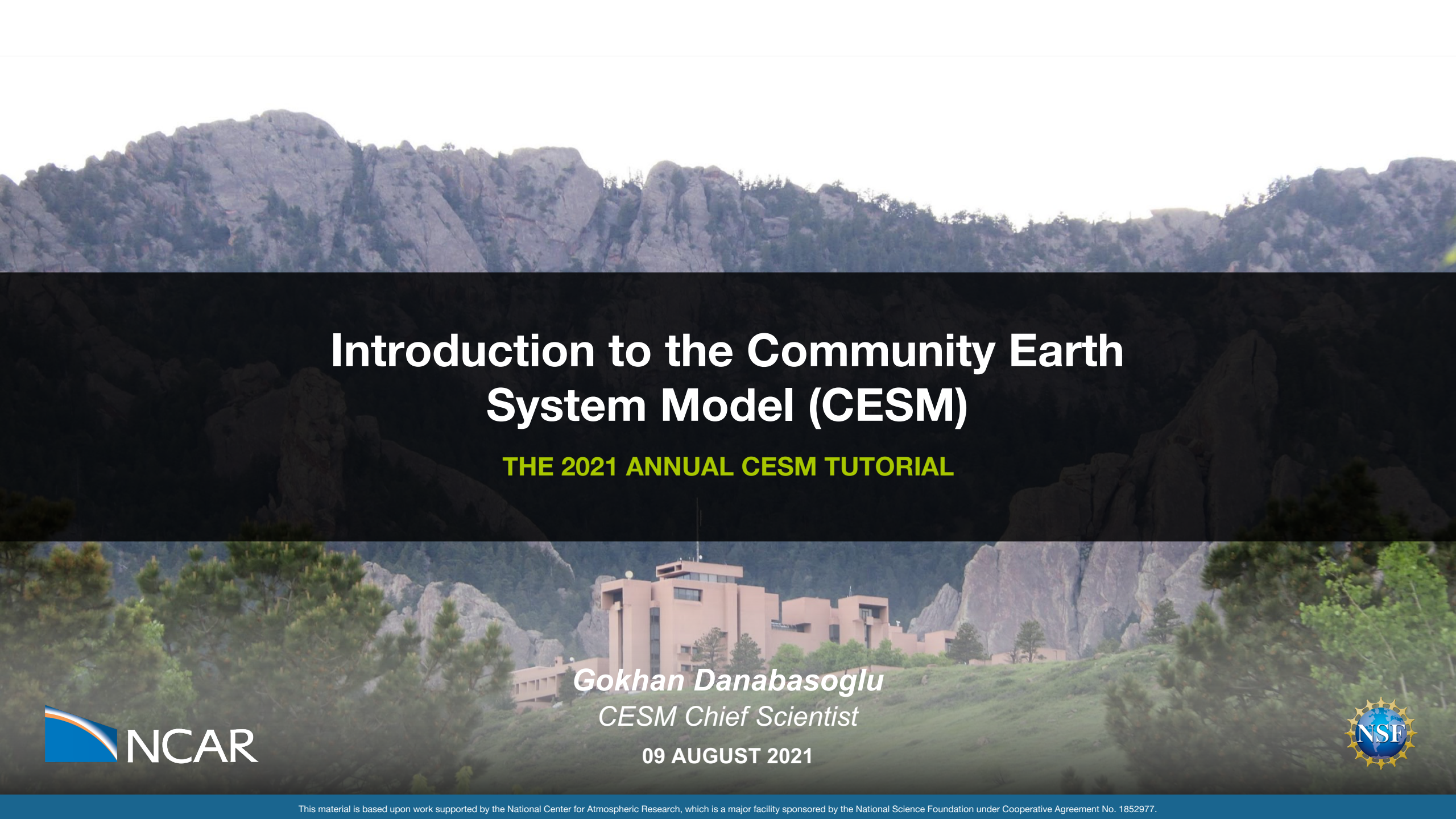


Introduction to the Community Earth System Model (CESM)

THE 2021 ANNUAL CESM TUTORIAL

Gokhan Danabasoglu

CESM Chief Scientist

09 AUGUST 2021

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Outline

- Global Earth system models and CESM
- Coupled Model Intercomparison Project phase 6 (CMIP6) Efforts
- Updates and highlights from ongoing activities
- Towards CESM3

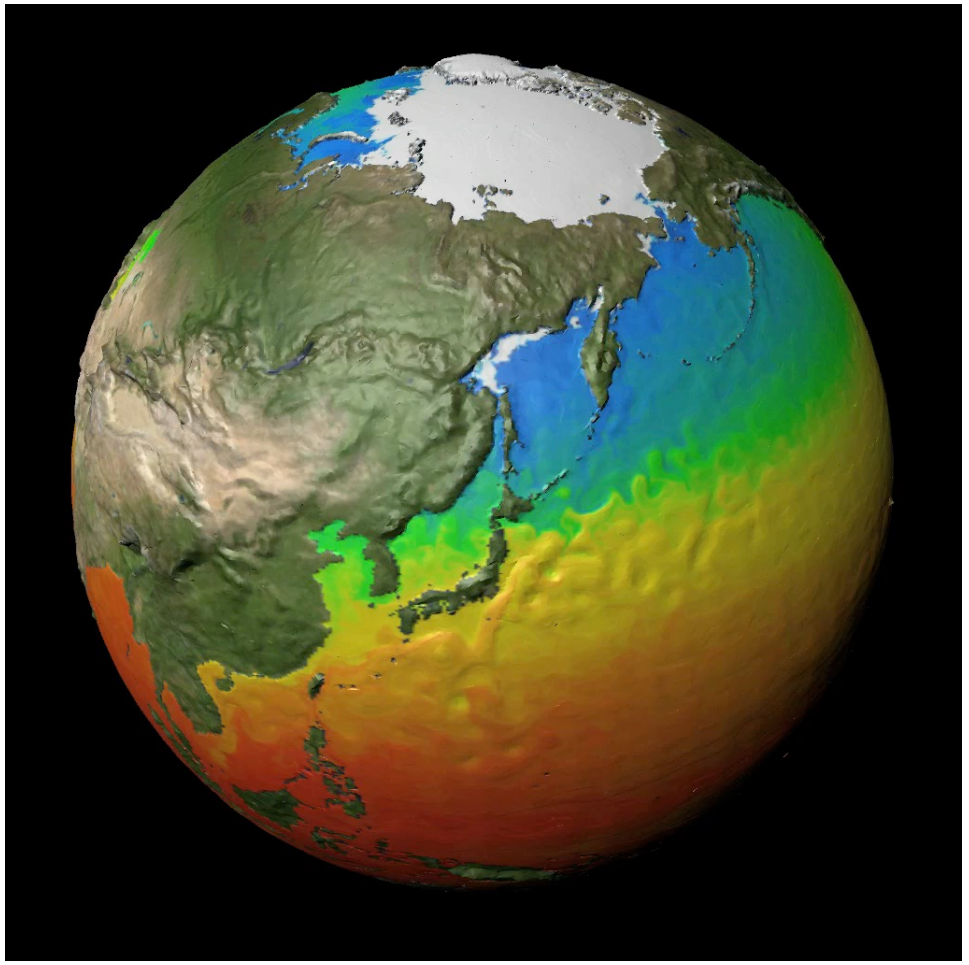
Global Earth System Models and CESM

Global Earth System Models

A virtual laboratory for experimentation ….

General purposes include:

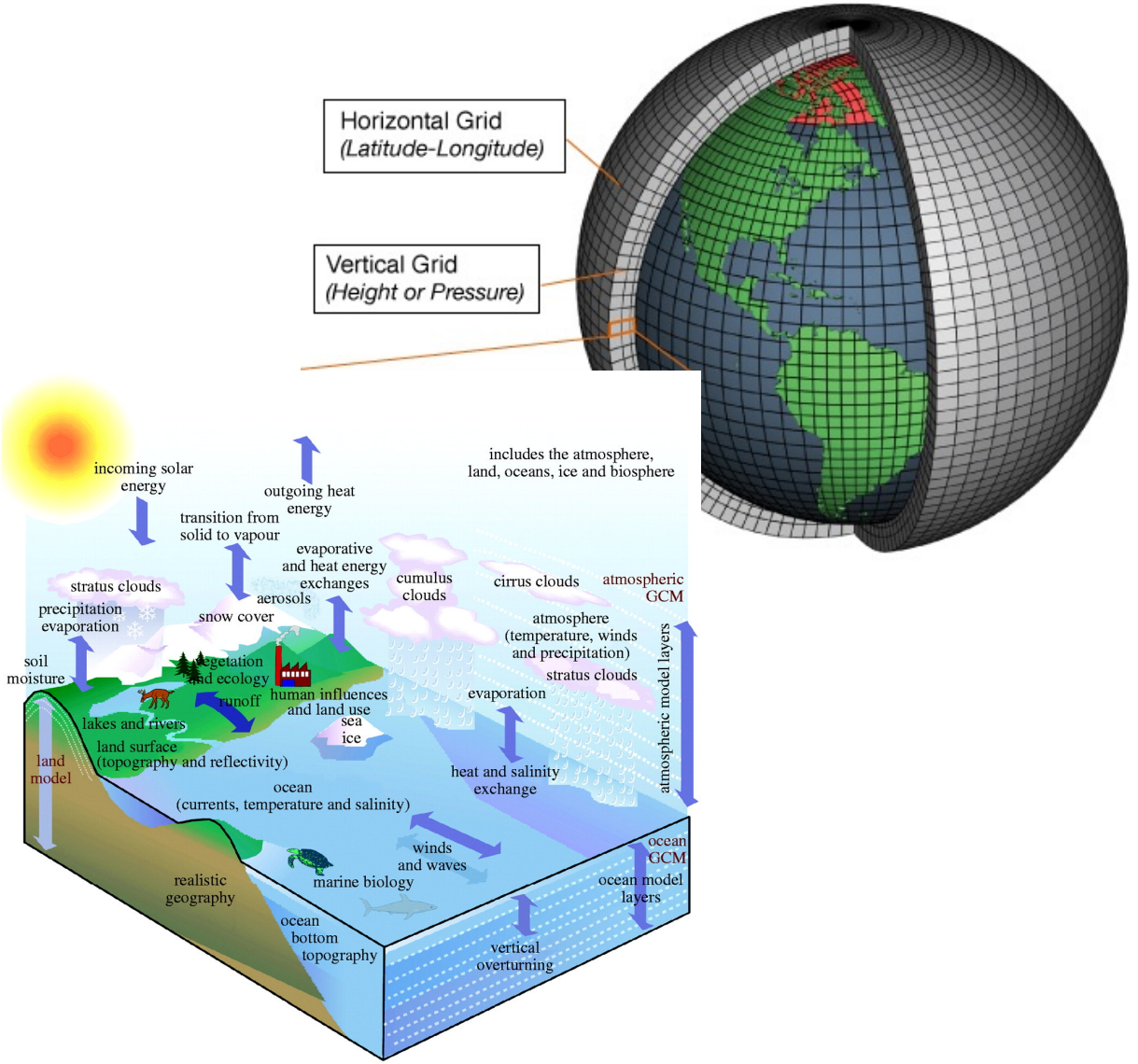
- Providing scientific understanding of past observed events and changes;
- Simulating future climate change and its impacts;
- Making future predictions of climate changes and variability; and
- Providing actionable, societally-relevant information.



Small and Scheitlin

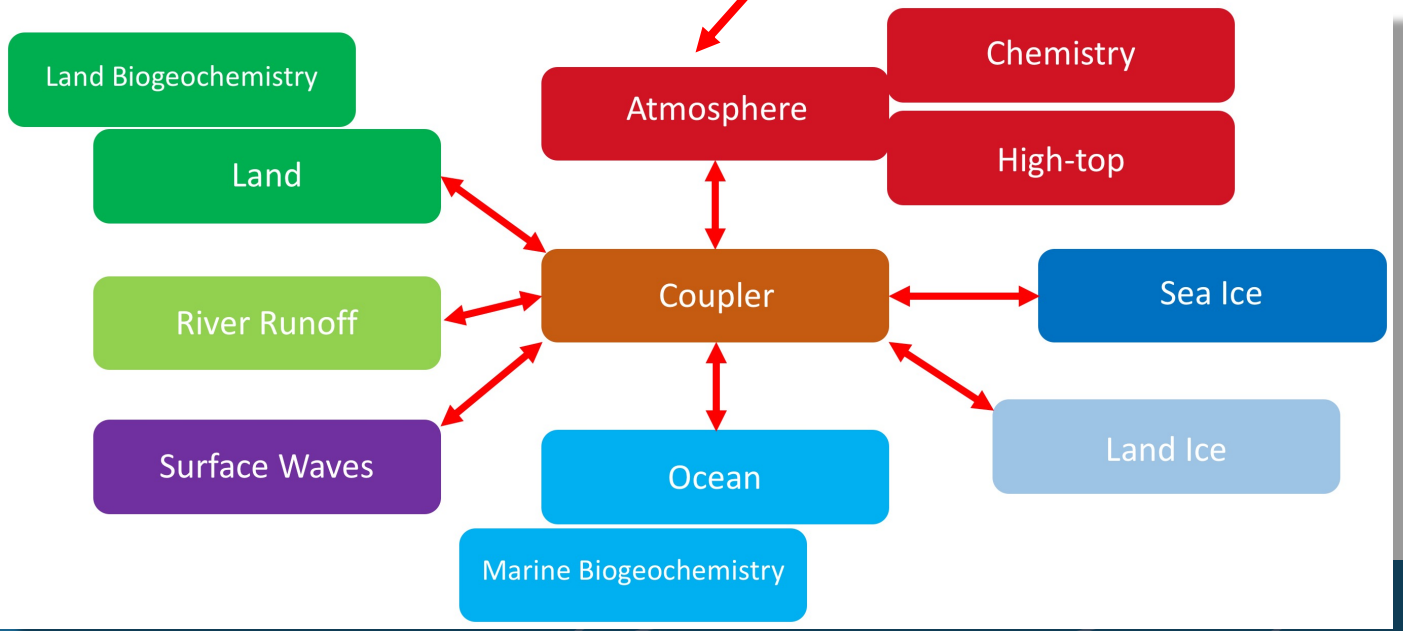
Global Earth System Models

- 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).



