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# STATE OF CESM

*Gokhan Danabasoglu*
*CESM Chief Scientist*

15 JUNE 2020

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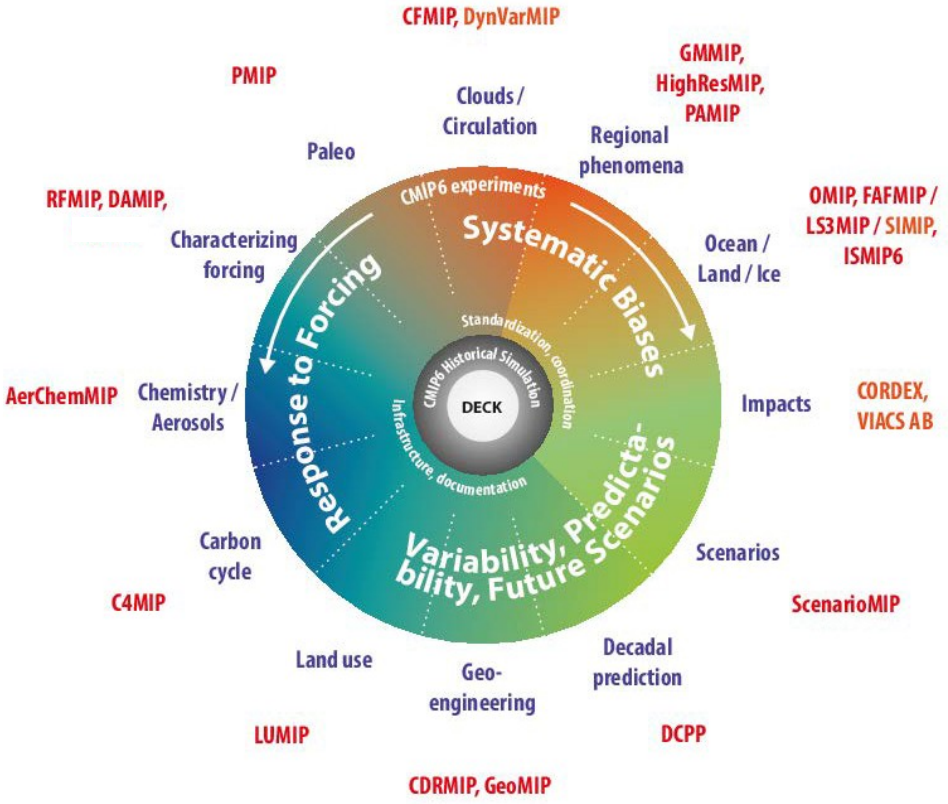
## Outline

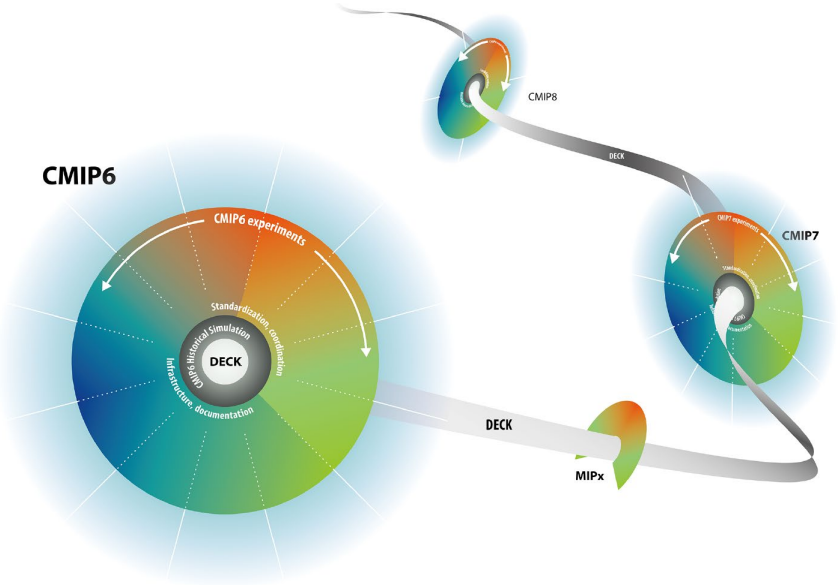
- Coupled Model Intercomparison Project phase 6 (CMIP6) Efforts
- Updates on code release and large ensemble and high-resolution simulations
- Towards CESM3

