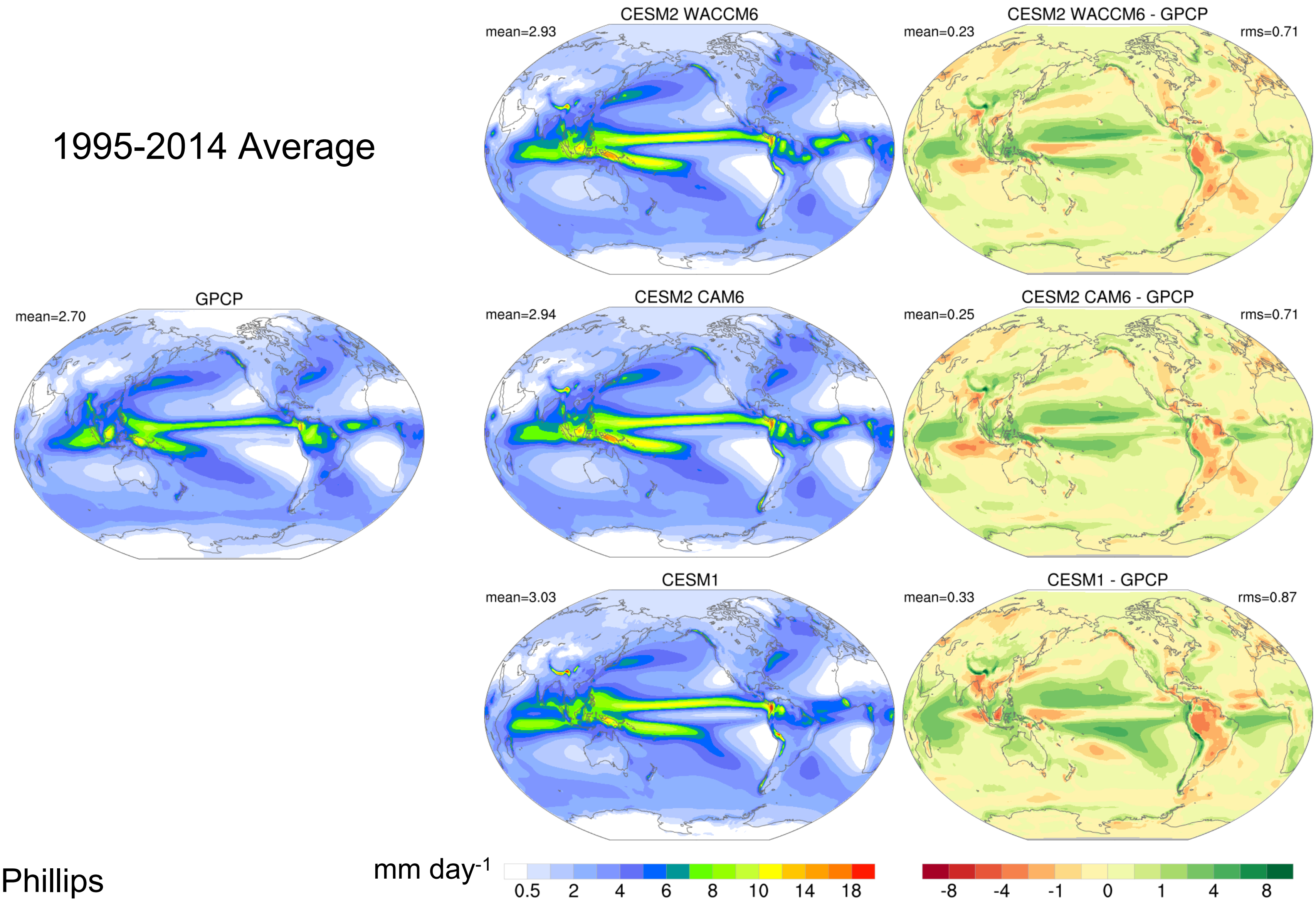
Equilibrium Climate Sensitivity (2 x CO2)