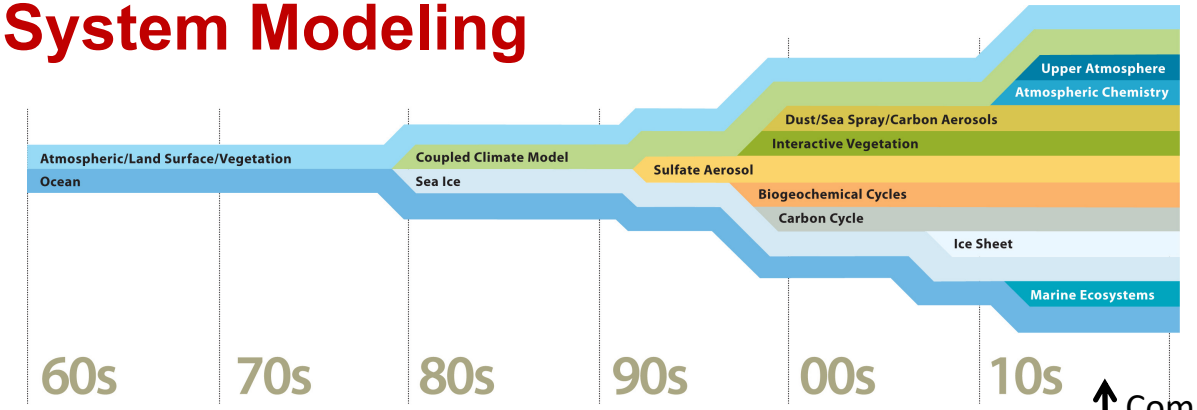
Global Earth System Models

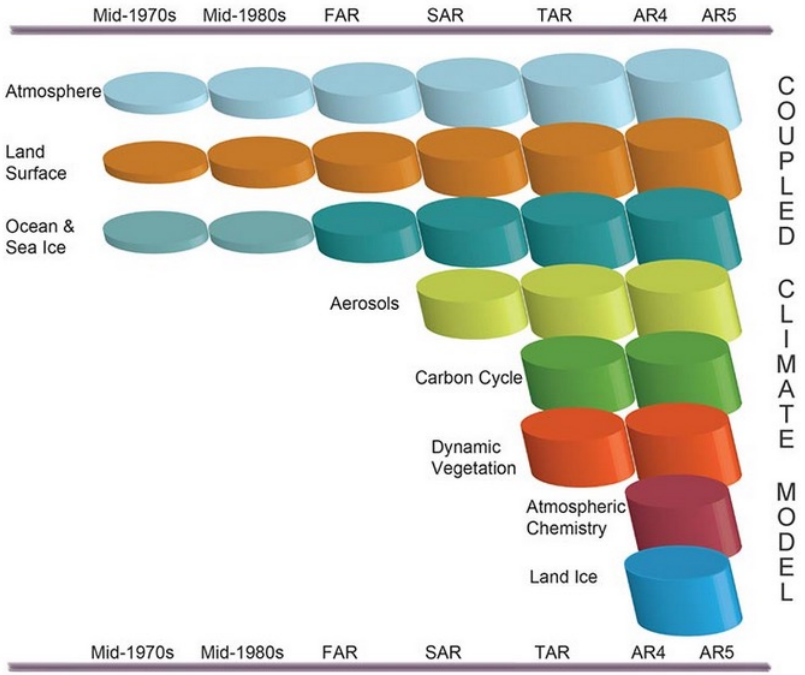
Forcings:
- Greenhouse gases
- Anthropogenic aerosols
- Volcanic eruptions
- Solar variability

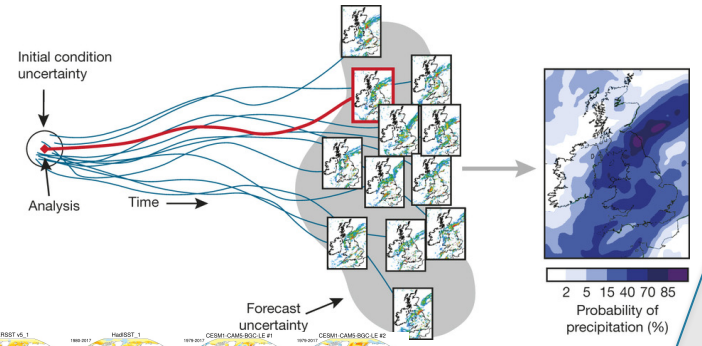


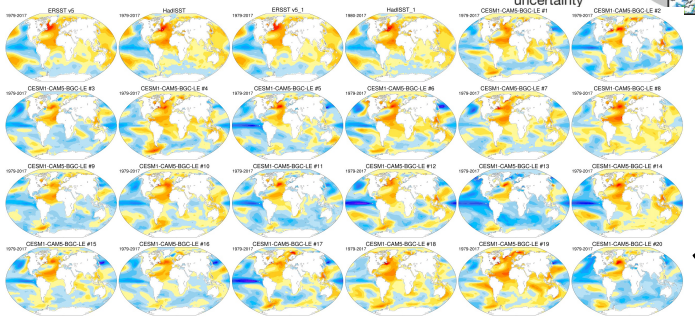
Community Earth System Model

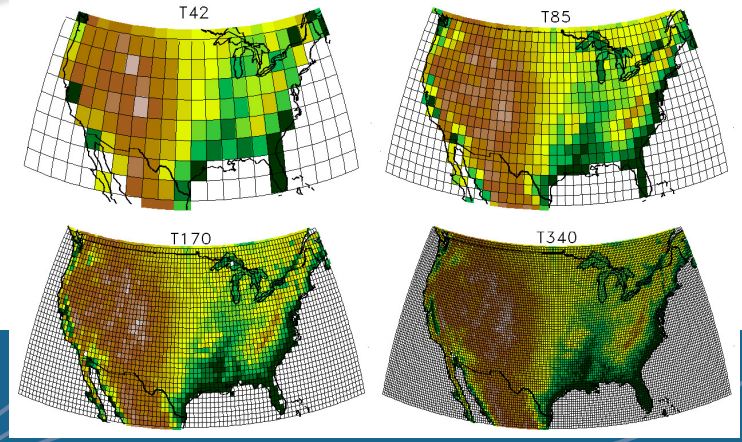
Growth of Climate / Earth System Modeling









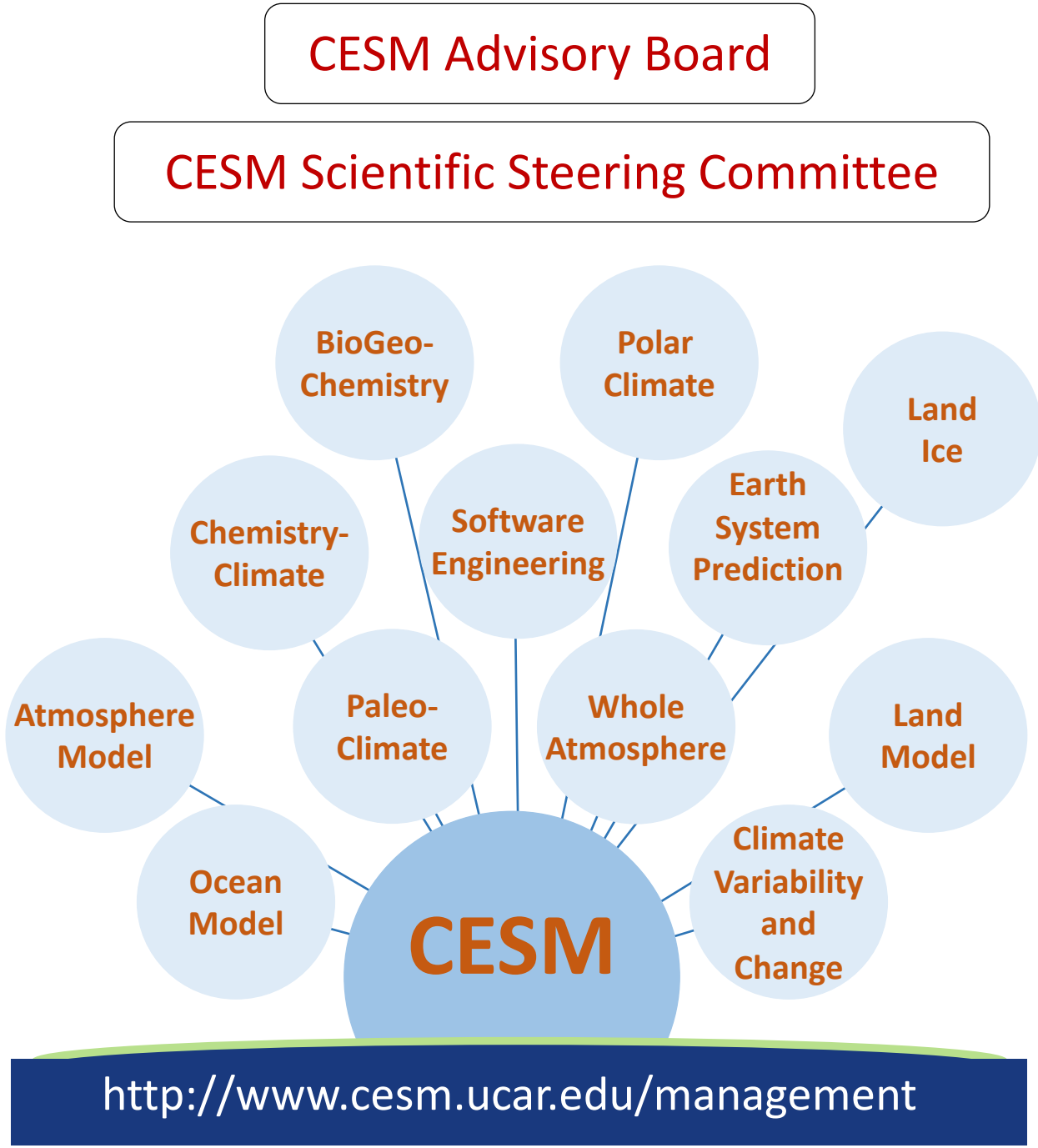


CESM Project

25+ years of model development and applications

Annual CESM Workshops are held in summers.

Most working groups have winter/spring meetings.

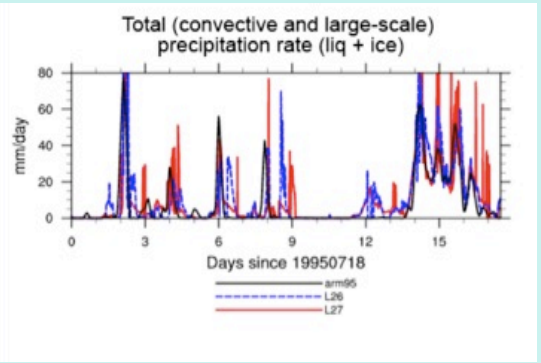


CESM supports a range of climate science goals through a single model code base

Containerized (cloud) configurations are also available.