# 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

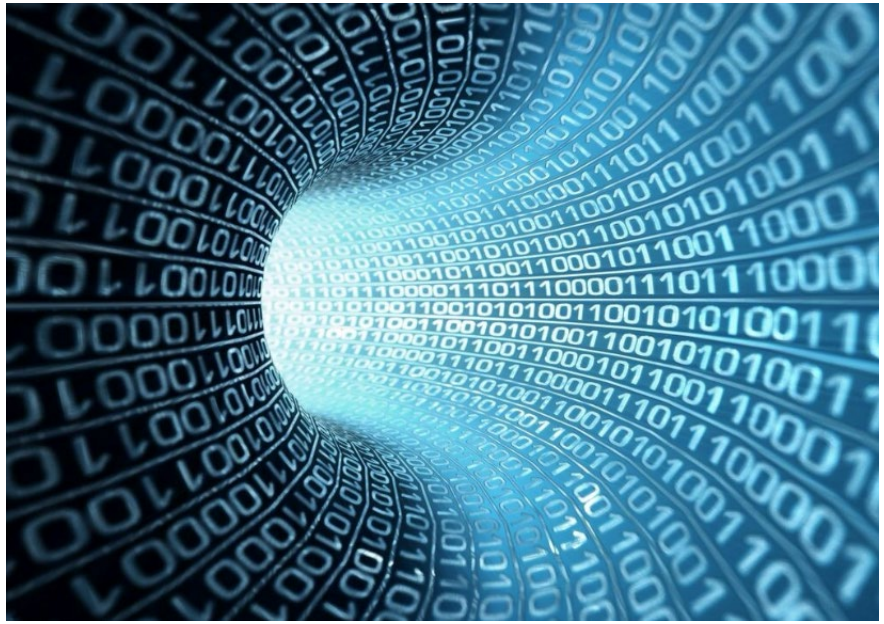
Set II: w/ 2° versions of CAM6 and WACCM6, but otherwise identical (primarily DECK)

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

Eyring et al. (2016, GMD)

# By the numbers ….

- Since August 2018, about 1000 CESM2 simulations for CMIP6 have been run, with order 10 simulations left to complete
- ~1.7 PB of compressed time series files have been generated
- ~550+ TB of compressed CMIP6 files from 950+ cases have been already published on the Earth System Federation Grid (ESGF), with < 40 TB waiting to be published
- Over 830 000 files have been published on the ESGF
- When we are *done* with CMIP6, CESM2 will have ~600 TB published to the ESGF – 7x the grand total from CESM's CMIP5 contribution



# 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.*
View PDF

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*
View PDF View Supporting Information

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.*
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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]

