Introduction to the Community Earth System Model (CESM)

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CESM Chief Scientist

03 AUGUST 2020

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Outline

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

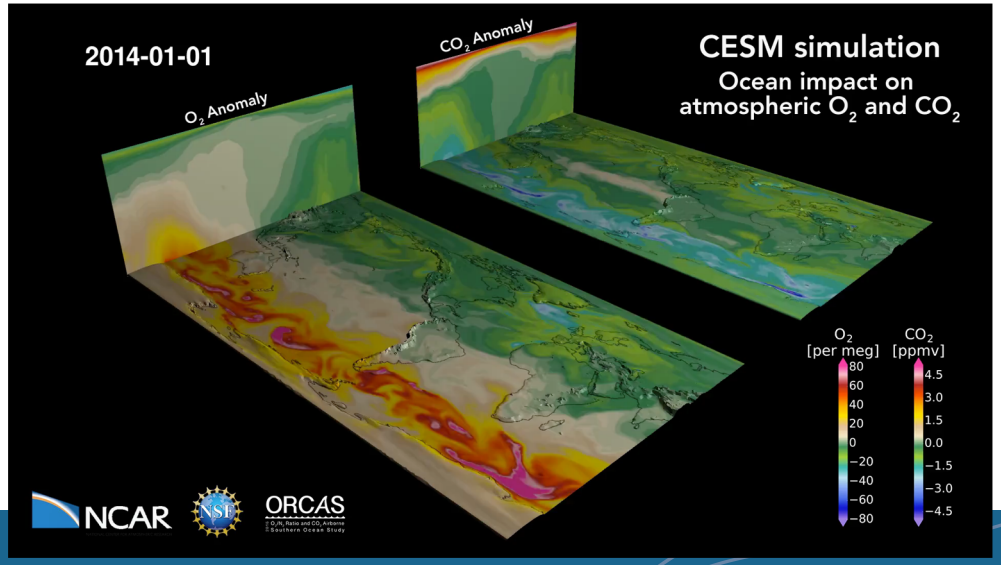
Global Earth System Models and CESM

Global Earth System Models

A virtual laboratory for experimentation ….

General purposes include:

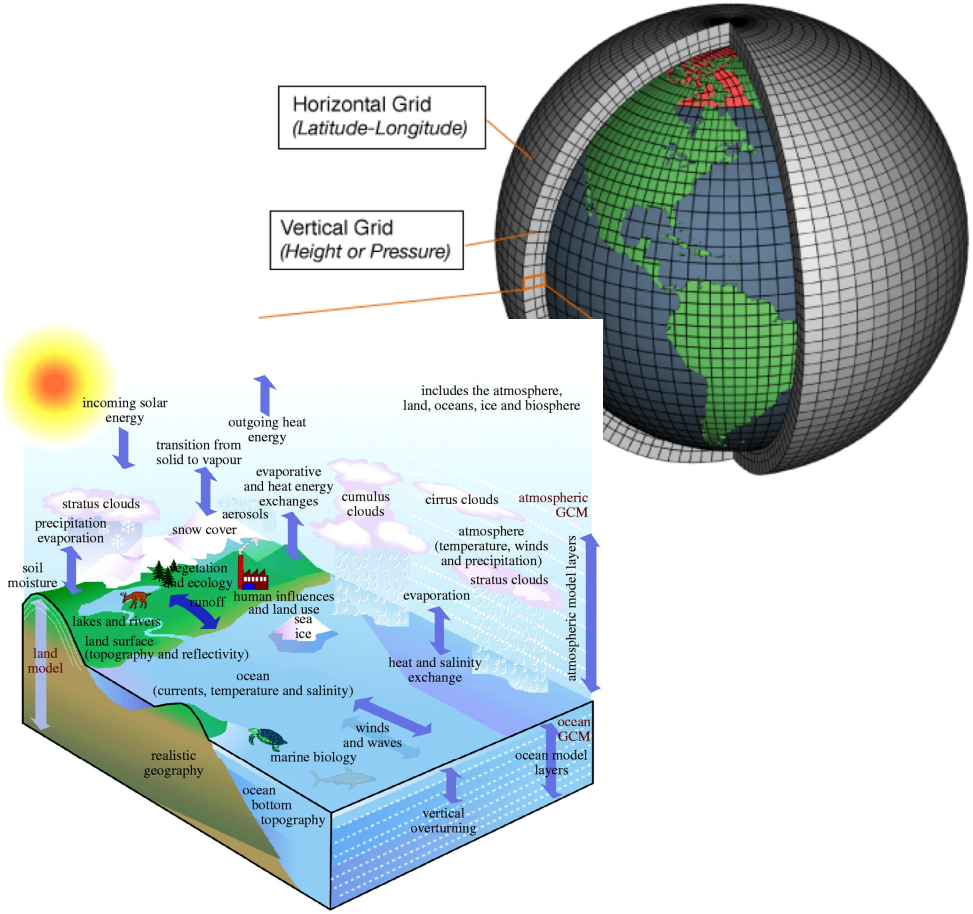
- To provide scientific understanding of observed events, climate change (historical, paleo), etc.,
- To simulate future climate change and its impacts,
- To make future predictions of weather and climate variability.



Long and Scheitlin

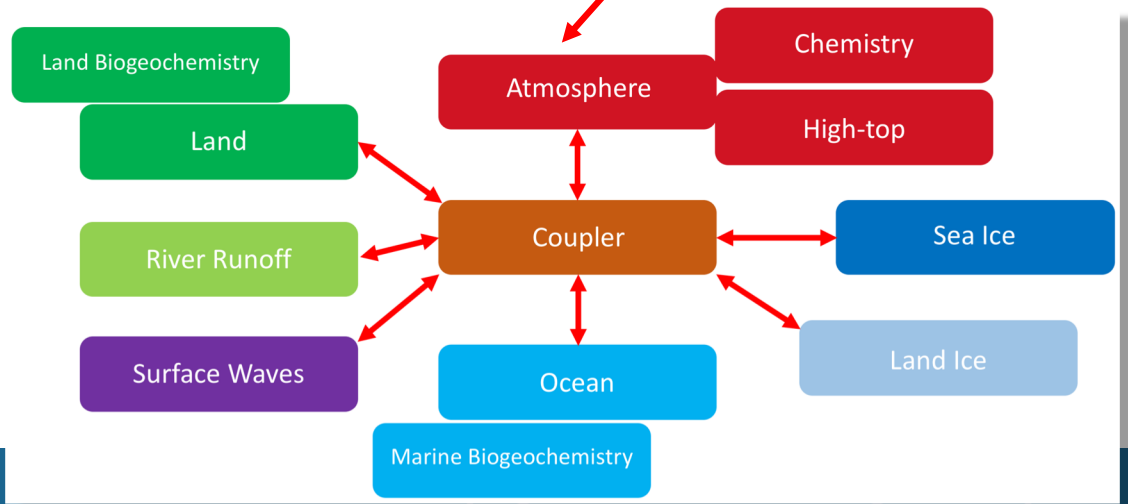
Global Earth System Models

- 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).