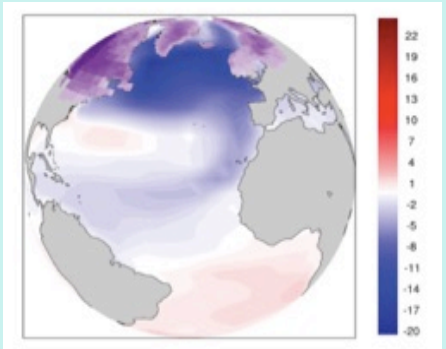
Desktop

Single column/
Coarse resolution:
Physics development



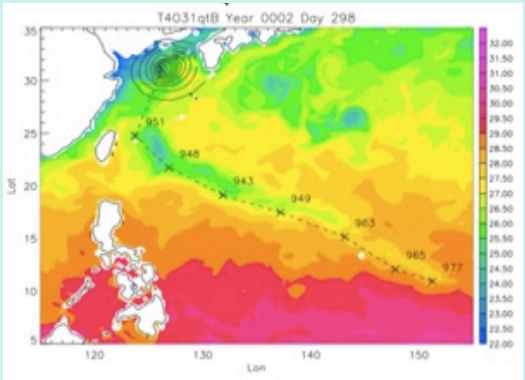
Small cluster

Low resolution:
Paleo applications,
University research



HPC

Medium & High Resolution:
CMIP, Large Ensembles,
New Frontiers



CESM supports a range of climate science goals through a single model code base

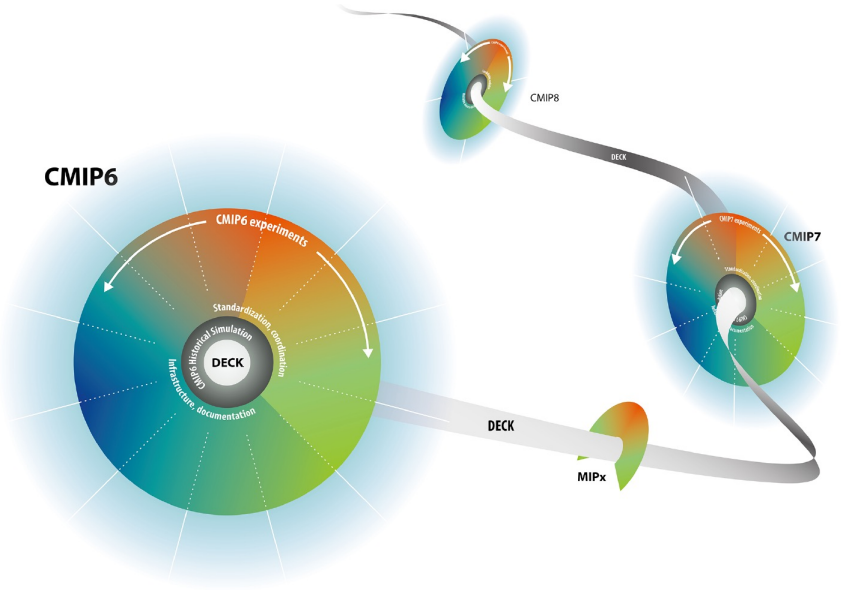
- All component models can be active.
- All component models can be replaced with “data models”:

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

Coupled Model Intercomparison Project phase 6 (CMIP6) Efforts

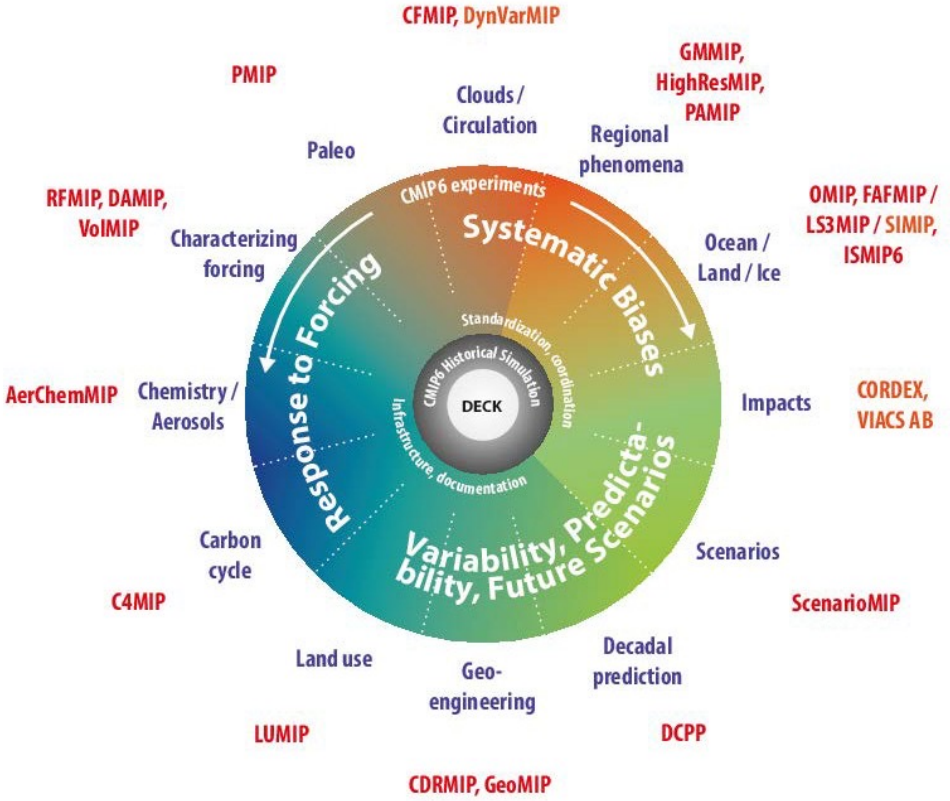
CESM2 participation in CMIP6

Diagnostic, Evaluation, and Characterization of Klima (DECK)



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

Eyring et al. (2016, GMD)



Set I: Two nominal 1° model versions w/ CAM6 and WACCM6 atmospheric model components

Set II: w/ 2° versions of CAM6 and WACCM6, but otherwise identical (primarily DECK)

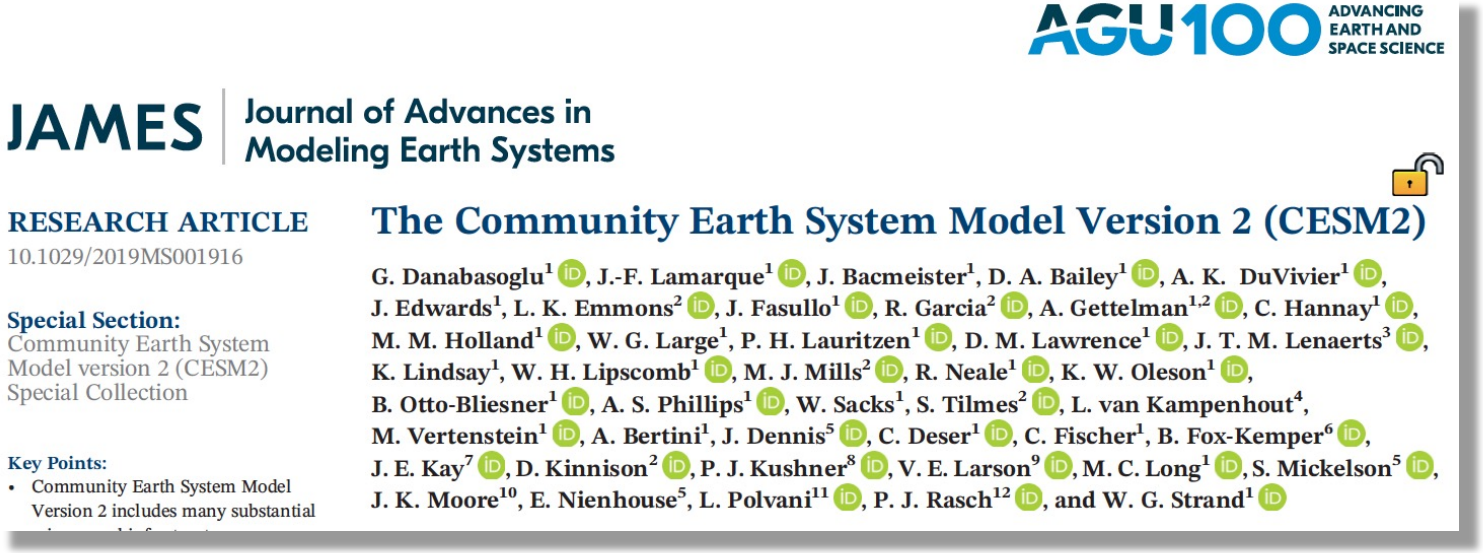
AGU CESM2 virtual special issue

43 manuscripts published;

Several in review

Articles available at both the AGU site and at

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



AGU100 ADVANCING EARTH AND SPACE SCIENCE

JAMES | Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE
10.1029/2019MS001916

Special Section:
Community Earth System Model version 2 (CESM2) Special Collection

Key Points:
- Community Earth System Model Version 2 includes many substantial

The Community Earth System Model Version 2 (CESM2)

G. Danabasoglu[1], J.-F. Lamarque[1], J. Bacmeister[1], D. A. Bailey[1], A. K. DuVivier[1], J. Edwards[1], L. K. Emmons[2], J. Fasullo[1], R. Garcia[2], A. Gettelman[1,2], C. Hannay[1], M. M. Holland[1], W. G. Large[1], P. H. Lauritzen[1], D. M. Lawrence[1], J. T. M. Lenaerts[3], K. Lindsay[1], W. H. Lipscomb[1], M. J. Mills[2], R. Neale[1], K. W. Oleson[1], B. Otto-Bliesner[1], A. S. Phillips[1], W. Sacks[1], S. Tilmes[2], L. van Kampenhout[4], M. Vertenstein[1], A. Bertini[1], J. Dennis[5], C. Deser[1], C. Fischer[1], B. Fox-Kemper[6], J. E. Kay[7], D. Kinnison[2], P. J. Kushner[8], V. E. Larson[9], M. C. Long[1], S. Mickelson[5], J. K. Moore[10], E. Nienhouse[5], L. Polvani[11], P. J. Rasch[12], and W. G. Strand[1]

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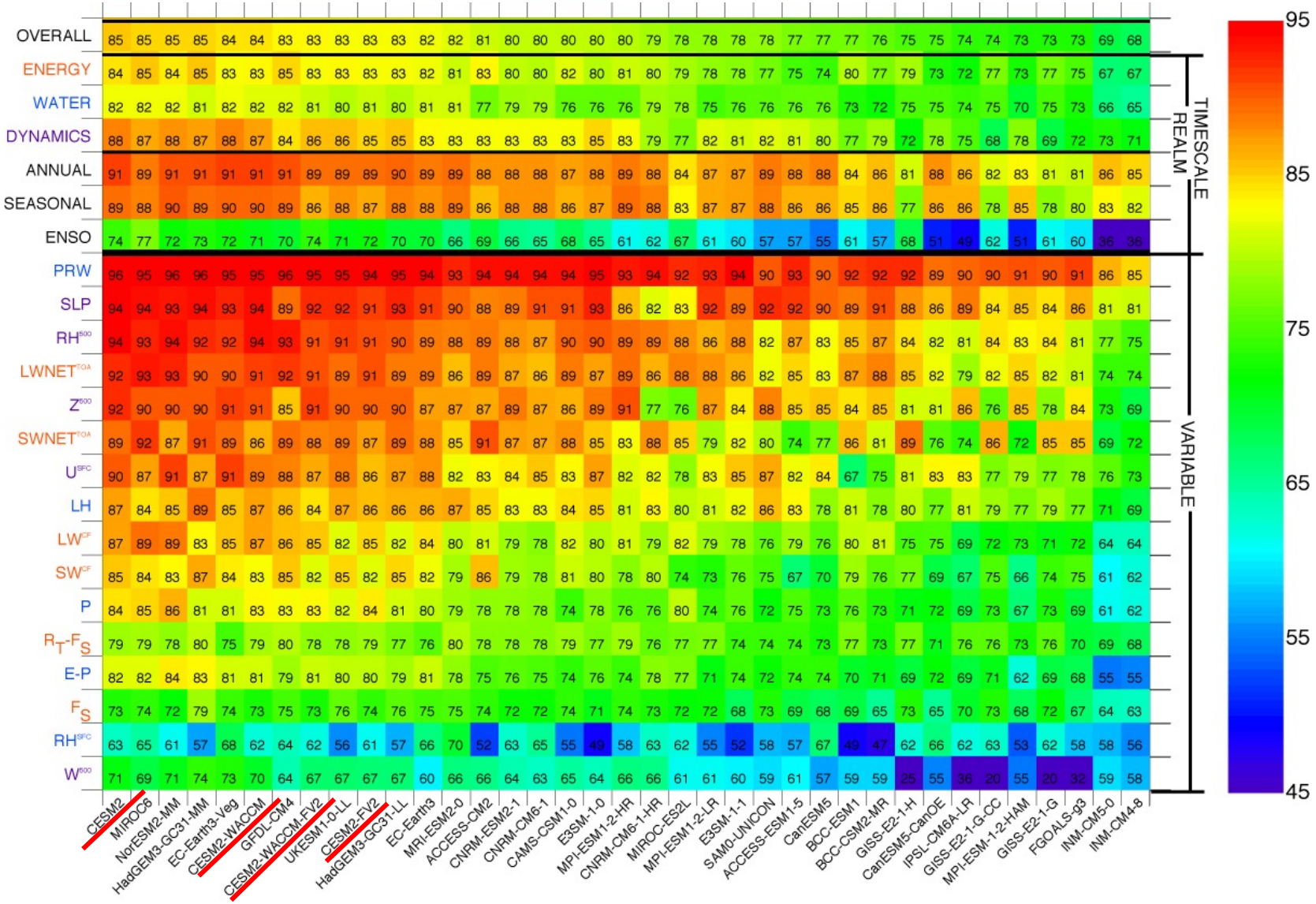
ATMOSPHERIC SCIENCES | Opinion

Building a Better Model to View Earth's Interacting Processes

Researchers collaborated to produce and evaluate a new version of the Community Earth System Model, and they are documenting their work in the AGU CESM2 virtual special issue.