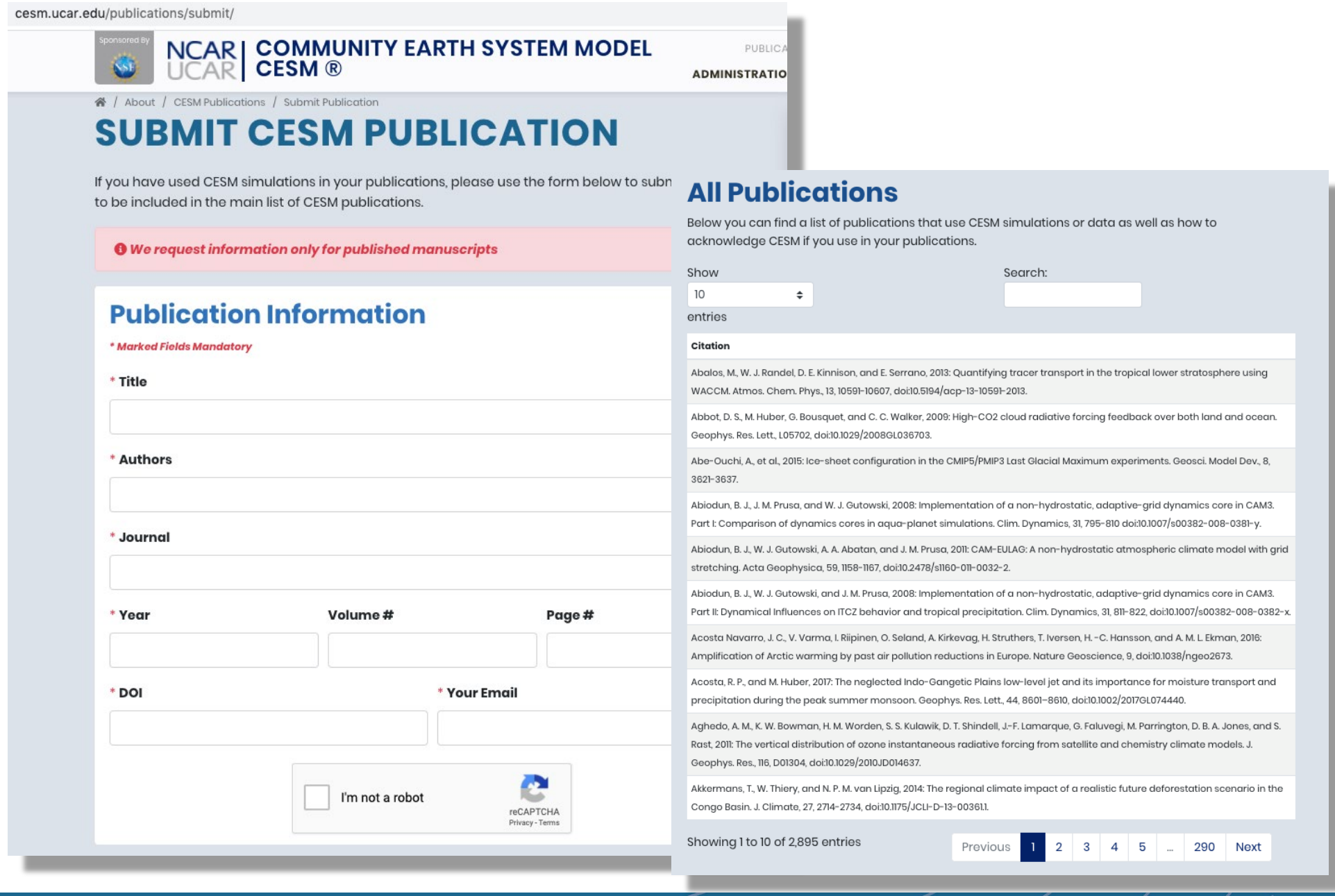
~70 total manuscripts anticipated

38 already published or submitted

Submission deadline: 30 September 2020

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

# Collecting information on publications that primarily use CESM



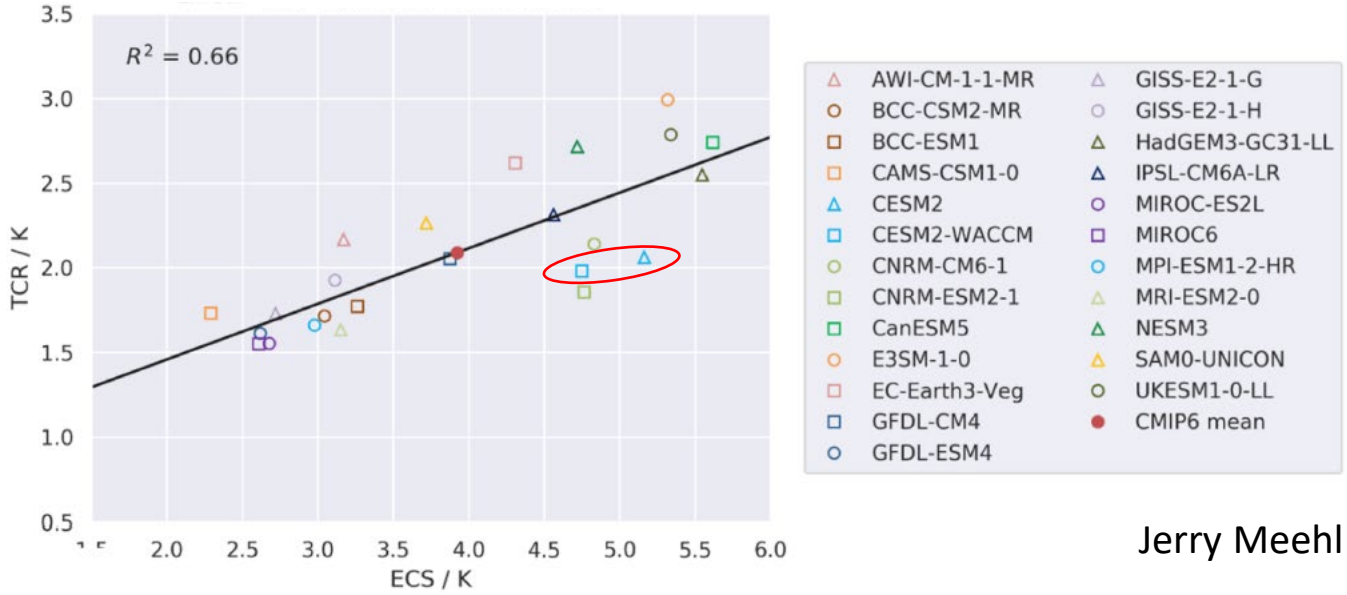