Eyring

Precipitation

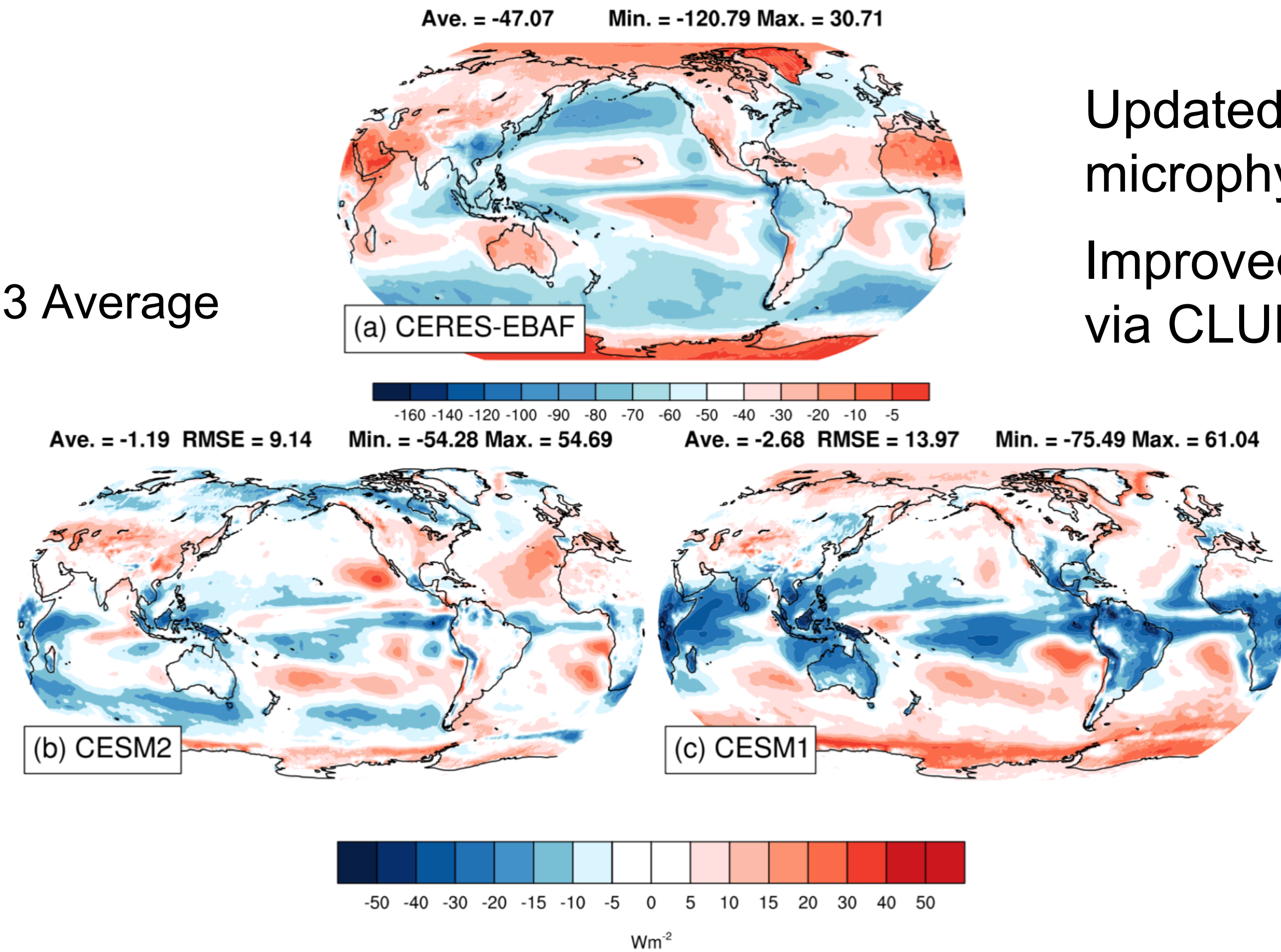
1995-2014 Average



Phillips

Short-Wave Cloud Forcing

2000-2013 Average



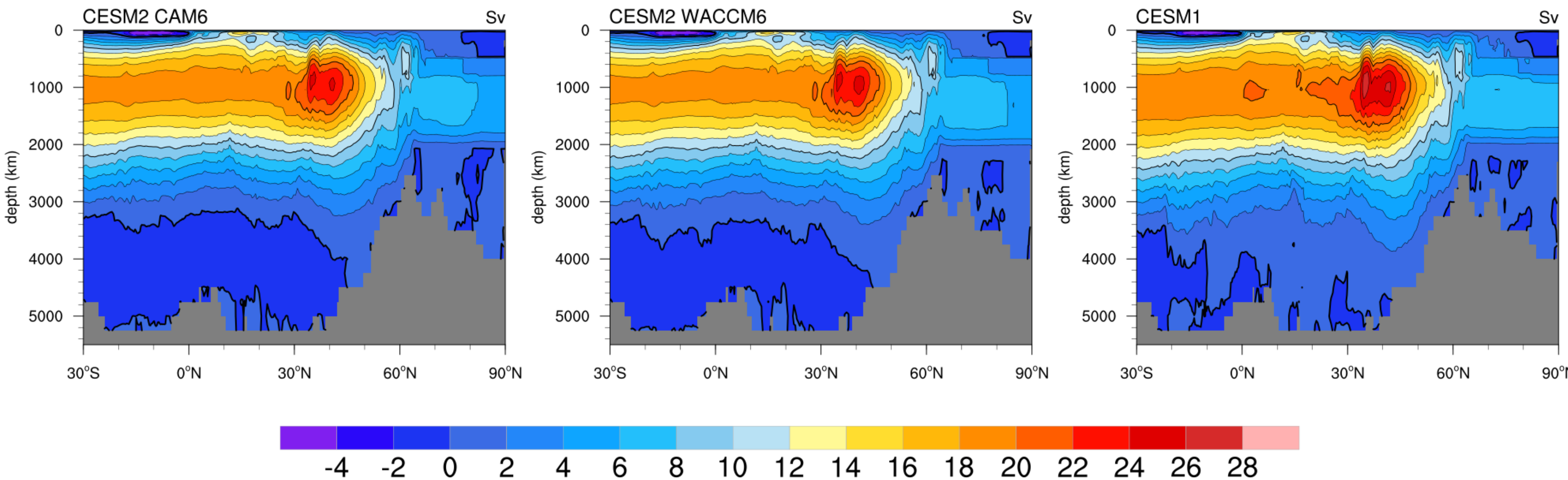
Updated MG2 microphysics

Improved low clouds via CLUBB*