By Gokhan Danabasoglu and Jean-François Lamarque | 15 March 2021

A model performance summary



Climate Model Analysis Tool (CMAT; *Fasullo 2020, GMD*)

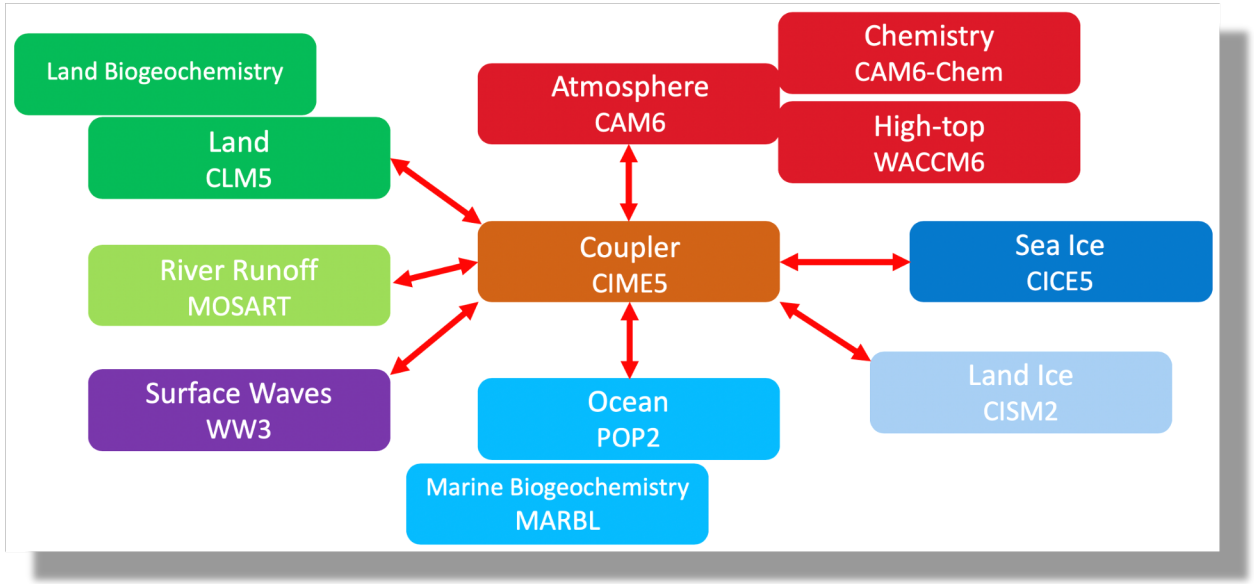
CESM2 releases

Since December 2018, there have been three incremental releases as CESM2.1.x series.

These releases were non-answer-changing; they further expand the available set of out-of-the-box configurations for readily performing the CMIP DECK, historical, and many MIP Tier 1 simulations for CMIP6.

CESM2.2 was released on 29 September 2020.

This release contains many new developments since 2018, including a functional release of MOM6 ocean model.



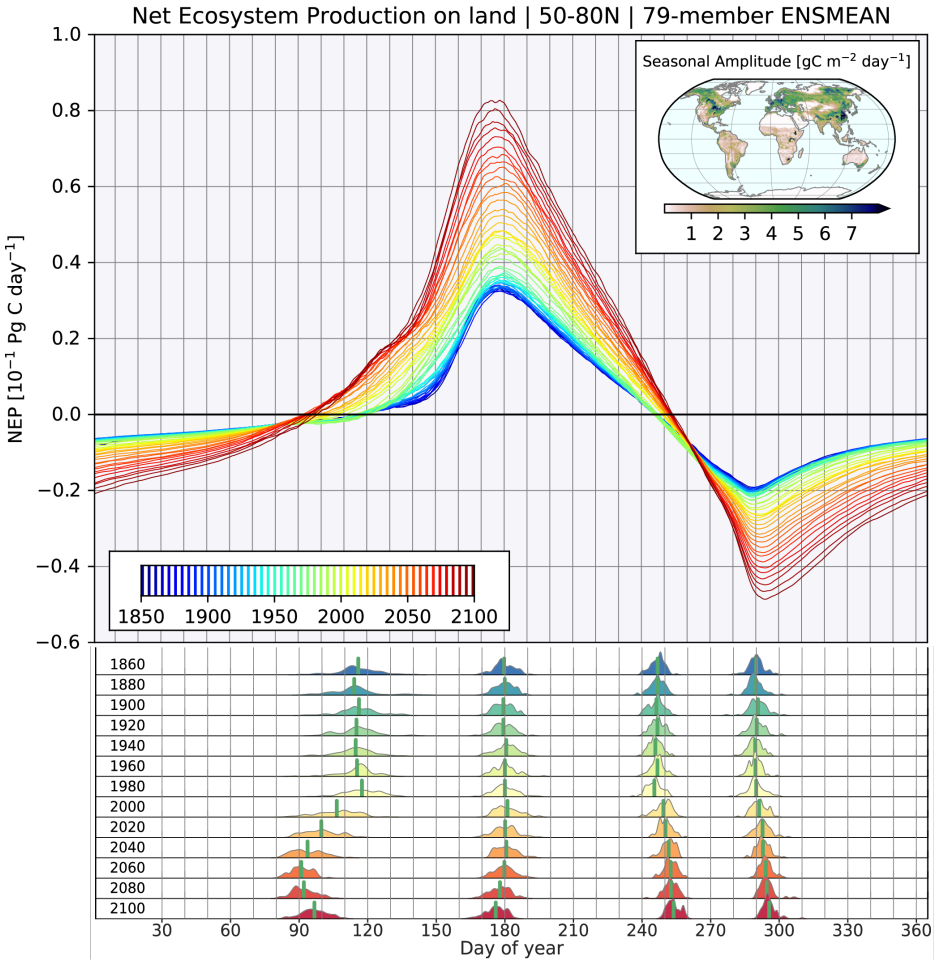
Updates and Highlights from on Ongoing Activities

CESM2 Large Ensemble (CESM2-LENS)

A partnership with the Institute for Basic Science (IBS) Center for Climate Physics (ICCP) in Busan, S. Korea

- A 100-member ensemble for the 1850-2100 period, using the SSP-3.70 scenario for the future extension;
- Data sets were released to the community on 14 June 2021!

Expansion of the growing season length



Rodgers et al. (2021, Earth Sys. Dyn., submitted)

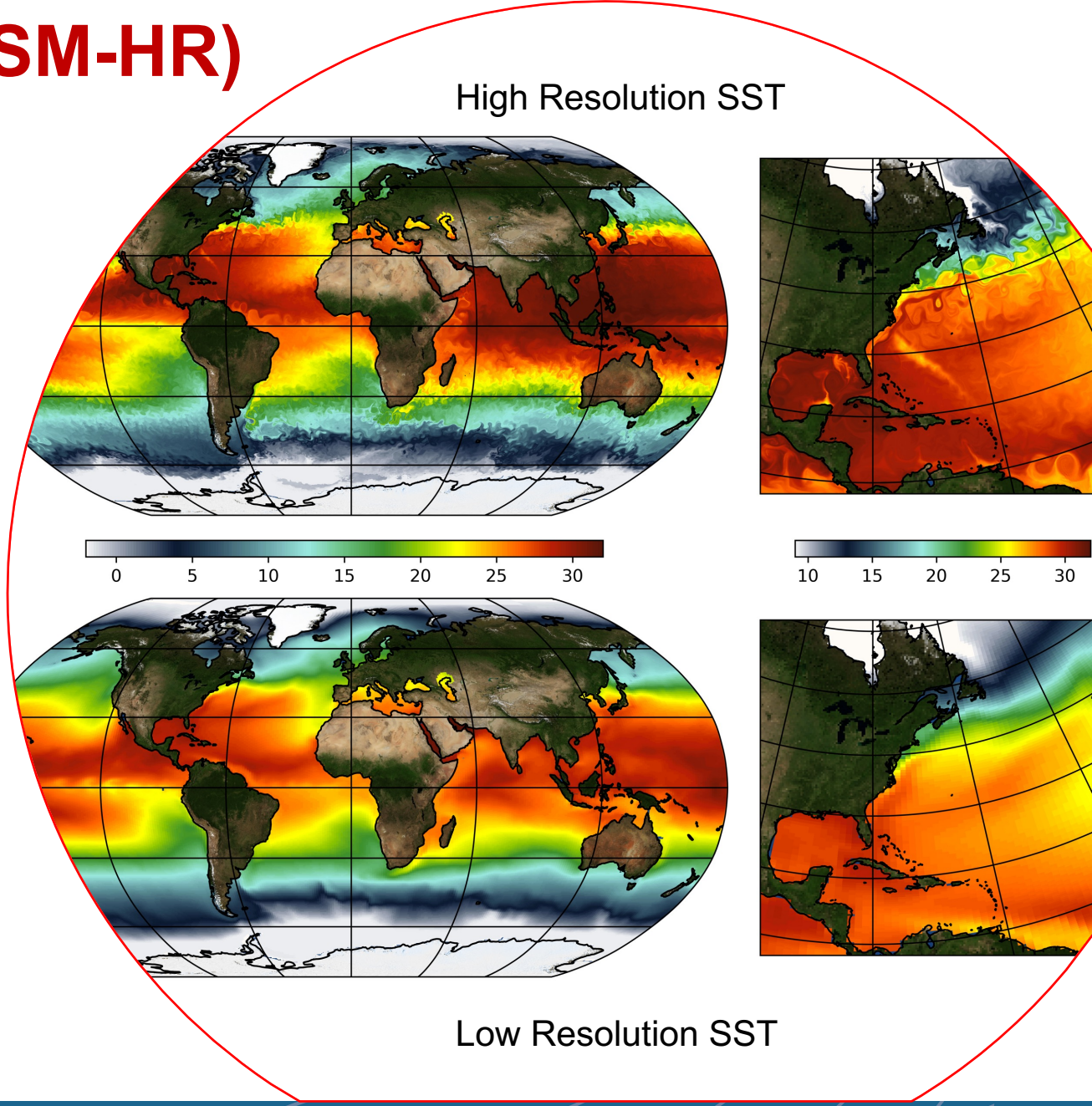
CESM high-resolution (CESM-HR) simulations

International Laboratory for High-Resolution Earth System Predictions (iHESP)

Qingdao National Laboratory for Marine Science and Technology (QNLM)

Texas A&M University (TAMU)

National Center for Atmospheric Research (NCAR)



CESM-HR:

Atmosphere and land at 0.25°; ocean and sea-ice at nominal 0.1° resolution

CESM v1.3 code base

CESM high-resolution simulations (0.1° ocn; 0.25° atm)

Completed

650-year PI control;
80-year 1%CO2;
3-member 1850-2100 transient;
All HighResMIP Coupled and AMIP;
5 cycles of 1958-2018 OMIP