Elizabeth Faircloth
Ryan Johnson

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

CESM1(CAM5): 4.0-4.1ºC

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

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

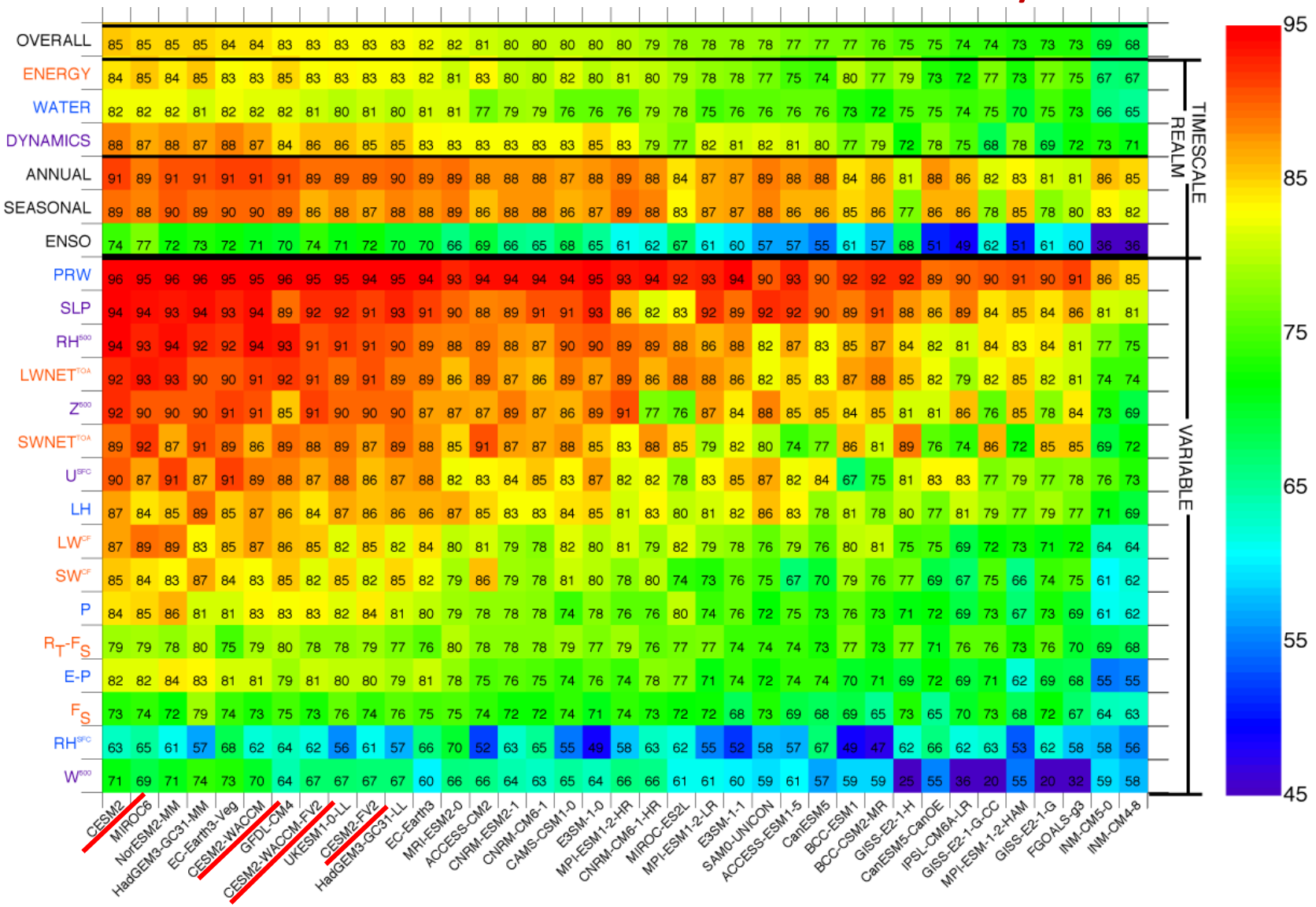



Jerry Meehl