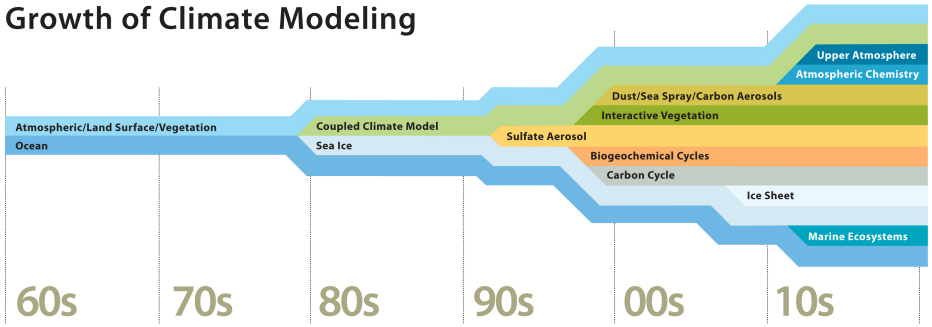
Global Earth System Models

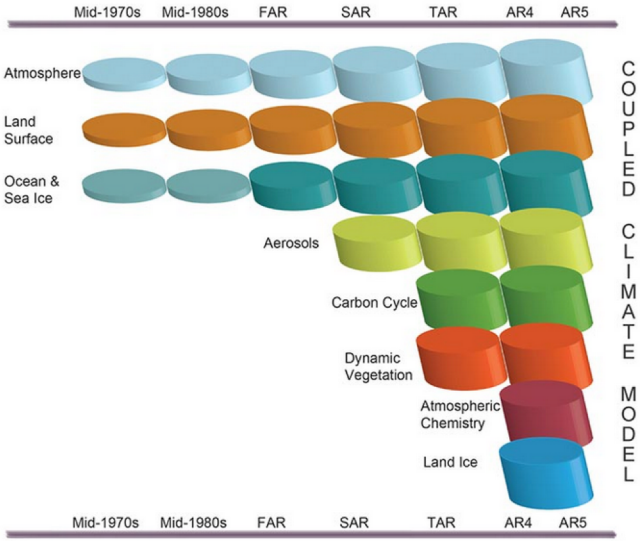
Forcings:
- Greenhouse gases
- Anthropogenic aerosols
- Volcanic eruptions
- Solar variability

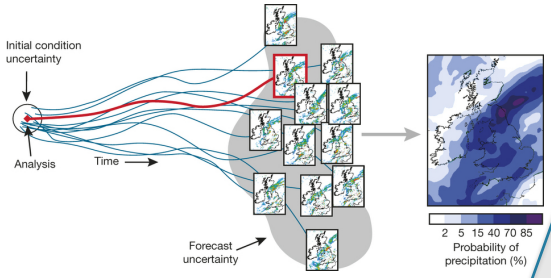


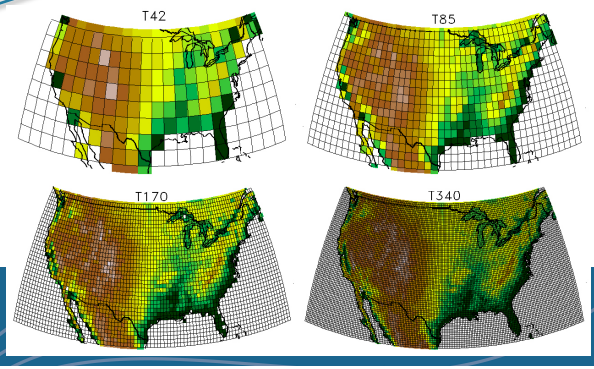
Community Earth System Model

Growth of Climate Modeling









CESM Project

~25 years of model development and applications

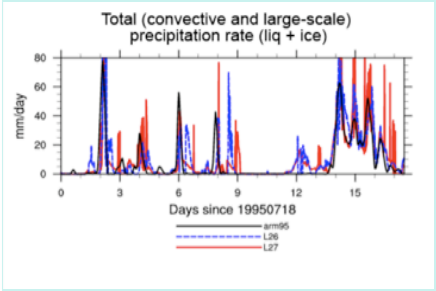
Annual CESM Workshops are held in summers.

Most working groups have winter/spring meetings.

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

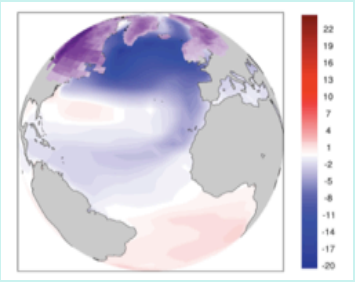
Desktop

Single column/
Coarse resolution:
Physics development



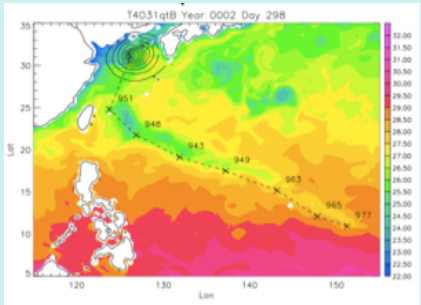
Small cluster

Lower resolution:
Paleo/Large Ensemble
University research



HPC

Higher resolution:
CMIP
Breakthrough Applications



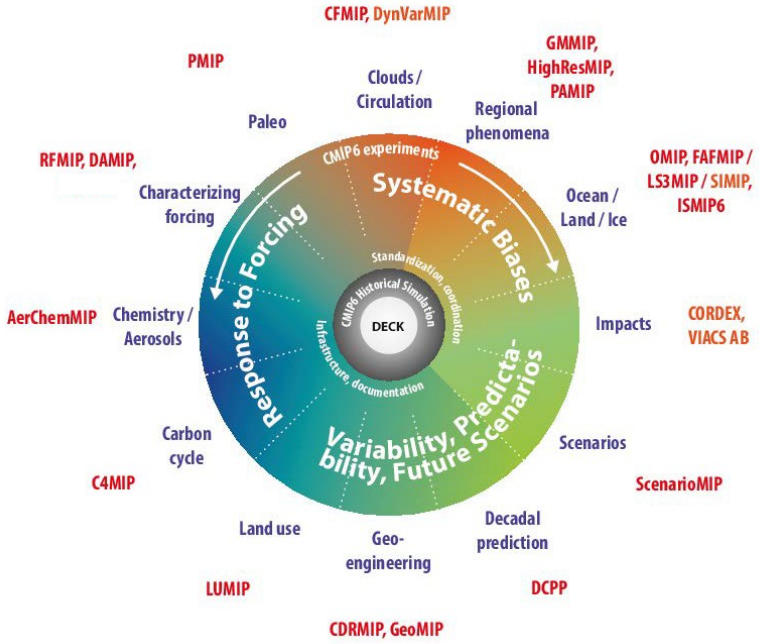
CESM Supports a Range of Climate Science Goals Through a Single Model Code Base

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

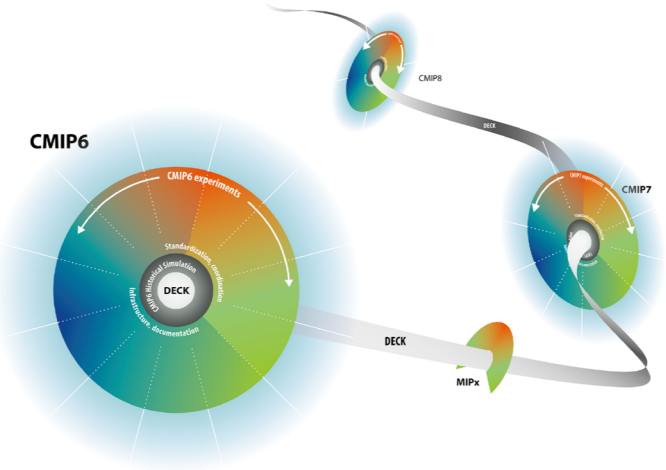
  Allowing, for example, ocean-only, ocean – sea-ice coupled, land-only, atmosphere-only, etc. configurations / experiments.
- Aqua planet, several atmospheric dynamical cores, and slab ocean model options are available.
- Numerous options are available within components.
- Increasing number of supported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