Ongoing

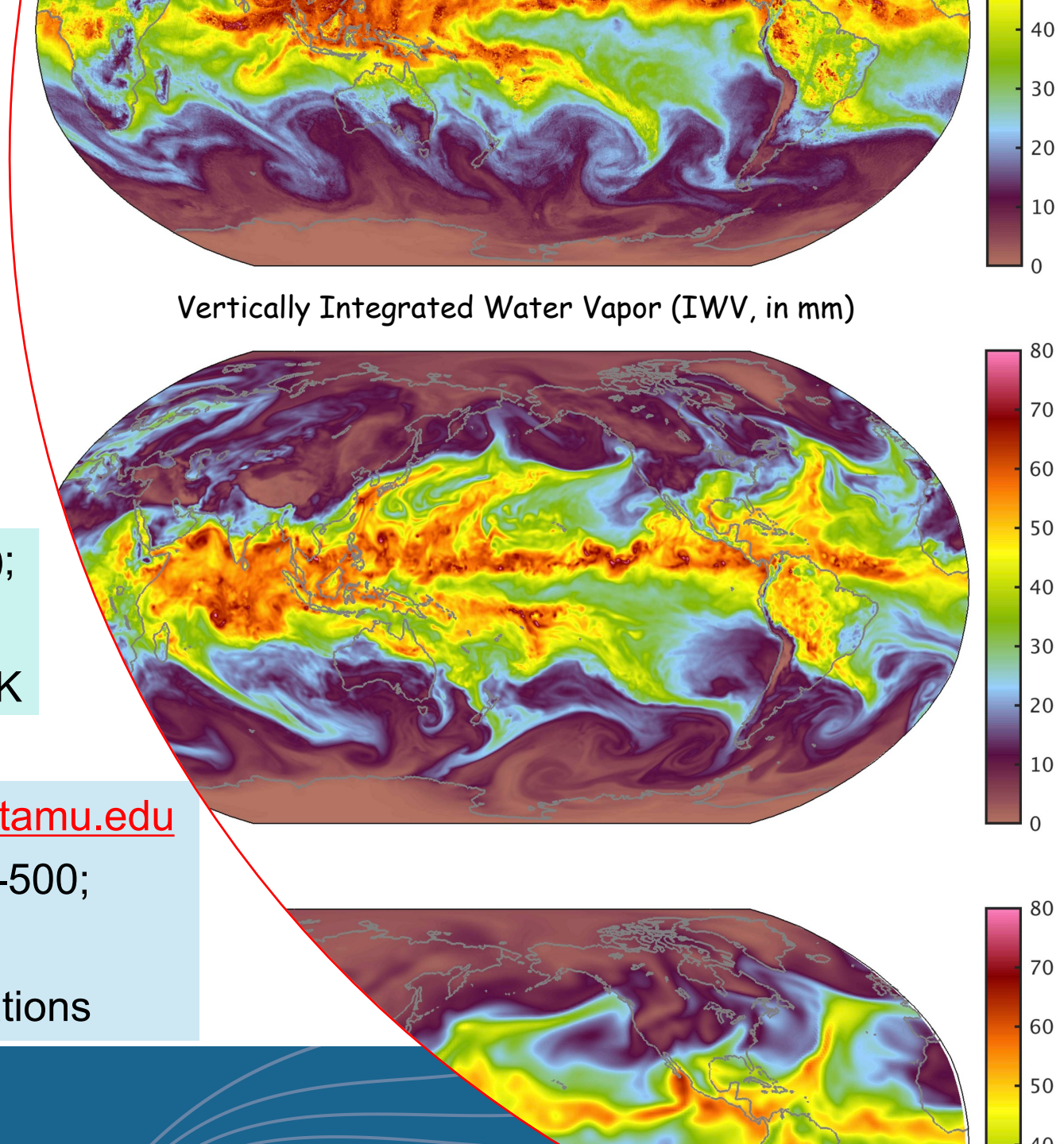
Decadal Predictions (1980 – 2018);
Extend 1%CO2 to year 150;
150-year 4xCO2 to complete DECK

Data Release

12 June 2021!

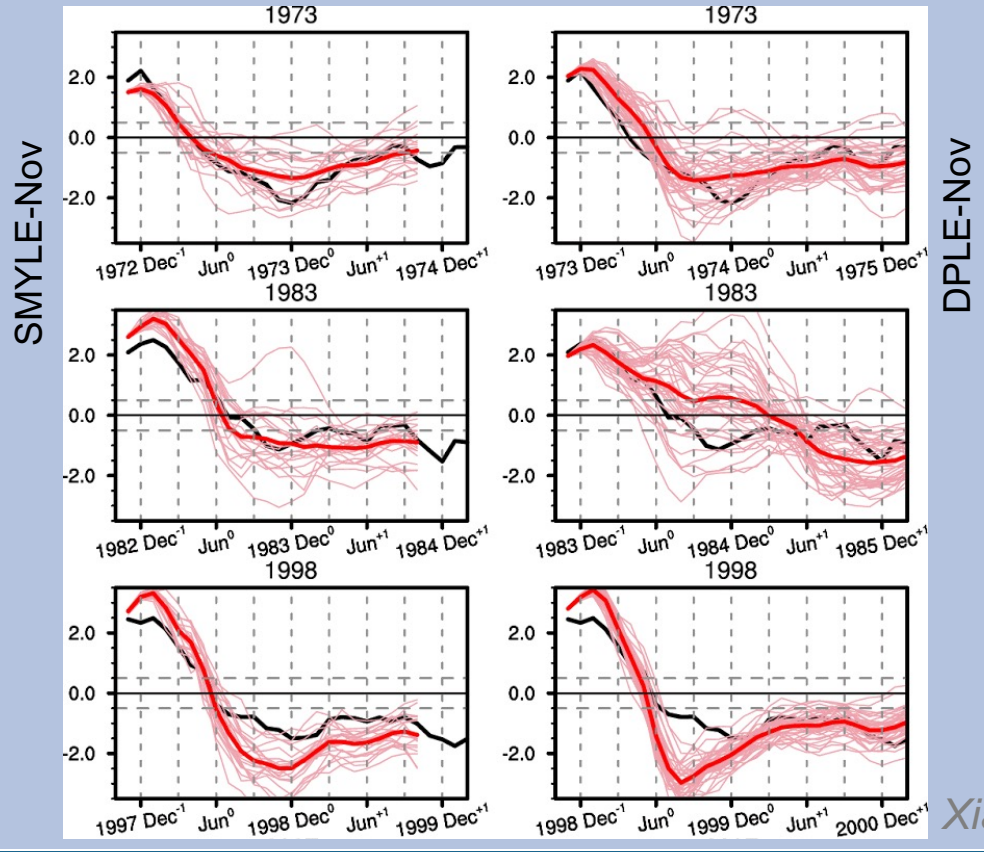
Web site: https://ihesp.tamu.edu
PI Control for years 21-500;
1 transient member;
All HighResMIP simulations

Chang et al. (2020, JAMES)



SMYLE project: Seasonal-to-MultiYear Large Ensemble

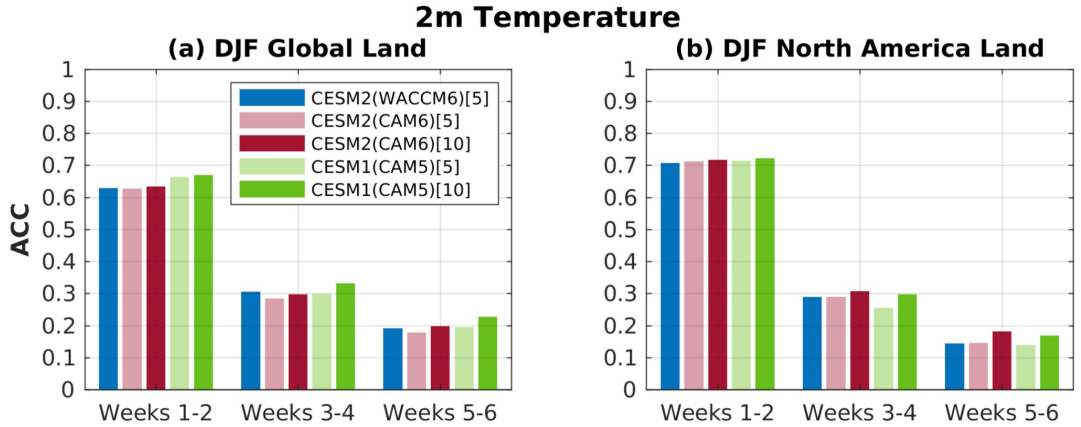
- New initialized hindcast set using CESM2
- 2-year, 20-member ensembles, 4 starts/year, 1970-2018
- Improved 2-year La Niña skill compared to CESM1-DPLE



Xian Wu et al.

Subseasonal-to-Seasonal (S2S) hindcasts & real-time forecasts

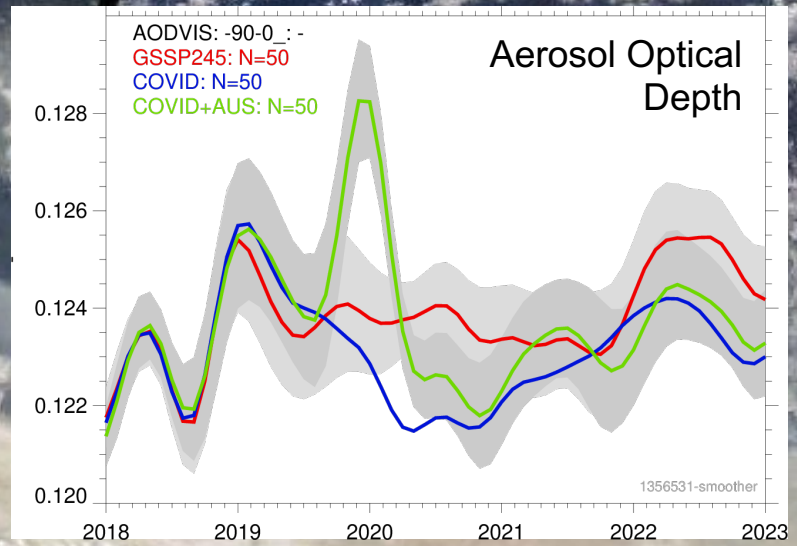
- 11-member hindcast set with CESM2(CAM6), 1999-2020; weekly starts; 45-day long simulations
- Similar 5-member hindcast set with CESM2(WACCM6) for winter season only
- Weekly real-time forecasts: 21-member ensemble:
  since Sep 2020 with CESM2(WACCM6)
  since Apr 2020 with CESM2(CAM6)
  Contributing to the operational NOAA week 3-4 Outlook

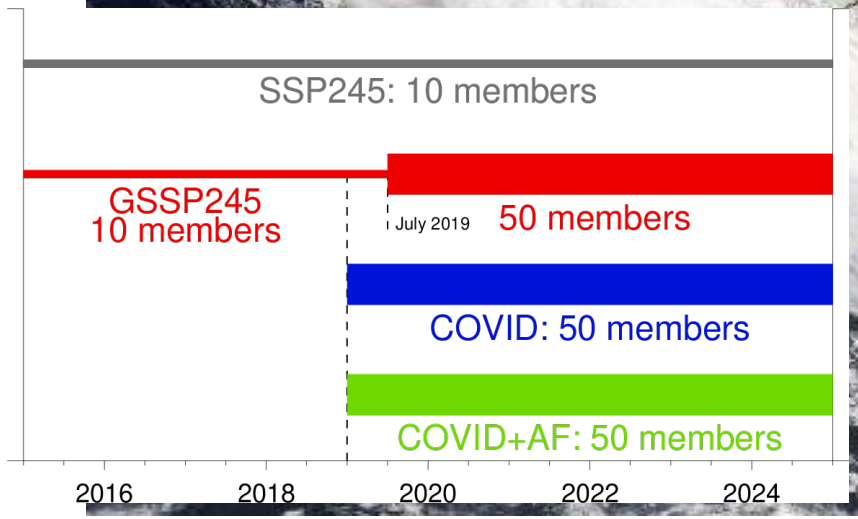


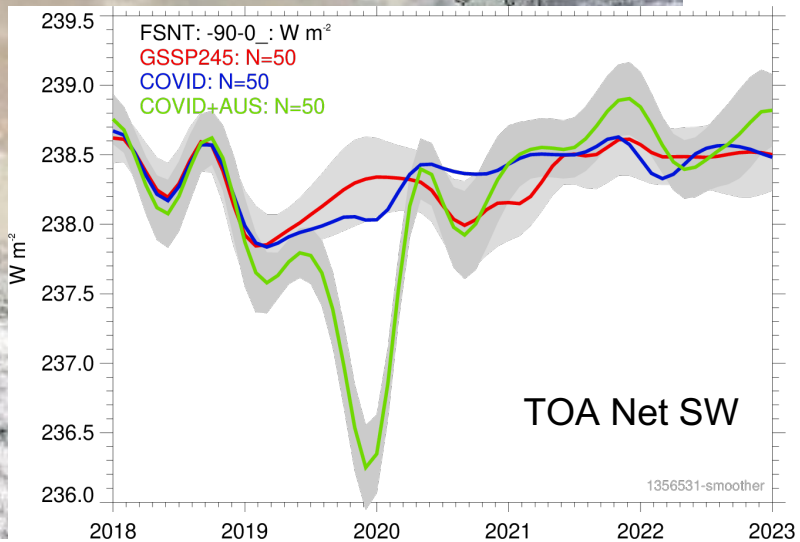
Richter et al. (2021, JAMES)