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 Code Release and Large Ensemble and High-Resolution Simulations

# CESM2 *Incremental* Releases

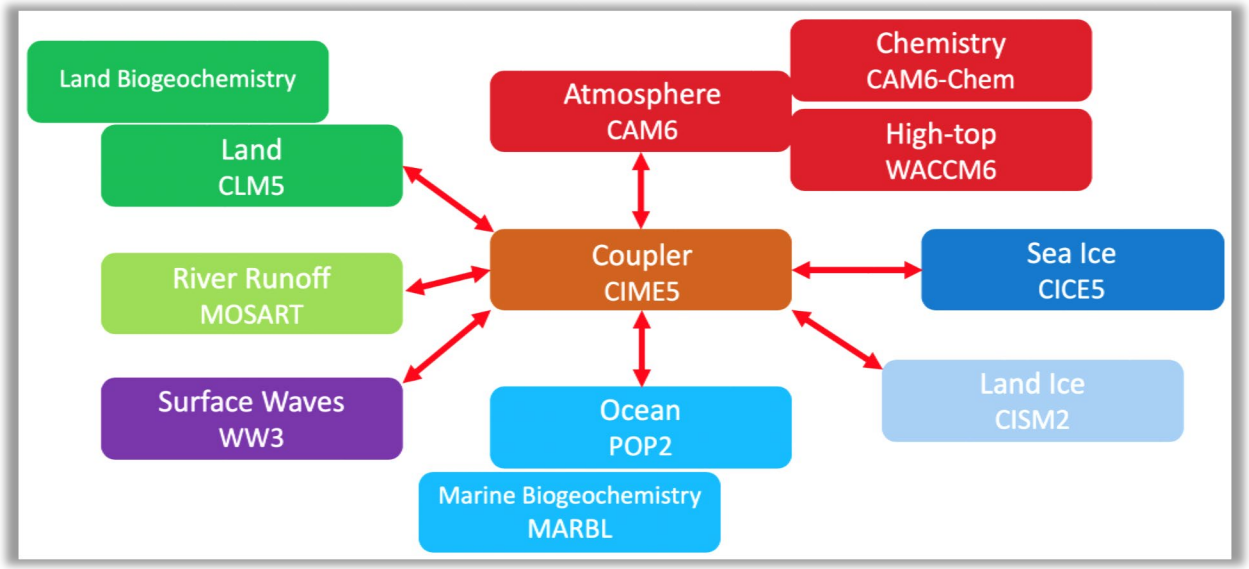
CESM2.1.0 on 10 December 2018

CESM2.1.1 on 10 June 2019

CESM2.1.2 on 14 February 2020

CESM2.2 on 07 August 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.