Coupled Model Intercomparison Project phase 6 (CMIP6) Efforts

CESM2 Participation in CMIP6



Diagnostic, Evaluation, and Characterization of Klima (DECK)

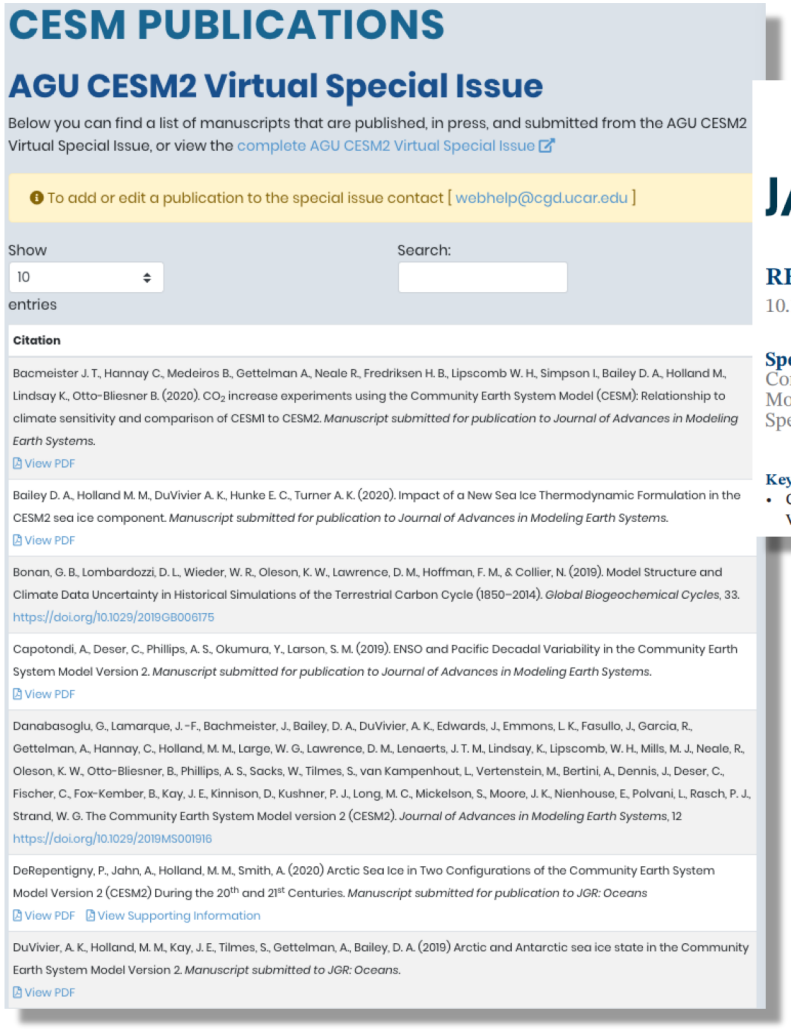


Set I: Two nominal 1° model versions w/ CAM6 and WACCM6 atmospheric model components

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

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

Eyring et al. (2016, GMD)



CESM PUBLICATIONS

AGU CESM2 Virtual Special Issue

Below you can find a list of manuscripts that are published, in press, and submitted from the AGU CESM2 Virtual Special Issue, or view the complete AGU CESM2 Virtual Special Issue

To add or edit a publication to the special issue contact [webhelp@cgd.ucar.edu]

Show 10 entries Search:

Citation

Bacmeister J. T., Hannay C., Medeiros B., Gettelman A., Neale R., Fredriksen H. B., Lipscomb W. H., Simpson I., Bailey D. A., Holland M., Lindsay K., Otto-Bliesner B. (2020). CO_2 increase experiments using the Community Earth System Model (CESM): Relationship to climate sensitivity and comparison of CESM1 to CESM2. *Manuscript submitted for publication to Journal of Advances in Modeling Earth Systems.*
View PDF

Bailey D. A., Holland M. M., DuVivier A. K., Hunke E. C., Turner A. K. (2020). Impact of a New Sea Ice Thermodynamic Formulation in the CESM2 sea ice component. *Manuscript submitted for publication to Journal of Advances in Modeling Earth Systems.*
View PDF

Bonan, G. B., Lombardozzi, D. L., Wieder, W. R., Oleson, K. W., Lawrence, D. M., Hoffman, F. M., & Collier, N. (2019). Model Structure and Climate Data Uncertainty in Historical Simulations of the Terrestrial Carbon Cycle (1850–2014). *Global Biogeochemical Cycles*, 33.
https://doi.org/10.1029/2019GB006175

Capotondi, A., Deser, C., Phillips, A. S., Okumura, Y., Larson, S. M. (2019). ENSO and Pacific Decadal Variability in the Community Earth System Model Version 2. *Manuscript submitted for publication to Journal of Advances in Modeling Earth Systems.*
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Danabasoglu, G., Lamarque, J.-F., Bachmeister, J., Bailey, D. A., DuVivier, A. K., Edwards, J., Emmons, L. K., Fasullo, J., Garcia, R., Gettelman, A., Hannay, C., Holland, M. M., Large, W. G., Lawrence, D. M., Lenaerts, J. T. M., Lindsay, K., Lipscomb, W. H., Mills, M. J., Neale, R., Oleson, K. W., Otto-Bliesner, B., Phillips, A. S., Sacks, W., Tilmes, S., van Kampenhout, L., Vertenstein, M., Bertini, A., Dennis, J., Deser, C., Fischer, C., Fox-Kemper, B., Kay, J. E., Kinnison, D., Kushner, P. J., Long, M. C., Mickelson, S., Moore, J. K., Nienhouse, E., Polvani, L., Rasch, P. J., Strand, W. G. The Community Earth System Model version 2 (CESM2). *Journal of Advances in Modeling Earth Systems*, 12
https://doi.org/10.1029/2019MS001916

DeRepentigny, P., Jahn, A., Holland, M. M., Smith, A. (2020) Arctic Sea Ice in Two Configurations of the Community Earth System Model Version 2 (CESM2) During the 20th and 21st Centuries. *Manuscript submitted for publication to JGR: Oceans*
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DuVivier, A. K., Holland, M. M., Kay, J. E., Tilmes, S., Gettelman, A., Bailey, D. A. (2019) Arctic and Antarctic sea ice state in the Community Earth System Model Version 2. *Manuscript submitted to JGR: Oceans.*
View PDF

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]

~70 total manuscripts anticipated

40 already published or submitted

Submission deadline: 30 September 2020

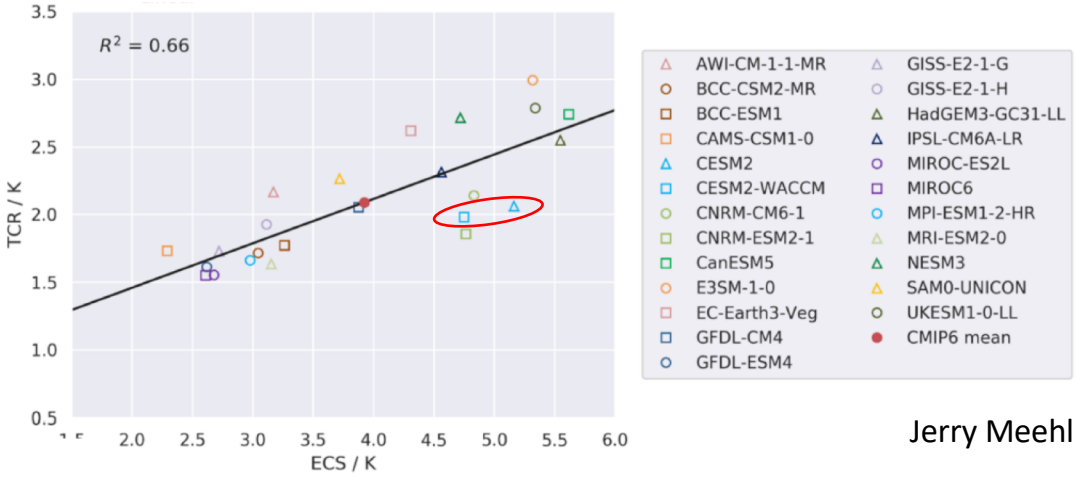
http://www.cesm.ucar.edu/publications/

Equilibrium Climate Sensitivity (ECS) & Transient Climate Response (TCR)