Climate responses to COVID-19 and the 2019/20 Australian bushfire season

Jan 6 2020 Australian bushfire emissions
Image credit NASA





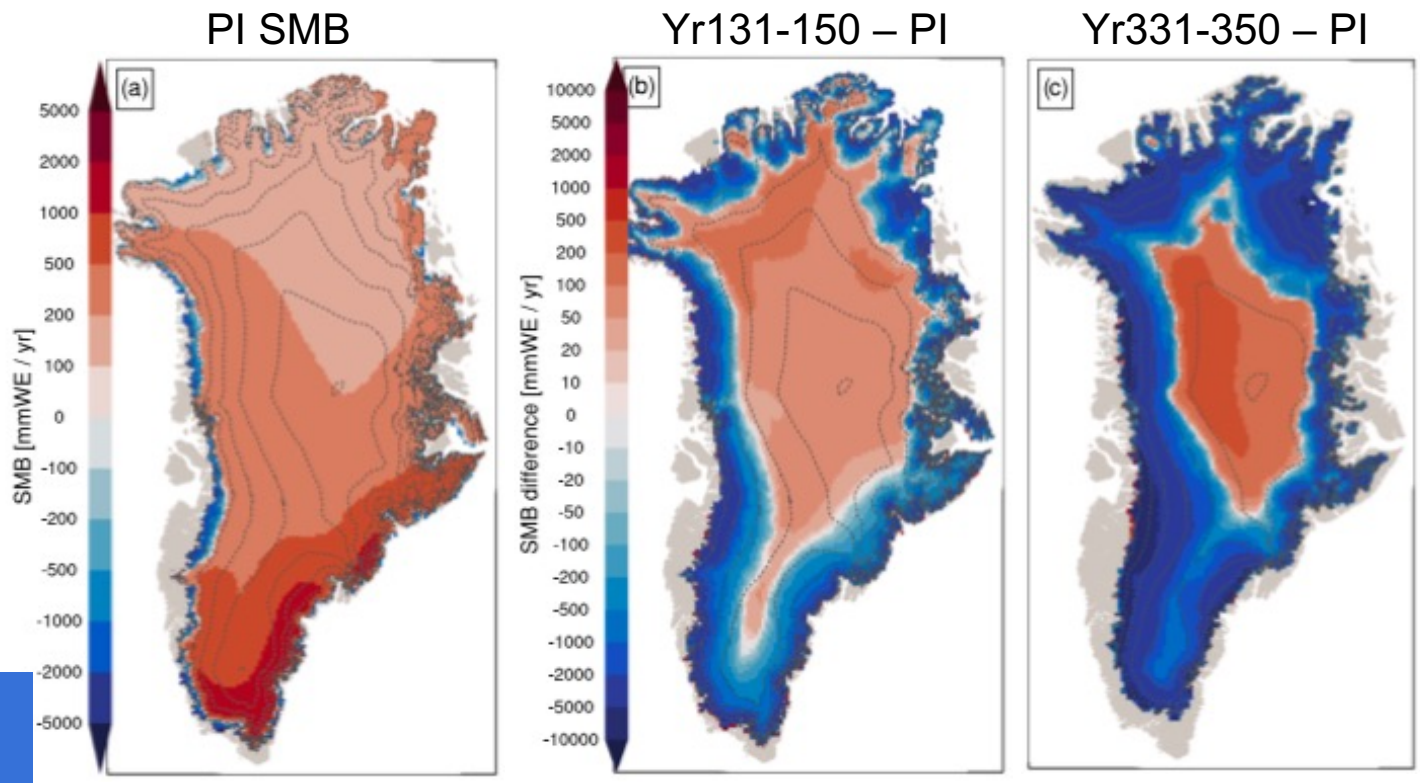


Fasullo et al. (2021, GRL)

Coupled land ice simulations

Surface mass balance (SMB) in a 350-year CESM2 simulation with a coupled Greenland ice sheet in which CO_2 concentration increases by 1% per year until quadrupling at year 140 and is then held constant.

Ablation areas expand; sea-level rise > 1 m by year 350 with 4xCO_2



Red = net accumulation, **blue** = net ablation

Antarctic Ice Sheet

CESM2 and CISM have been modified to support **multiple ice sheets**, including Antarctica

Testing underway with ice-ocean coupling

Muntjewerf et al. (2020, JAMES; 2020, GRL)

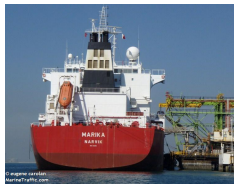
Actionable polar science

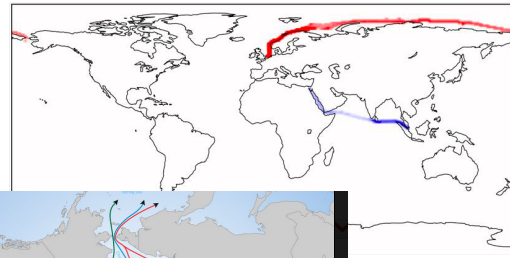
Co-producing Understanding of Drivers and Consequences of Environmental Arctic Change

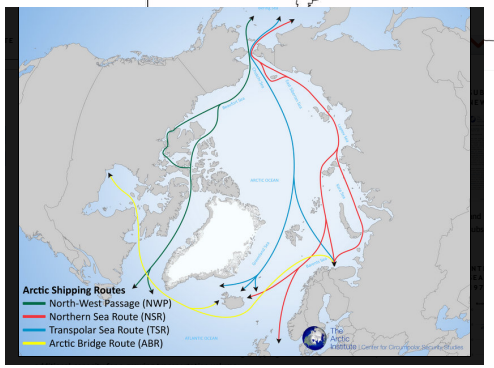
A collaboration between scientists, indigenous people, and decision-making experts to produce and share actionable knowledge

Holland, DuVivier, Bailey, & Landrum

Arctic Shipping



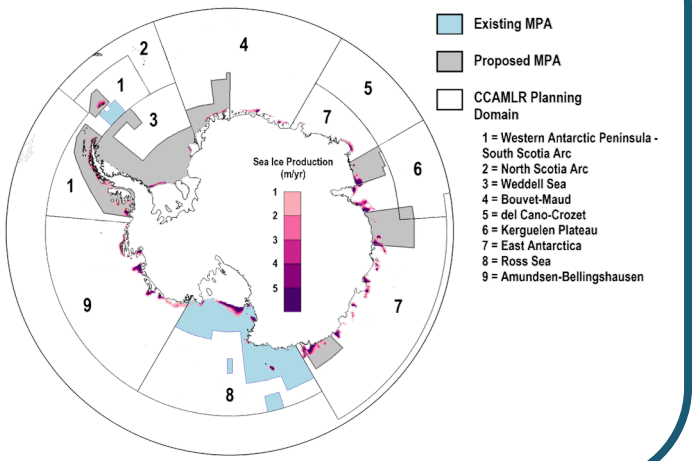




- Impacts of ship emissions
- Economic considerations
- Risk indices
- Transportation policy
- Likelihood of potential ship paths and assessment of maritime risk

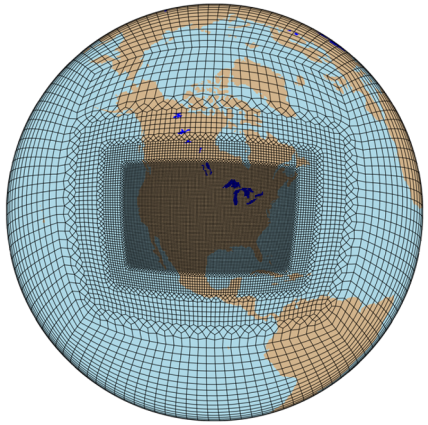
Antarctic Marine Protected Areas

- Identification of biological hotspots
- Forecasting locations of highest ecological value for protection
- Work in collaboration with the Scientific Committee on Antarctic Research, the Southern Ocean Coalition, the Pew Charitable Trusts, and Sea Legacy



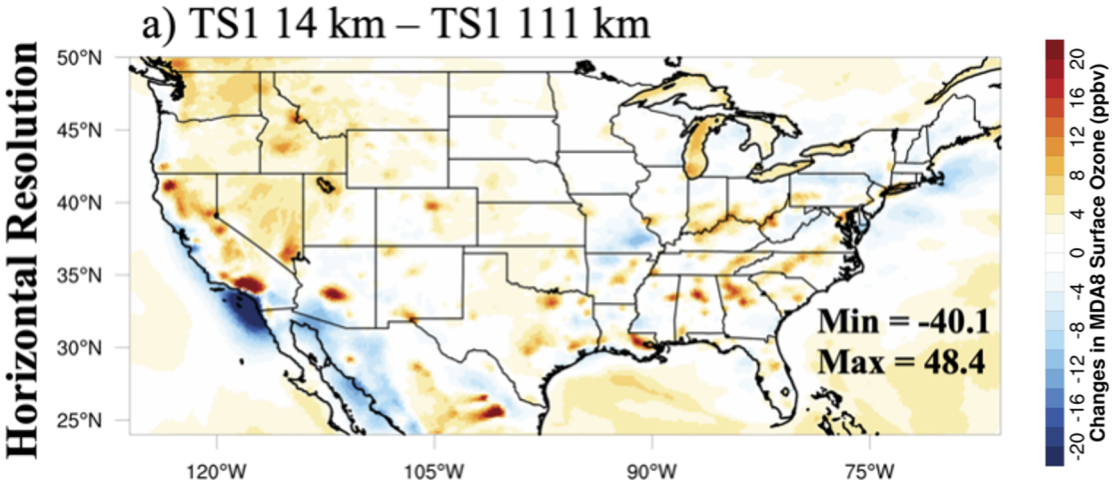
NCAR | UCAR

MUSICA-V0: Impacts of horizontal resolution and chemical complexity

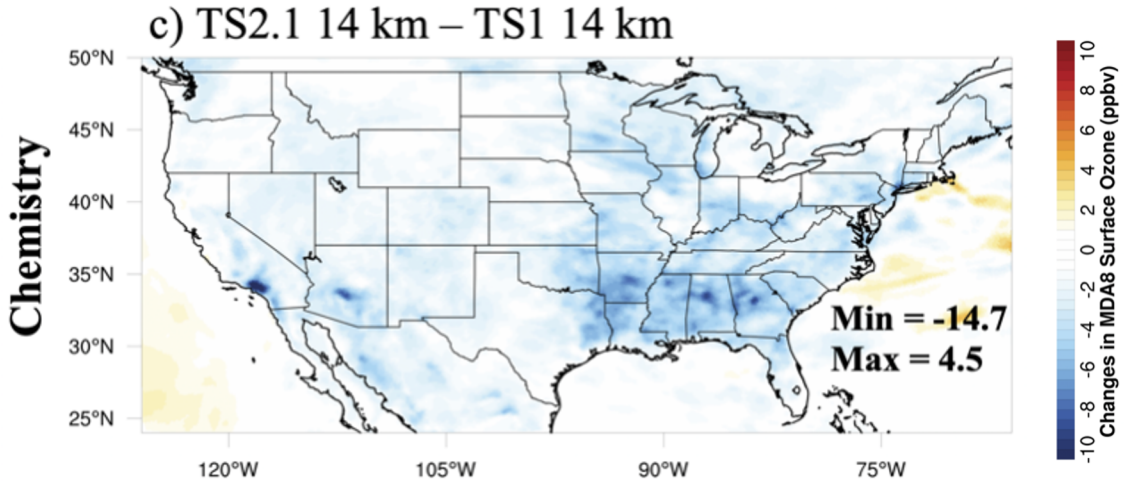


- MUSICA-V0 = CAM-chem, Spectral Element with regional refinement
- Default grid: 14 km over US, 1° rest of globe
- Providing capability for regional-scale air quality analyses in a global model
- Improving estimates of human health impacts from PM2.5 (Lacey)
- Improving simulation of surface ozone (Schwantes)

Finer resolution more accurately represents emissions and chemistry of cities and fires

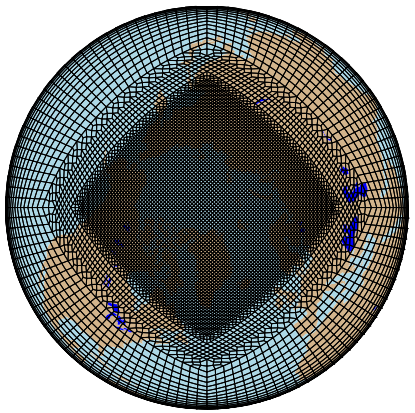


Increased chemical complexity has more impact at higher resolution, improving ozone over southeast U.S.

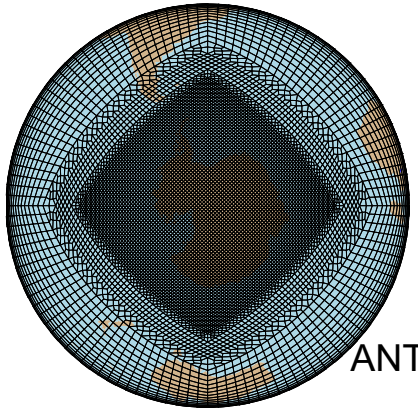


Variable-resolution grids

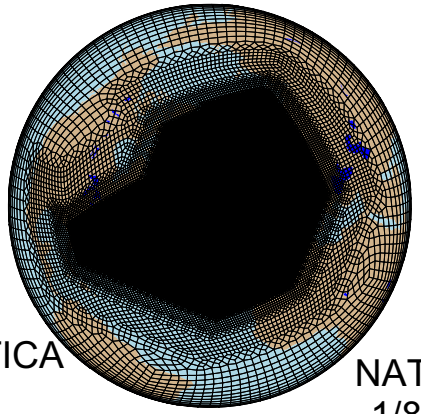
CESM (w/ university collaborators) has been developing a library of variable-resolution grids for various scientific applications.