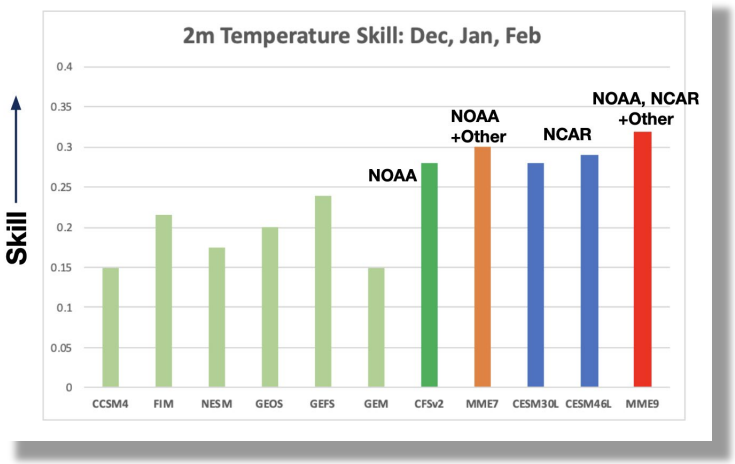


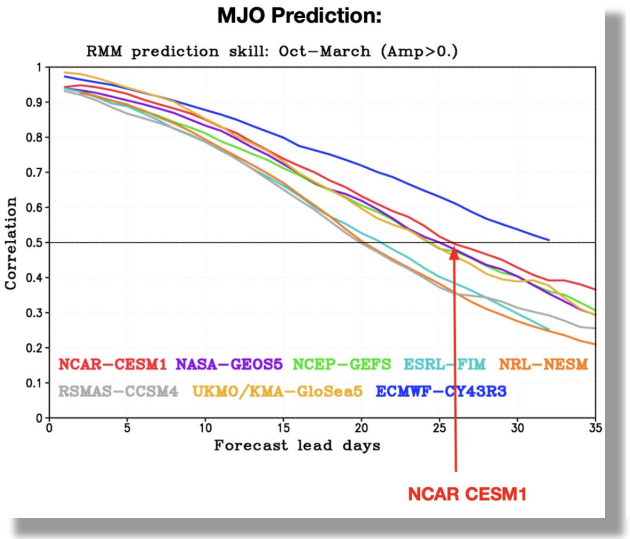

*CESM2.2 release will be answer changing.

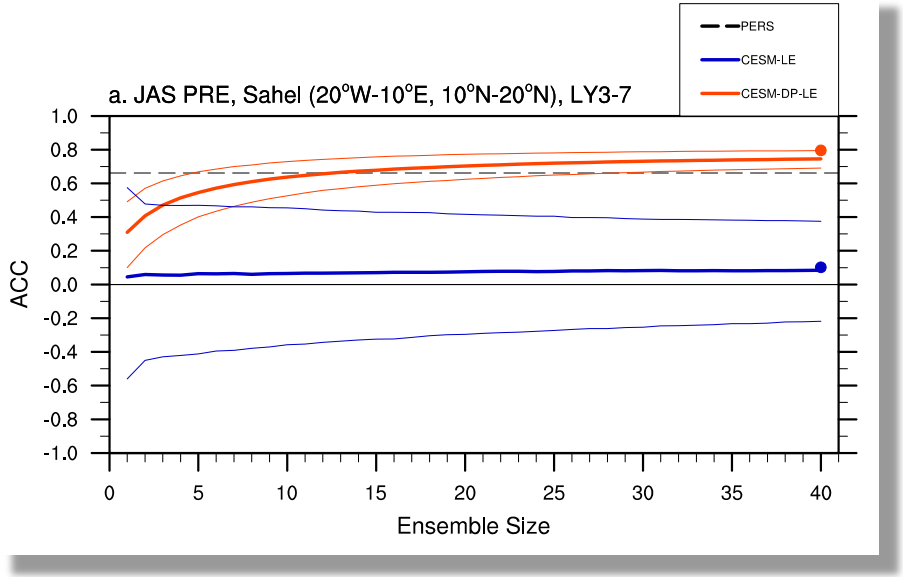
# Earth System Prediction Working Group (ESPWG)

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.




Richter, Yeager, et al.