CESM1(CAM5): 4.0-4.1°C

CESM2(CAM6): 5.3°C (SOM)
5.3°C ($E_{ff}CS$)

CESM2(WACCM6): 5.1°C (SOM)
4.8°C ($E_{ff}CS$)

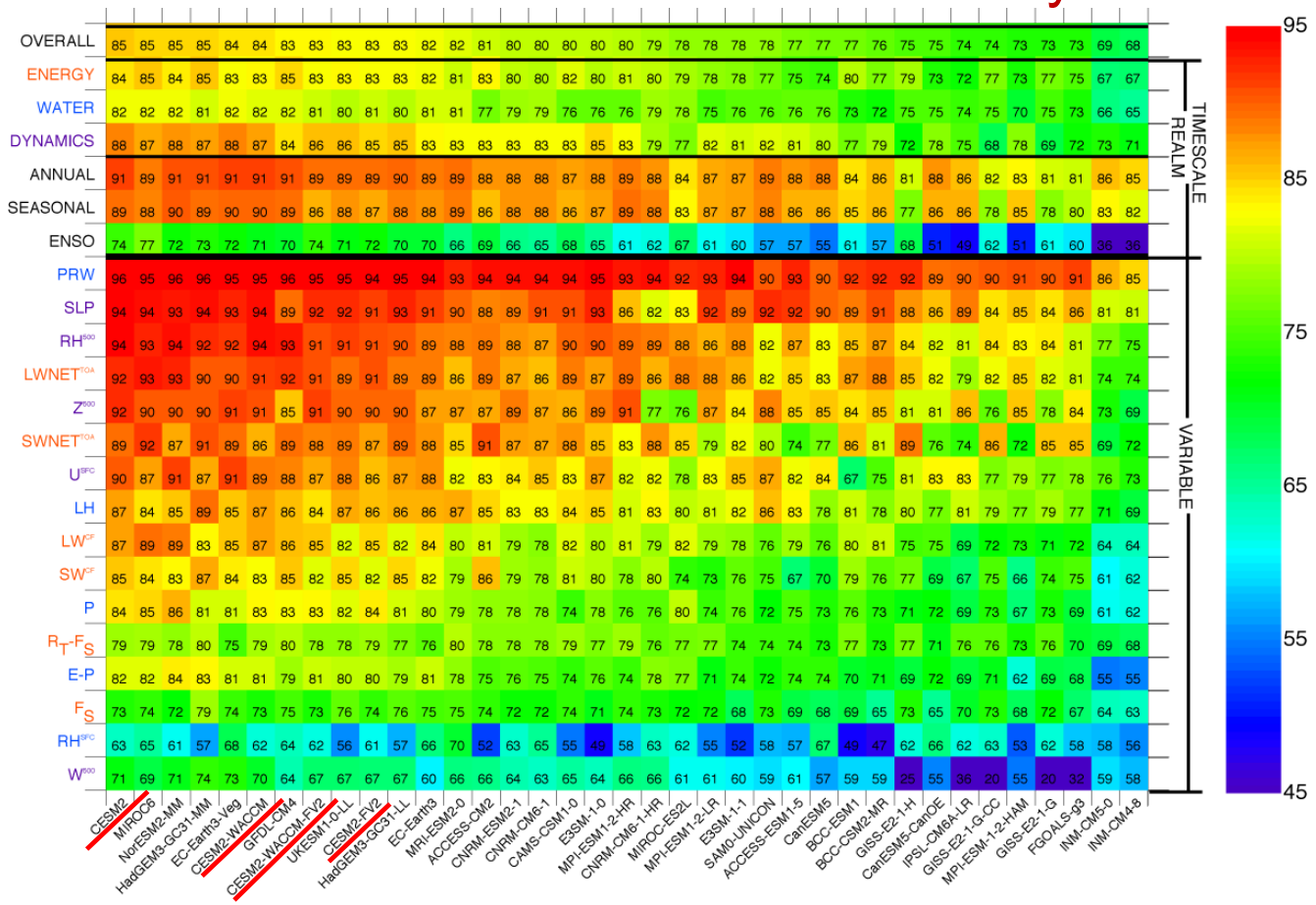


Jerry Meehl

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.

Cloud feedbacks particularly over the Southern Ocean latitudes are important.

A Model Performance Summary



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

Updates on Ongoing Activities

CESM2 *Incremental* Releases

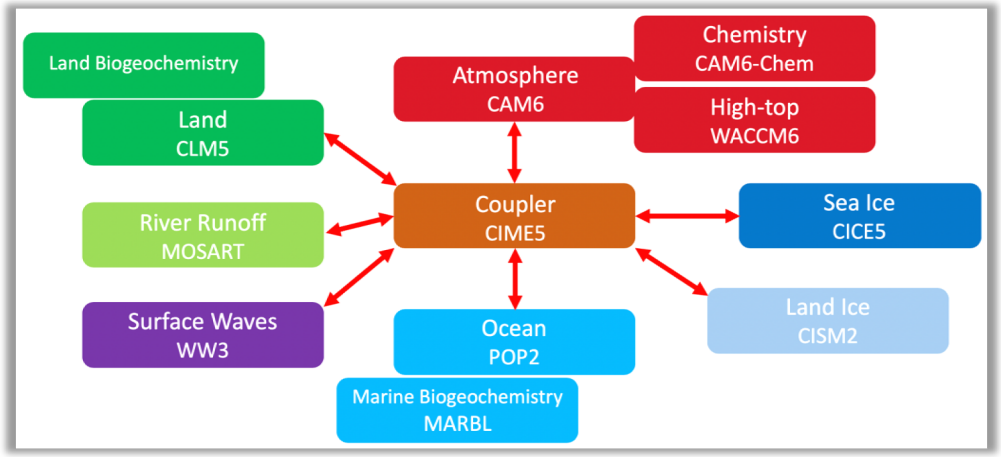
CESM2.1.0 on 10 December 2018

CESM2.1.1 on 10 June 2019

CESM2.1.2 on 14 February 2020

CESM2.2 on September 2020 (tentative)

CESM2.1.x series are non-answer-changing* and they further expand the available set of out-of-the-box configurations of CESM2 for readily performing all of the DECK, historical, and many MIP Tier 1 simulations for CMIP6.