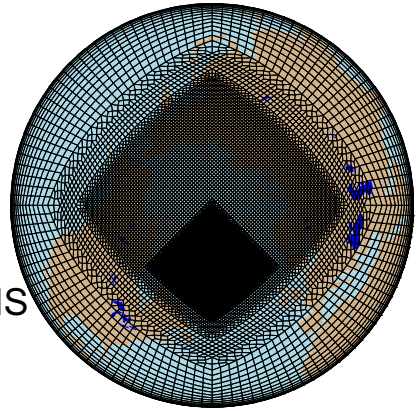
ARCTIC
1/4˚



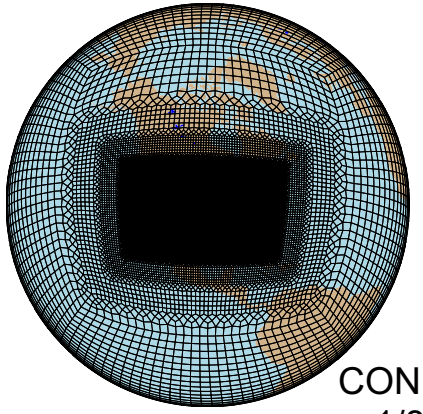
ANTARCTICA
1/4˚



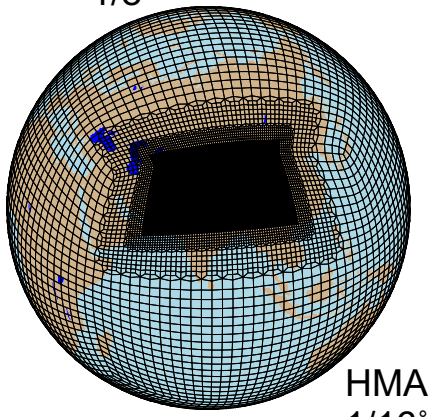
NATL
1/8˚



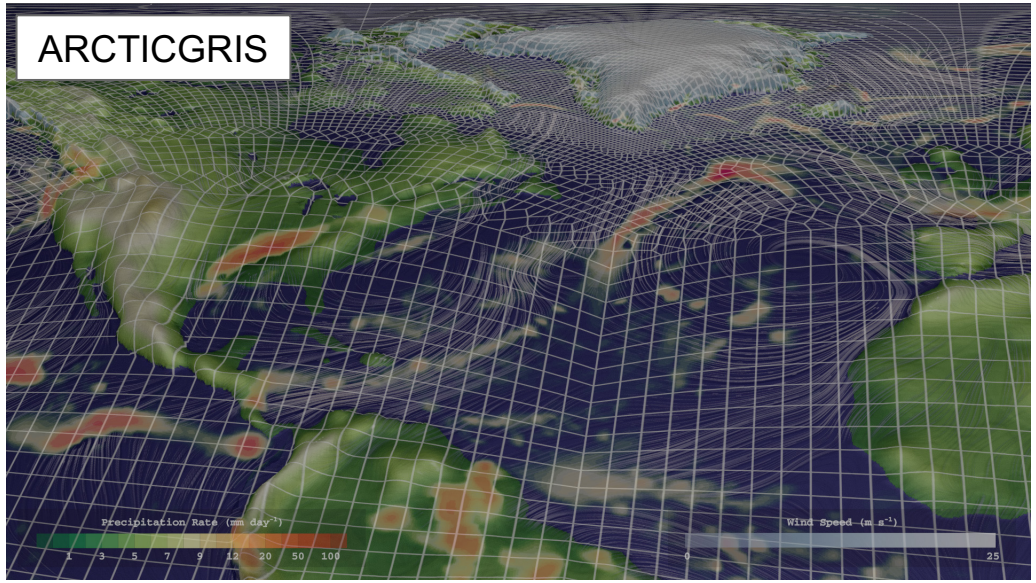
ARCTICGRIS
1/8˚



CONUS
1/8˚

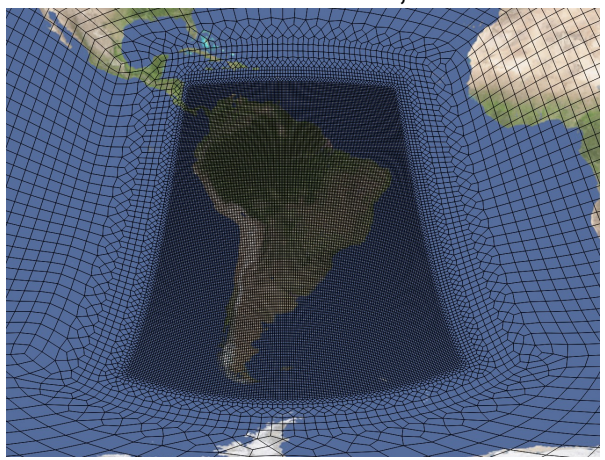


HMA
1/16˚



Snapshot from NCAR VisLab

S. AMERICA 1/8˚, 1/16˚



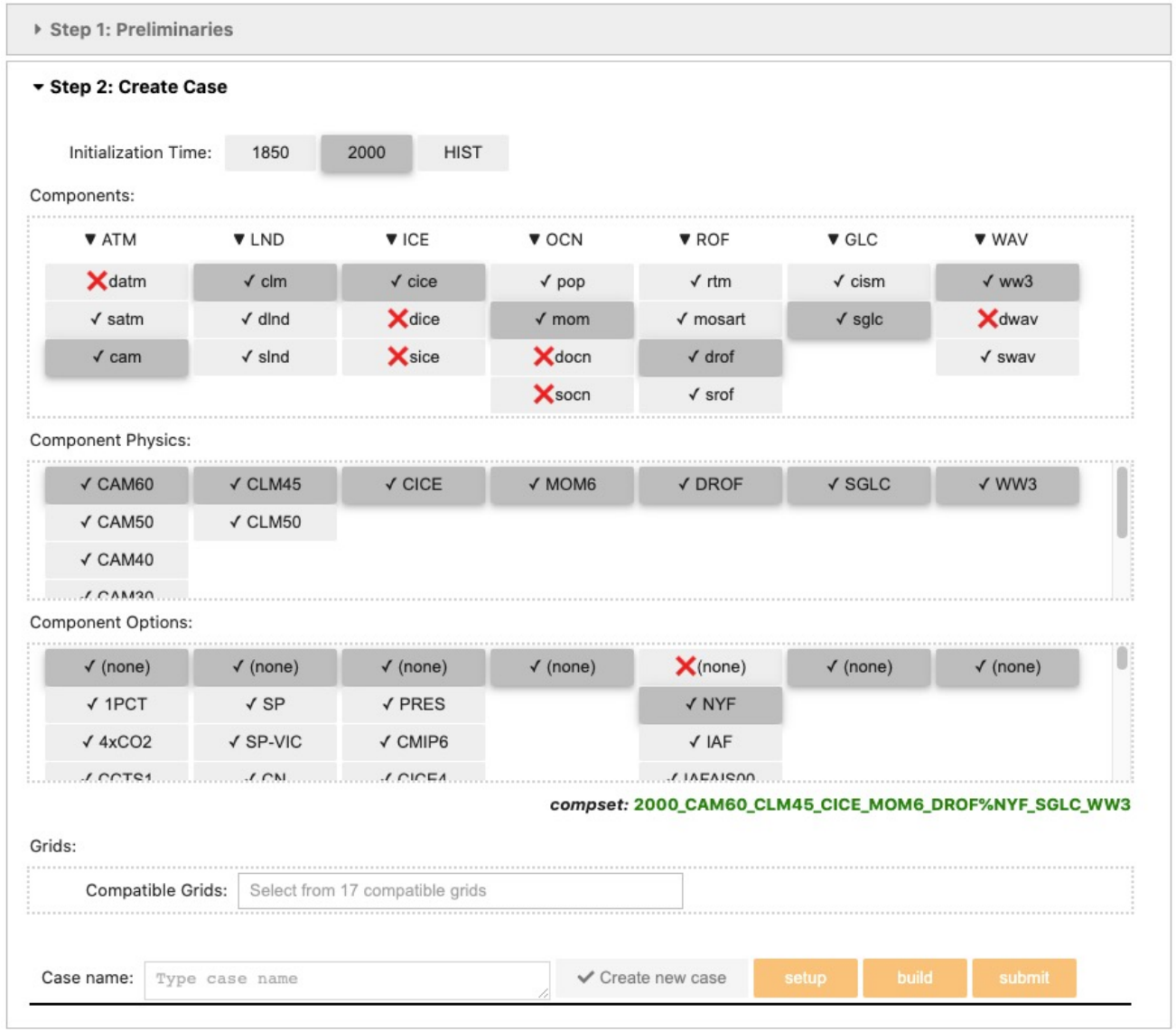
Herrington, Callaghan, Wijngaard, Datta, Wills

Streamlining coupled, simplified modelling within CESM

Ocean bathymetry tool

CESM configuration query tool

Prototype CESM configuration query tool



Next steps:

Tools for generation of idealized land surface conditions

Completion of coupled simpler models tool chain

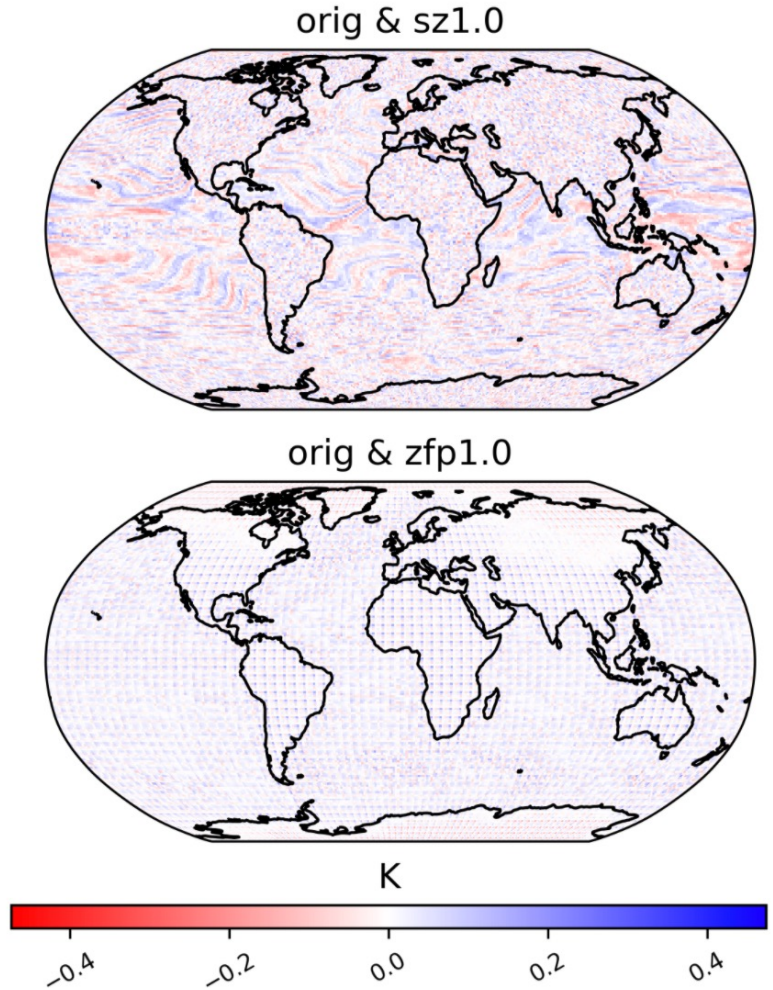
Bachman, Simpson, Danabasoglu, Vertenstein, Sacks, Altuntas, & Dobbins

Lossy compression of CESM data

Application of lossy compression applied to climate datasets can result in a large amount of data reduction with minimal drawbacks – ***IF*** it can be applied carefully.

Optimal compression settings are determined for several test datasets using a metric called the Data Structural Similarity Index Measure (SSIM)… Available for testing by users!

A new Python package can assist users in analyzing potential compression effects visually and through budgets and more.