Neale

*Cloud Layers Unified By Binormals

Atlantic Meridional Overturning Circulation (AMOC)



1995-2014 Average

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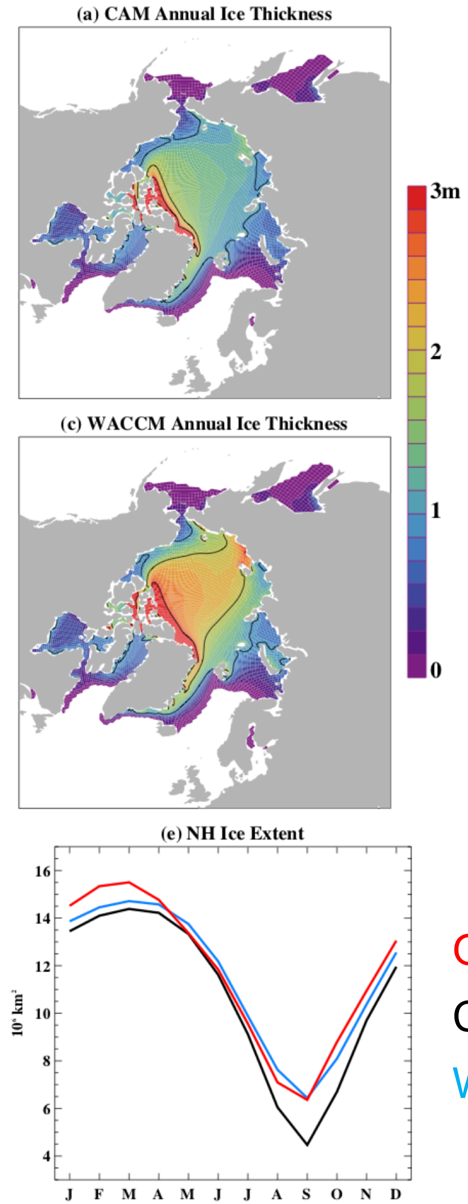
Arctic Sea Ice
(1979-2014 Average)