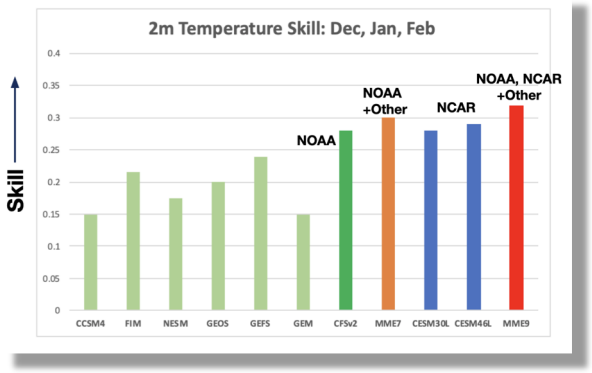


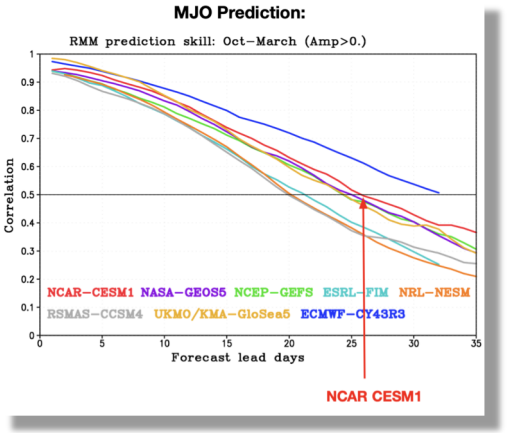
*CESM2.2 release will be answer changing.

Earth System Prediction Working Group (ESPWG)

Co-chairs: Kathy Pegion (GMU), Yaga Richter (NCAR), and Steve Yeager (NCAR)

- ESPWG will serve the CESM and broader geoscience community by facilitating and coordinating fundamental research focused on understanding and advancing research on initialized Earth system predictions on timescales from subseasonal to multidecadal.
- A key aim is to facilitate ESP research through provision of large ensemble initialized hindcast / forecast simulations that are too computationally burdensome for individual university researchers to undertake.

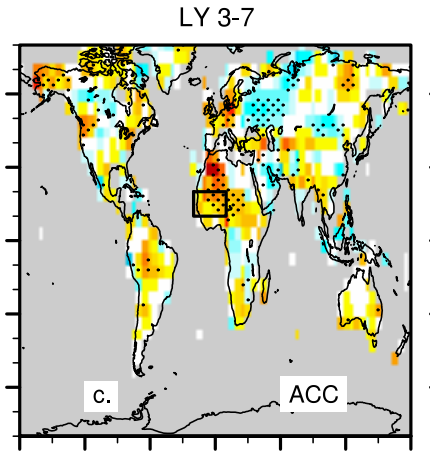


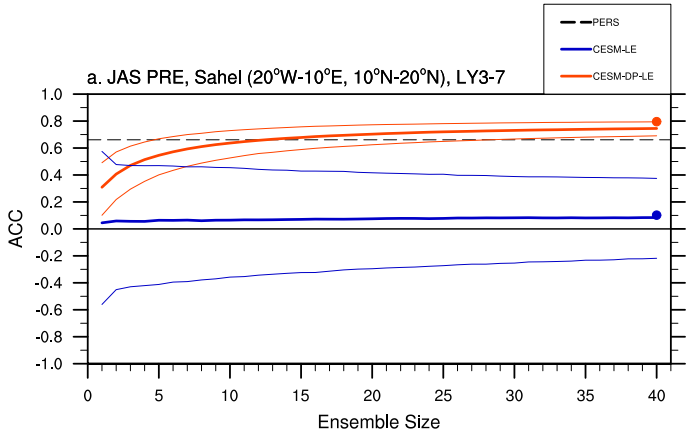


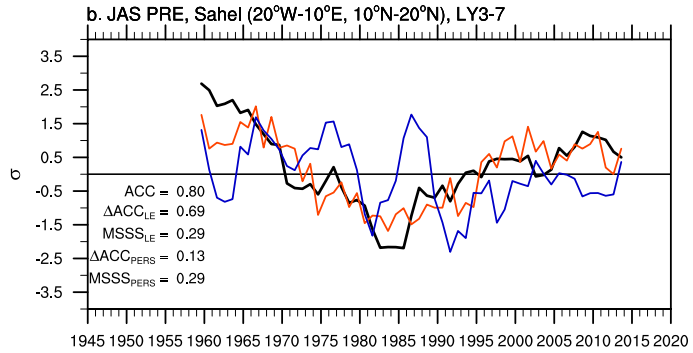
Yaga Richter

CESM Decadal Prediction Large Ensemble (CESM-DPLE)

Summer Precipitation in the Sahel



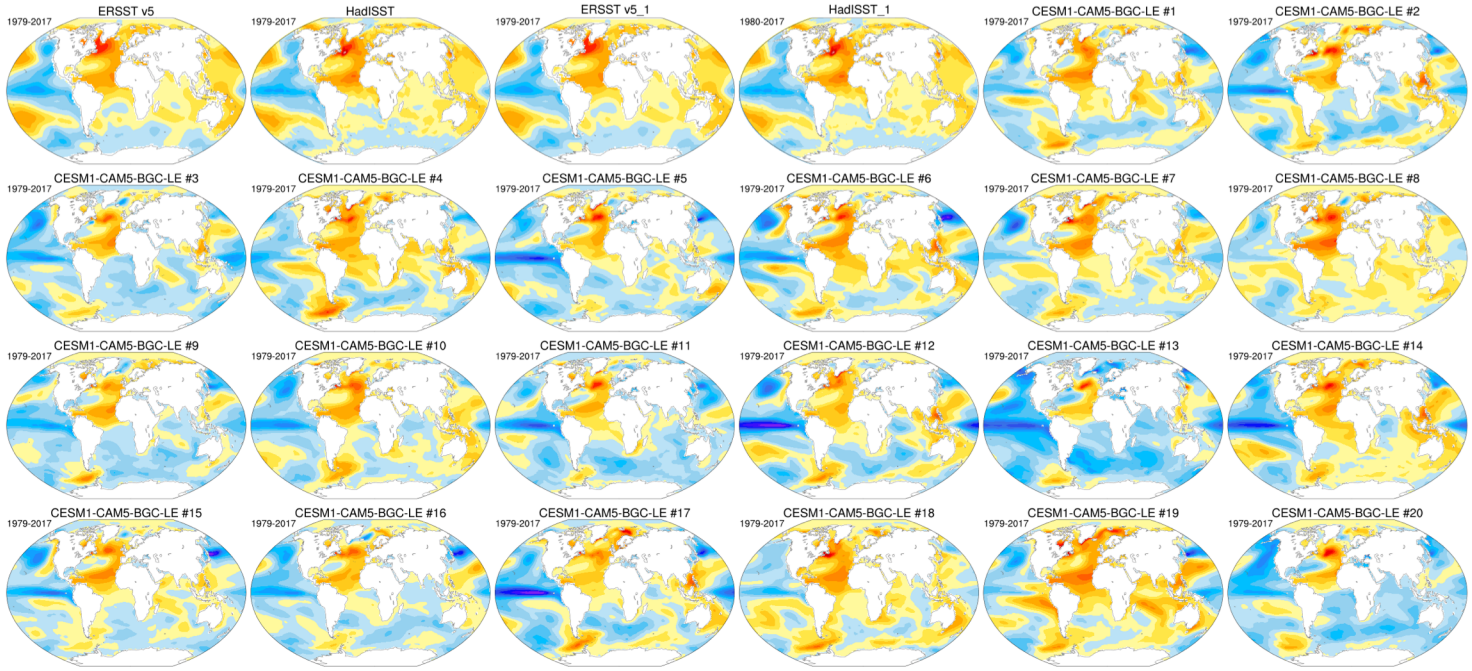




Yeager et al. (2018, *BAMS*)

CESM1 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

Kay et al. (2015, *BAMS*)

CESM2 Large Ensemble (CESM2-LENS)

A collaboration / 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;
- 40 members have been completed;
- Anticipated completion date for the full ensemble is early December 2020;
- Data are being transferred to NCAR and being CMORized; and will be available for use of the broader community via ESGF in early 2021.

NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

“Strongly” Coupled Data Assimilation: The Bleeding Edge

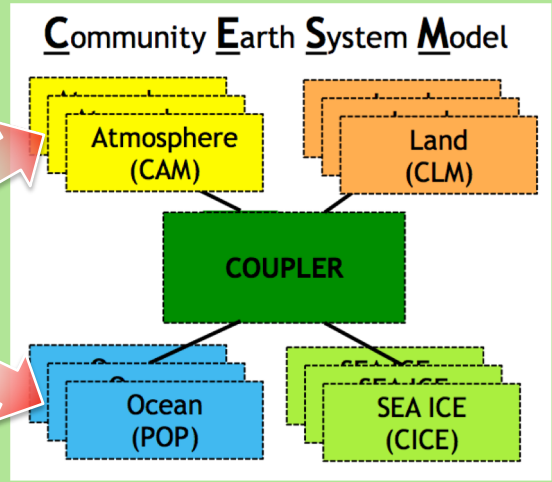
Observations of the climate system

Data Assimilation System

Data Assimilation Research Testbed (DART)

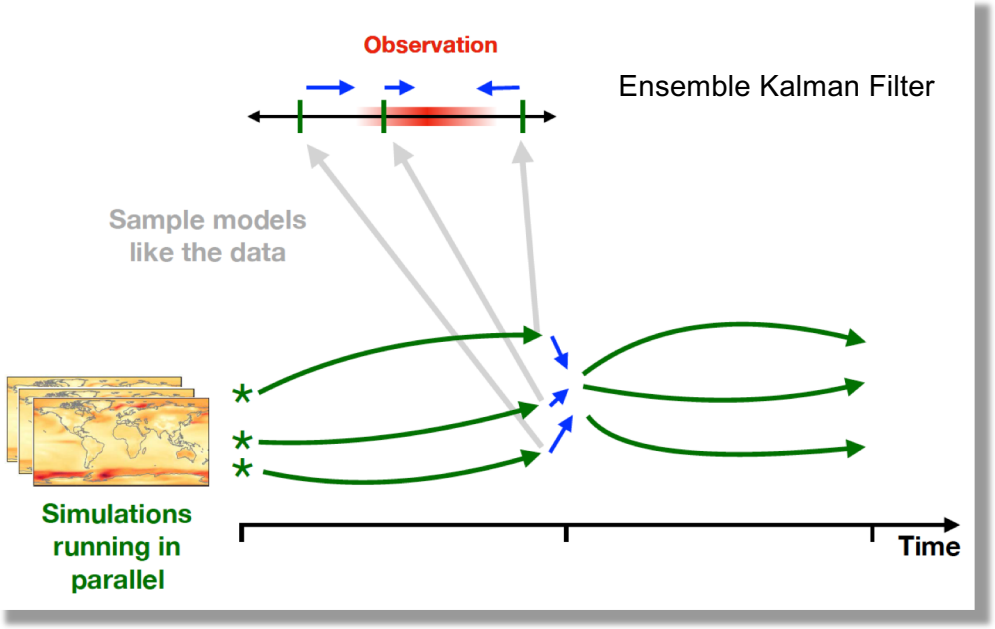
Ensemble Kalman Filter (EnKF)

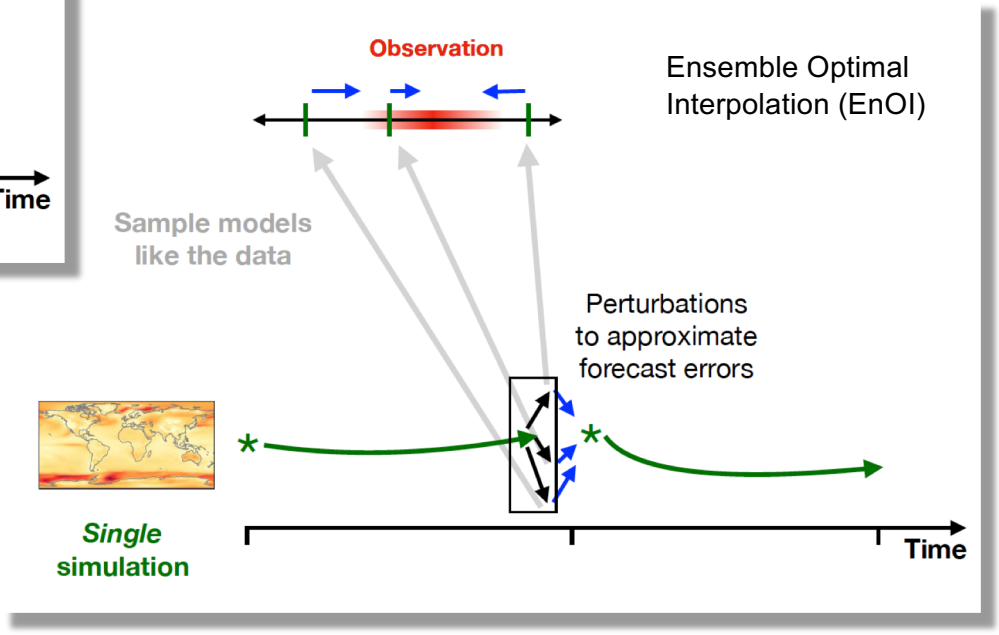
Geophysical Model



We have a prototype

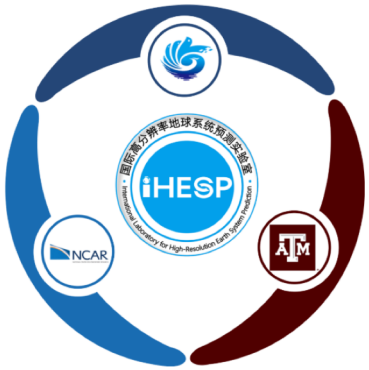
CESM – DART High-Resolution Data Assimilation





Castruccio et al. (2020, *JAMES*)

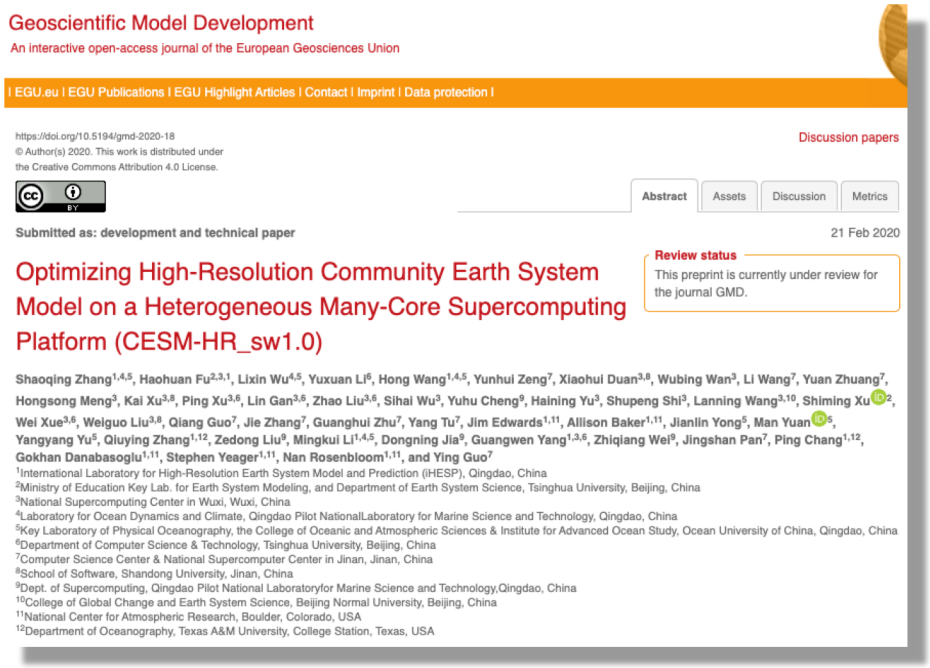
CESM High-Resolution (CESM-HR) Simulations



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 0.25º; ocean and sea-ice at nominal 0.1º resolution

The CESM (v1.3) code base used on the Sunway System is publicly available from the iHESP web site.