Plot of mean compression errors in a daily temperature dataset from CESM-LENS, compressed using the sz (top) and zfp (bottom) compression algorithms

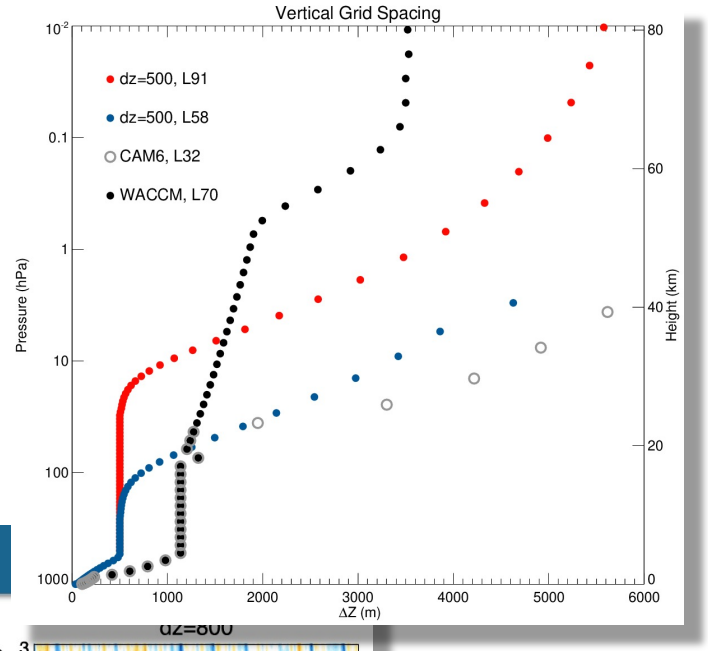
Hammerling, Baker, & Pinard

Towards CESM3

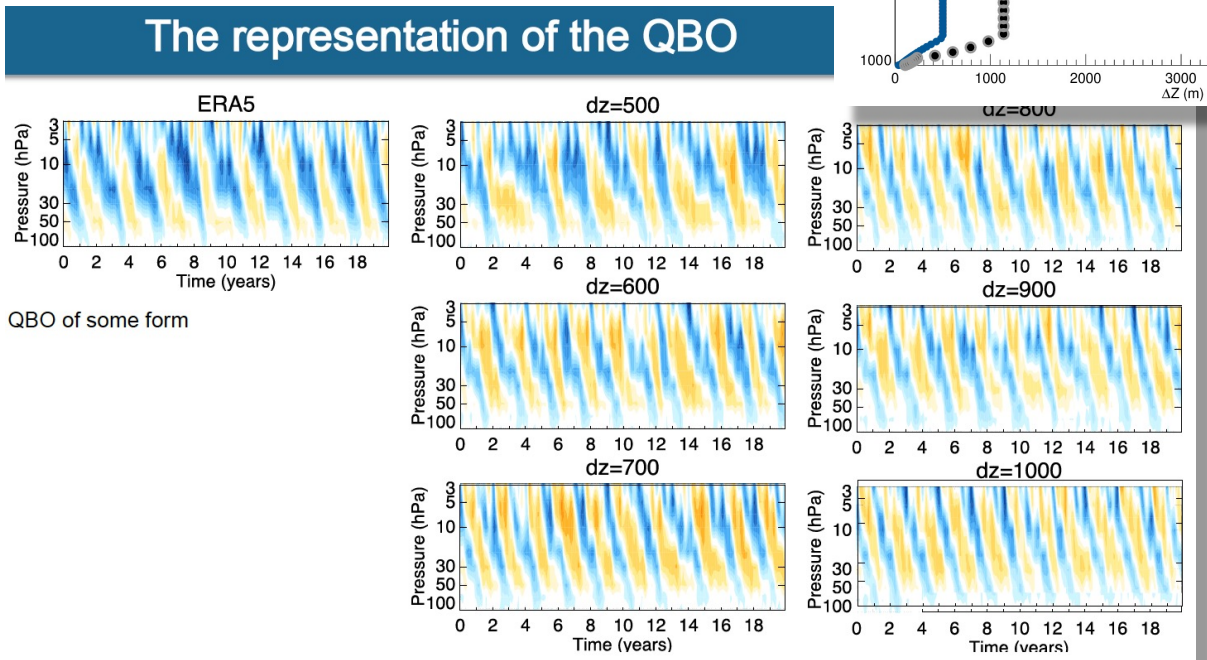
Vertical resolution evaluation for the next *workhorse* version of CESM

Motivation: Improve the representation of the stratosphere and boundary layer in our standard model for climate applications.

Improve/represent: QBO, stratospheric polar vortex, boundary layer clouds and moisture/temperature profiles, surface fluxes…..



- ~80 km top (91L) or ~40 km top (58L)
- 500-m grid spacing in the free troposphere and lower stratosphere
- 10 additional levels in the boundary layer
- New PBL resolution currently being tuned in CAM-SE with 40 km top.

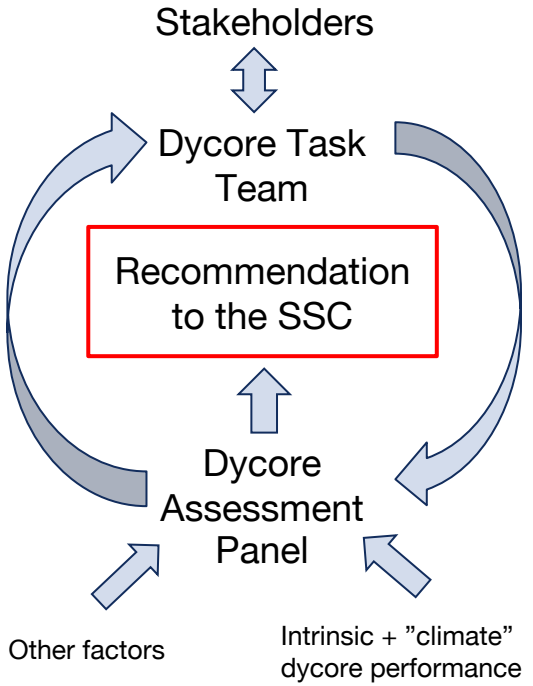


Isla Simpson & Task Team

Atmospheric dynamical core (dycore) evaluation for the next *workhorse* version of CESM

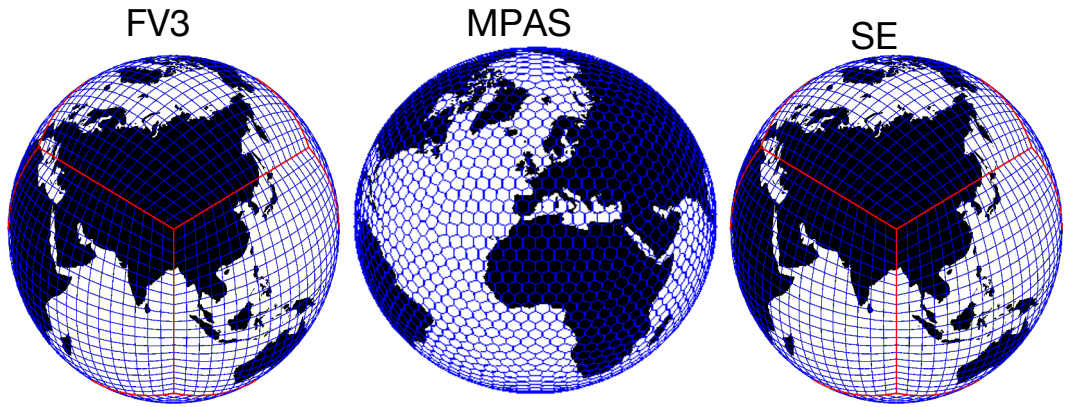
Three dynamical cores are under consideration for the next generation of ~1° CESM that will be used for climate applications.

Although one dycore will be chosen for this application, all dycores will remain within CESM and will be available for use for other applications.



Multiple facets of dycore performance to be considered:

- Phase 1: Inherent properties of the dycore, e.g., computational performance, tracer transport characteristics, energy and momentum conservation (near completion)
- Phase 2: General performance under comprehensive AMIP simulation mode (about to start)
- Phase 3,4,5,….: Coupled, chemistry-climate, … (to be defined)

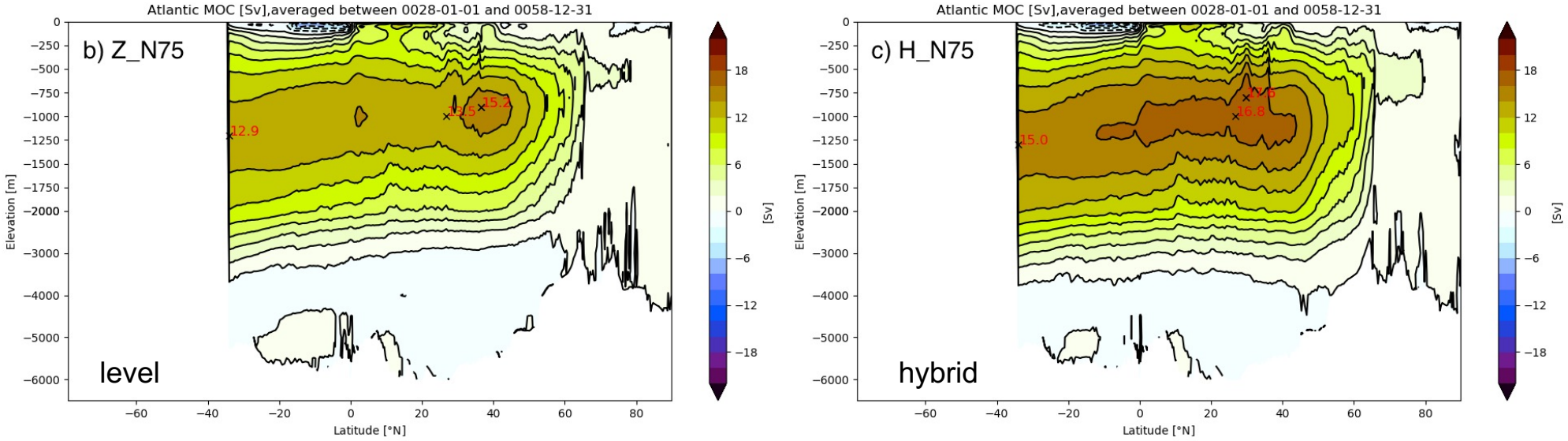


Peter Lauritzen & Isla Simpson

Modular Ocean Model version 6 (MOM6) in CESM3

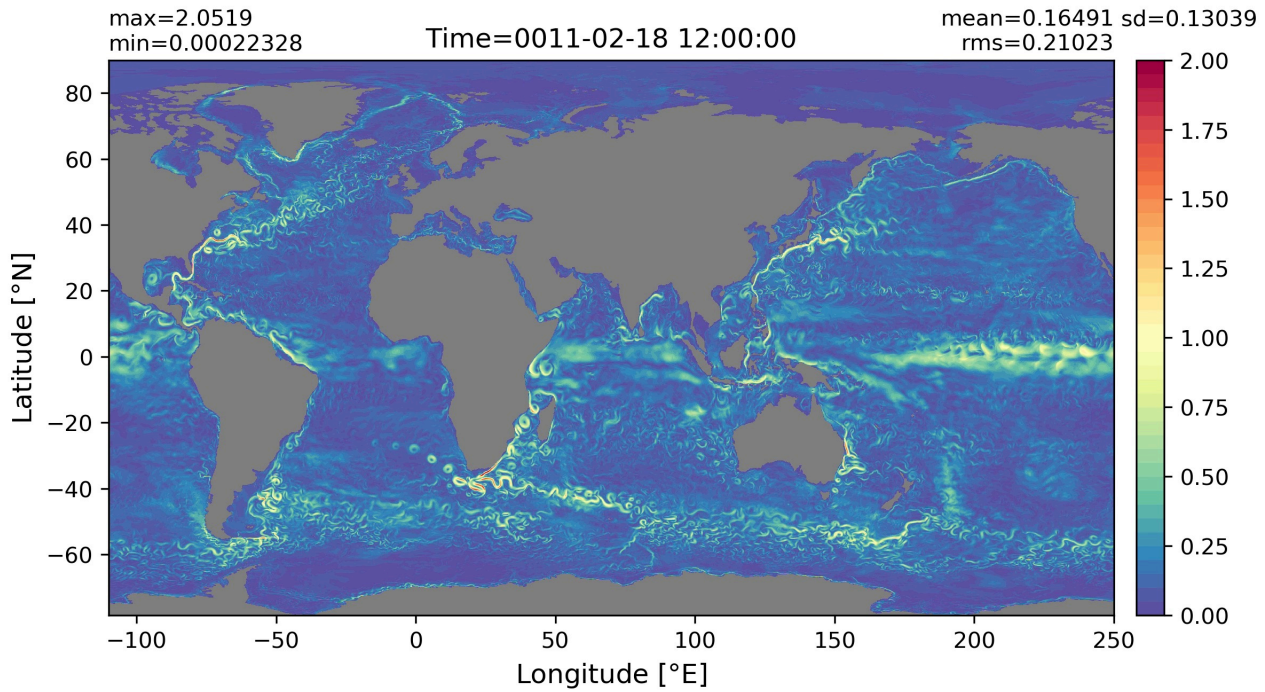
Conducting extensive simulations to gain experience and intuition for model sensitivities especially with vertical discretization and coordinate options

Atlantic Meridional Overturning Circulation (AMOC)



Gustavo Marques

Thank You!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