CAM6

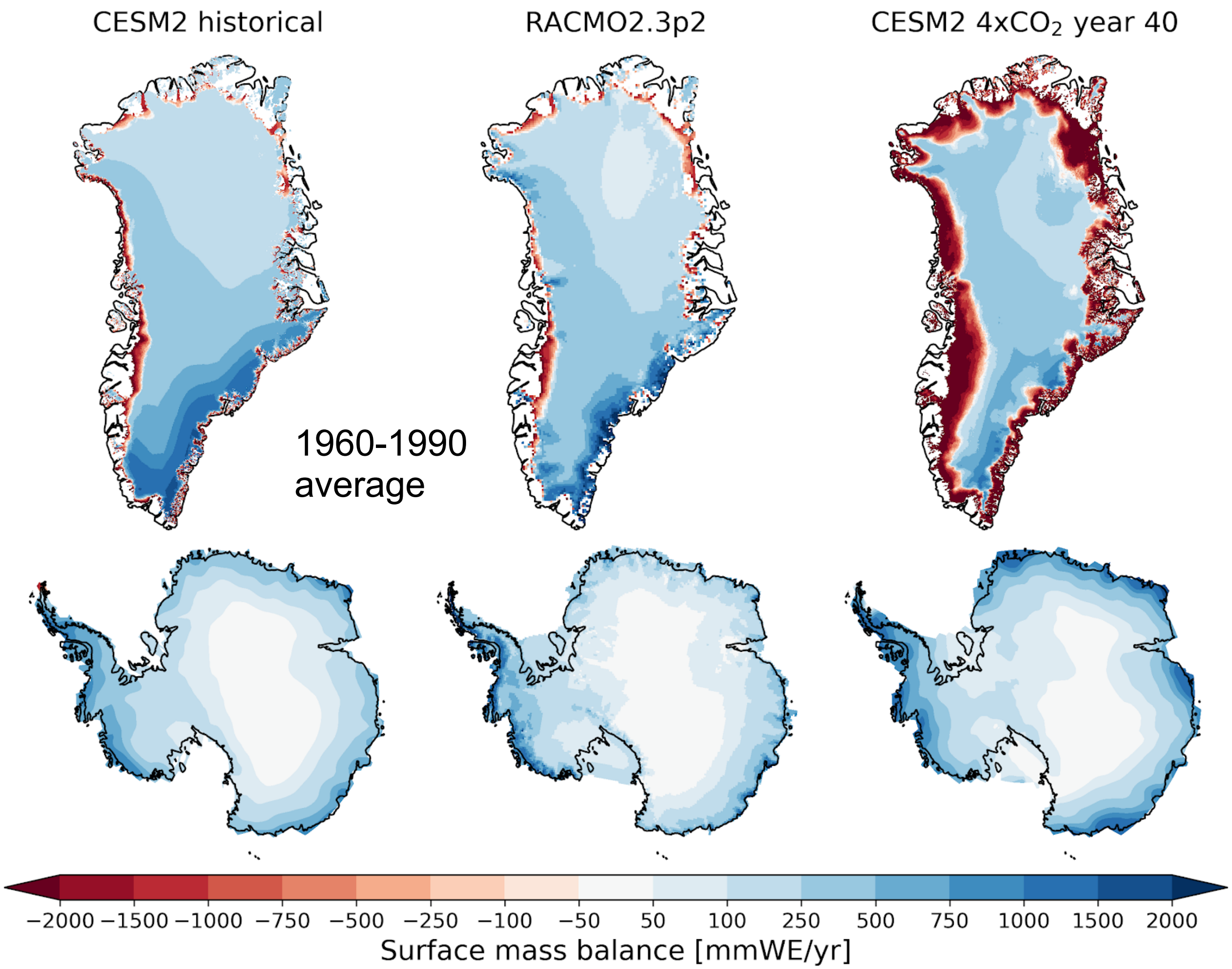
WACCM6



Obs
CAM6
WACCM6

Holland, Bailey, and DuVivier