Geoscientific Model Development
An interactive open-access journal of the European Geosciences Union

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https://doi.org/10.5194/gmd-2020-18
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Discussion papers

Abstract | Assets | Discussion | Metrics

Submitted as: development and technical paper

21 Feb 2020

Review status
This preprint is currently under review for the journal GMD.

Optimizing High-Resolution Community Earth System Model on a Heterogeneous Many-Core Supercomputing Platform (CESM-HR_sw1.0)

Shaoqing Zhang[1,4,5], Haohuan Fu[2,3,1], Lixin Wu[4,5], Yuxuan Li[6], Hong Wang[1,4,5], Yunhui Zeng[7], Xiaohui Duan[3,8], Wubing Wan[3], Li Wang[7], Yuan Zhuang[7], Hongsong Meng[3], Kai Xu[3,8], Ping Xu[3,6], Lin Gan[3,6], Zhao Liu[3,6], Sihai Wu[3], Yuhu Cheng[9], Haining Yu[3], Shupeng Shi[3], Lanning Wang[3,10], Shiming Xu[2], Wei Xue[3,6], Weiguo Liu[3,8], Qiang Guo[7], Jie Zhang[7], Guanghui Zhu[7], Yang Tu[7], Jim Edwards[1,11], Allison Baker[1,11], Jianlin Yong[5], Man Yuan[5], Yangyang Yu[5], Qiuying Zhang[1,12], Zedong Liu[9], Mingkui Li[1,4,5], Dongning Jia[9], Guangwen Yang[1,3,6], Zhiqiang Wei[9], Jingshan Pan[7], Ping Chang[1,12], Gokhan Danabasoglu[1,11], Stephen Yeager[1,11], Nan Rosenbloom[1,11], and Ying Guo[7]
[1]International Laboratory for High-Resolution Earth System Model and Prediction (iHESP), Qingdao, China
[2]Ministry of Education Key Lab. for Earth System Modeling, and Department of Earth System Science, Tsinghua University, Beijing, China
[3]National Supercomputing Center in Wuxi, Wuxi, China
[4]Laboratory for Ocean Dynamics and Climate, Qingdao Pilot NationalLaboratory for Marine Science and Technology, Qingdao, China
[5]Key Laboratory of Physical Oceanography, the College of Oceanic and Atmospheric Sciences & Institute for Advanced Ocean Study, Ocean University of China, Qingdao, China
[6]Department of Computer Science & Technology, Tsinghua University, Beijing, China
[7]Computer Science Center & National Supercomputer Center in Jinan, Jinan, China
[8]School of Software, Shandong University, Jinan, China
[9]Dept. of Supercomputing, Qingdao Pilot National Laboratoryfor Marine Science and Technology,Qingdao, China
[10]College of Global Change and Earth System Science, Beijing Normal University, Beijing, China
[11]National Center for Atmospheric Research, Boulder, Colorado, USA
[12]Department of Oceanography, Texas A&M University, College Station, Texas, USA

CESM-HR Simulations

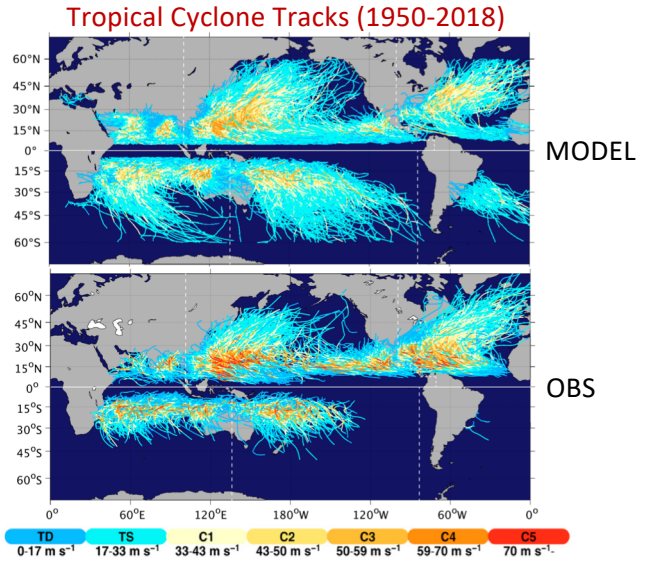
- 500-year pre-industrial (PI) control
- 1850-2100 transient simulation w/ RCP8.5
- 80-year 1%/year CO2 increase
- Ocean – sea-ice coupled simulation run for 4 cycles of JRA55-do for the 1958-2018 period

HighResMIP CESM Contributions

- 130-year 1950 control
- 1950-2050 transient simulation w/ RCP8.5
- 1950-2050 AMIP-style simulation

+ Low-resolution equivalents for all simulations

Data sets from coupled HighResMIP and the first 300 years of the PI control were released on 08 June 2020. The rest will be made available by the end of this year.

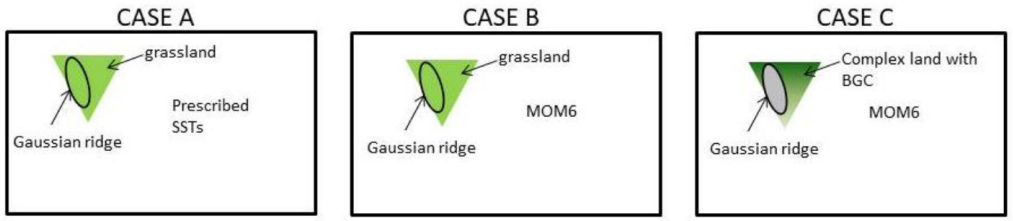


Courtesy of Fu and Chang

Towards CESM3

Development of Coupled Idealized Modelling Toolkits

- Develop a Simpler Models query tool to allow users to easily understand which simpler model configurations are available and supported, their compatibilities, different options (e.g., physics packages);
- Develop infrastructure for customization of ocean basin and land geometries (overlaps with needs of the Paleoclimate community);
- Provide a toolchain for seamless model setup (components, grids, domain, physics) for coupled idealized configurations.

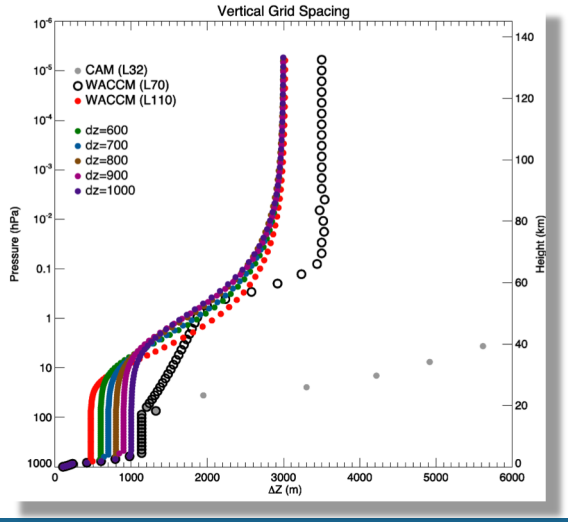


Isla Simpson et al.