Surface Mass Balance of the Greenland and Antarctic Ice Sheets



Lipscomb and Lofverstrom

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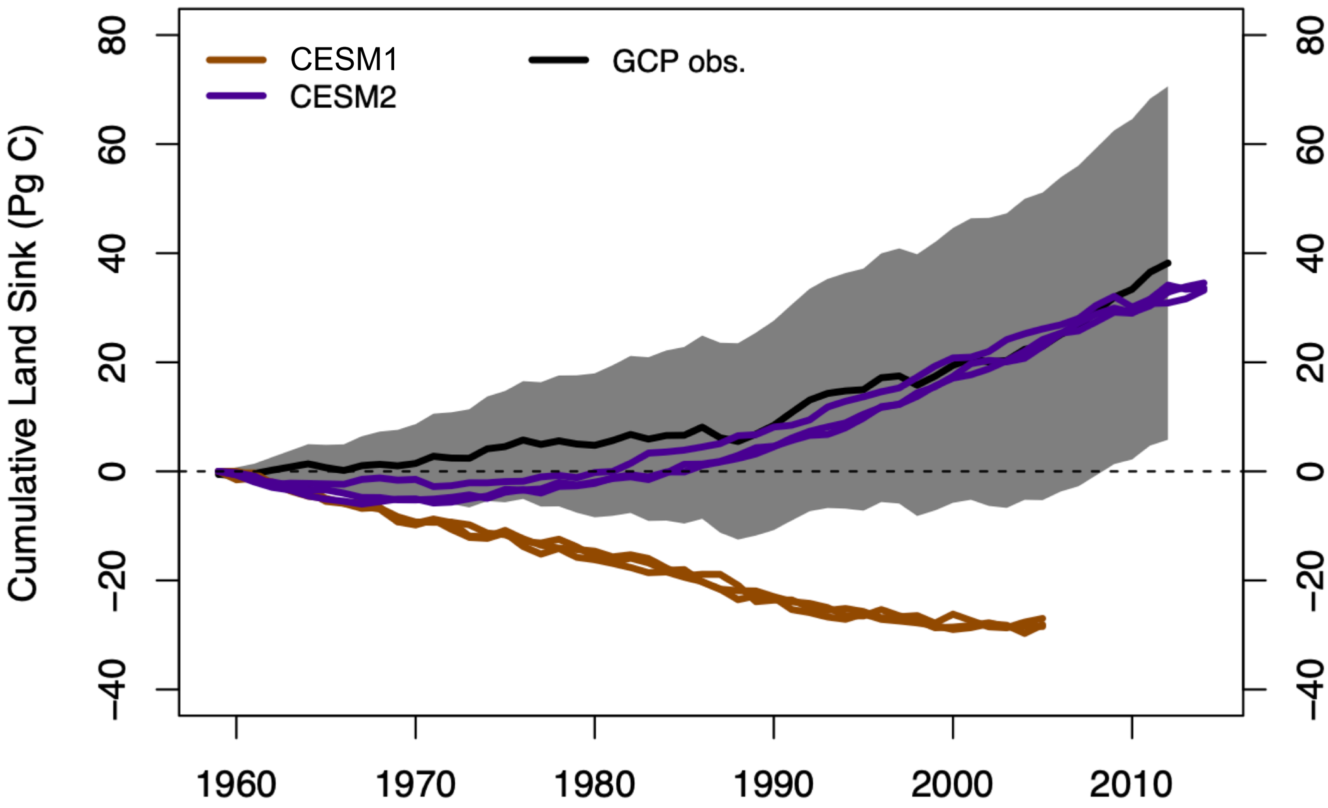
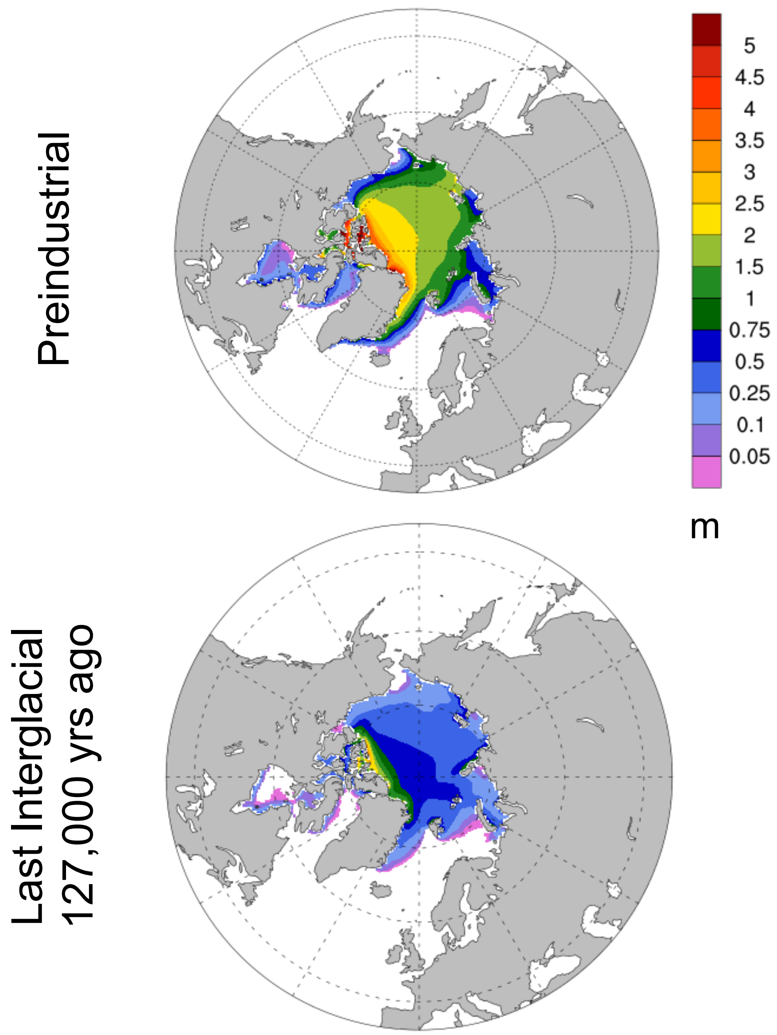
Land Carbon Accumulation



LMWG

CESM2 CMIP6 Last Interglacial Simulation

JAS ice thickness

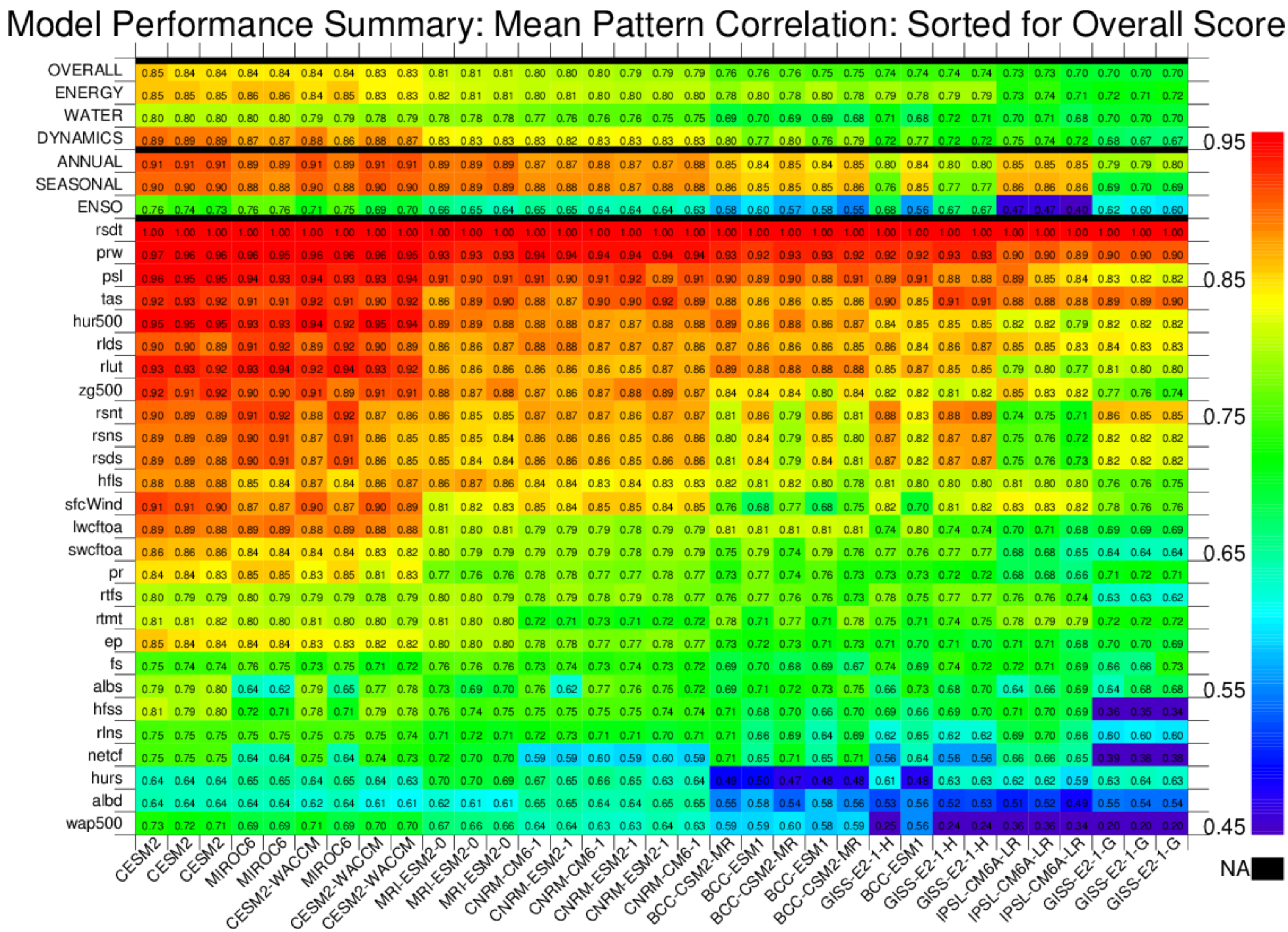


With enhanced summer insolation

- Proxies indicate reduced summer sea ice in the Arctic
- CESM2 simulates much thinner JAS sea ice & retreat of ice edge in GIN Seas
- Warmer temperatures contribute to the retreat of the Greenland ice sheet

Bailey, Brady, Otto-Bliesner, and Tomas

A Model Performance Summary



Fasullo; Climate Model Analysis Tool (CMAT)

Welcome to NCAR!