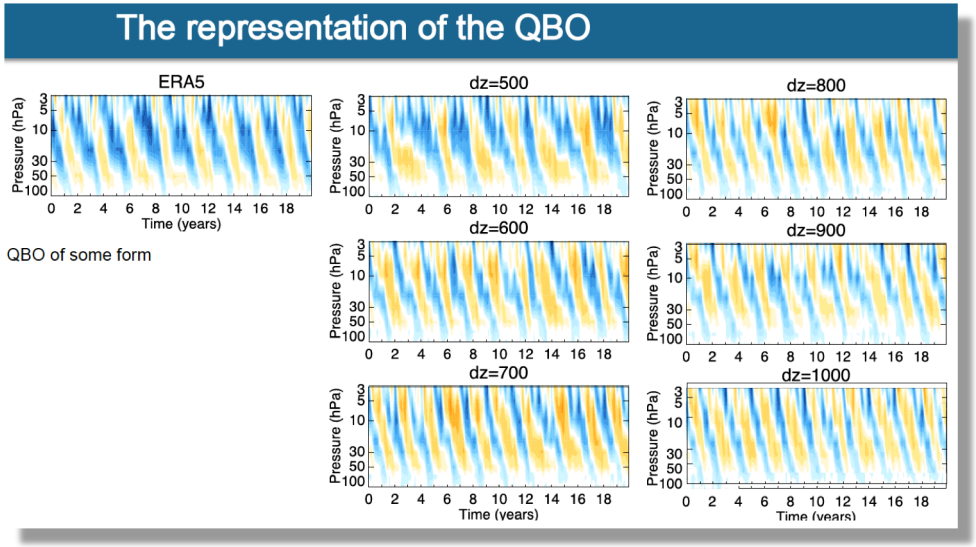
Atmospheric Model Vertical Resolution and Top for the Next Workhorse Version of CESM

Investigate possible vertical grid configurations and model tops for the next generation, workhorse atmospheric model version of CESM.

This will be a model that does not extend as high as WACCM, but extends higher than CAM and has a grid structure with improvements in vertical resolution in the free troposphere and stratosphere and the boundary layer in order to capture features of interest.



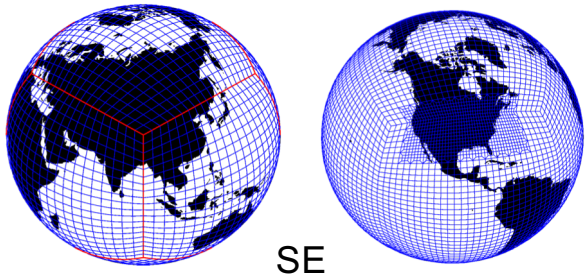
Isla Simpson et al.



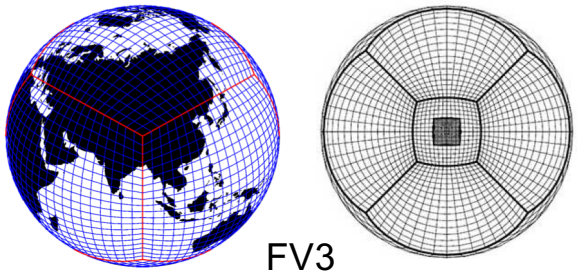
New Atmospheric Dynamical Cores in CESM

The following dynamical cores have been or are being integrated into the CESM:

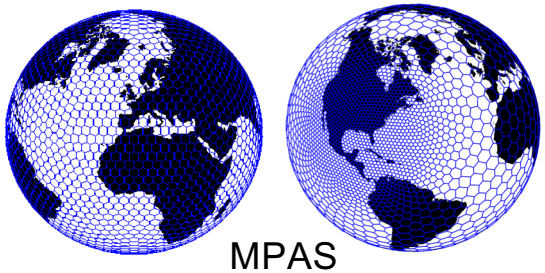
- **SE** dynamical core with option for accelerated transport scheme (**CSLAM**)
  - highly scalable hydrostatic dynamical core with flexible mesh-refinement options
  - capability of running physics on a separate (coarser) grid for uniform grid applications
- **FV3**: GFDL's dynamical core used by NCEP for global weather forecasting
  - scalable finite-volume dynamical core (currently using hydrostatic version; non-hydrostatic available)
- **MPAS**: NCAR's global weather forecast model
  - non-hydrostatic finite-volume dynamical core that also allows for flexible mesh-refinement



SE



FV3



MPAS

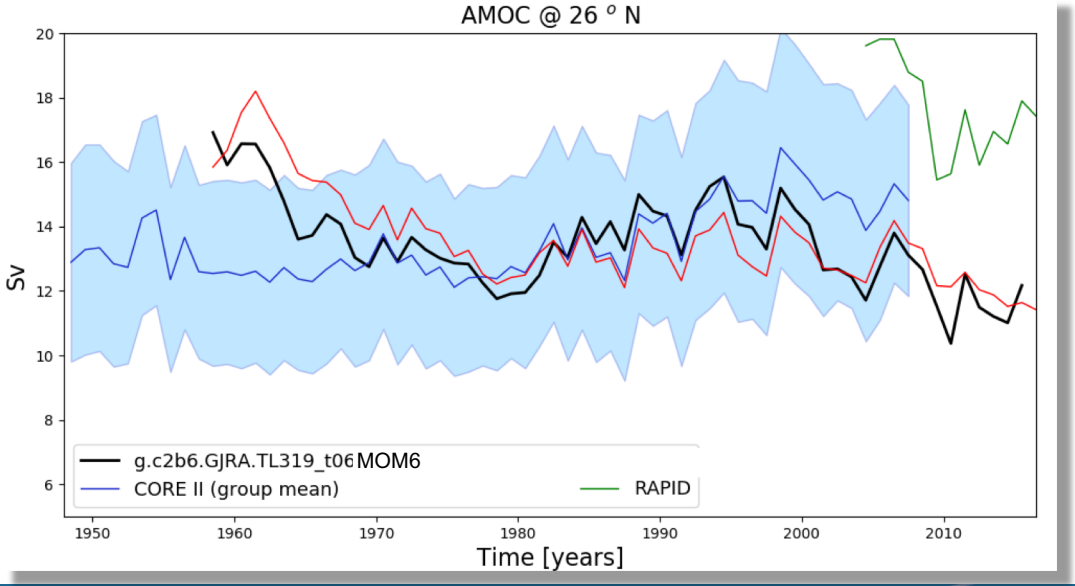
Modular Ocean Model version 6 (MOM6) in CESM3

A development prototype MOM6 version has been running within the CESM framework in ocean – sea-ice coupled and fully-coupled configurations;

The resolution is nominal 2/3^{o} in the horizontal (tripole grid with equatorial refinement) with 65 (z*) levels in the vertical;

Conducting extensive simulations to gain experience and intuition for model sensitivities especially with the new approaches for mesoscale mixing parameter prescriptions

Atlantic Meridional Overturning Circulation at 26^{o}N



Documentation and Training Opportunities: Webinars…. algorithms, practical, use cases

Early/friendly user functional release of MOM6 in CESM2.2

Thank You!