# 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.

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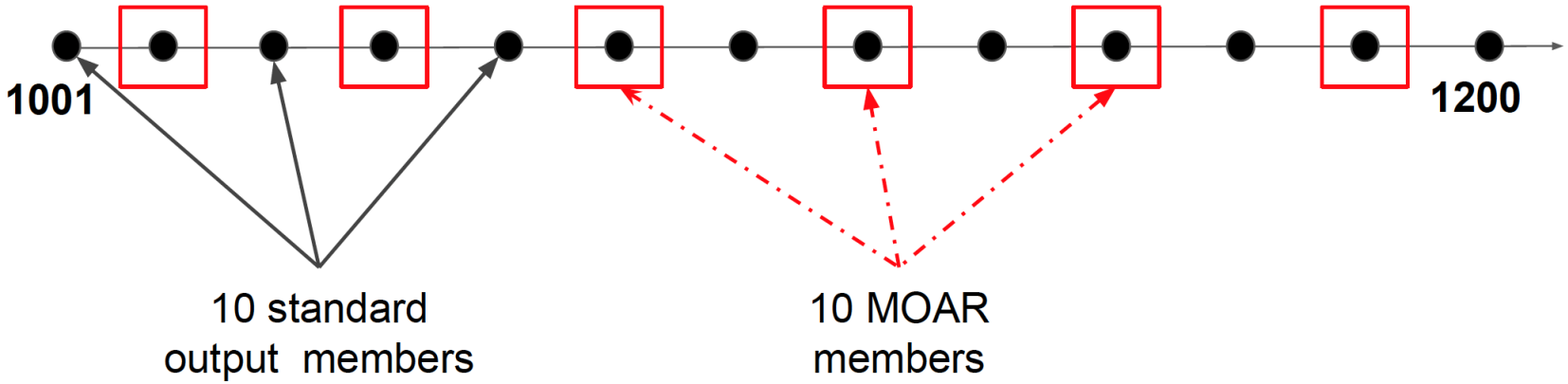
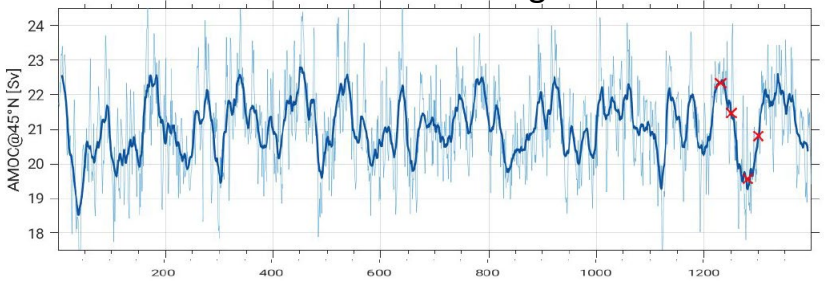
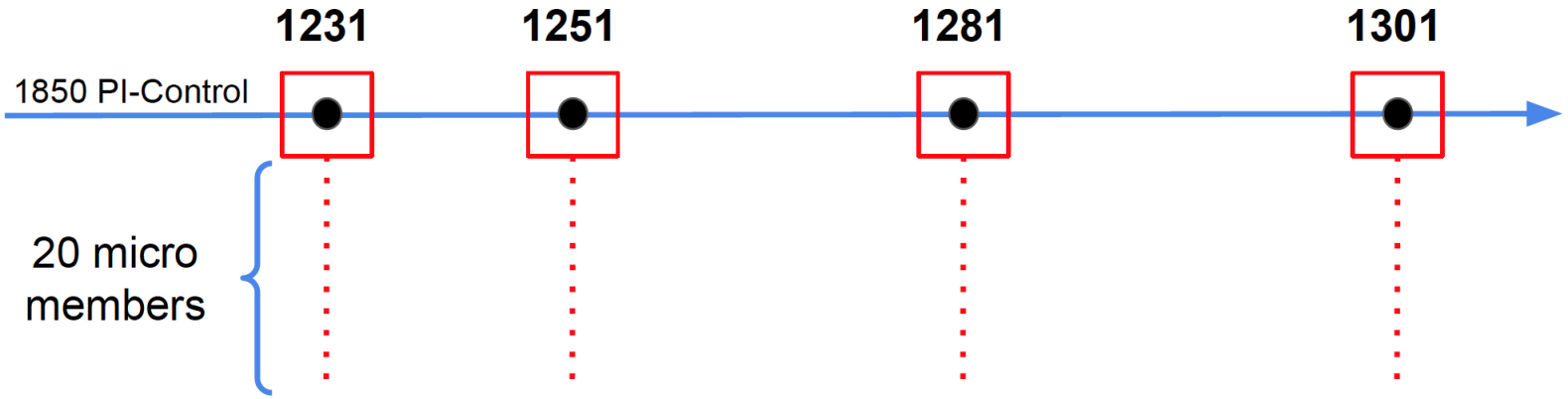
ICCP

# A Combination of Macro and Micro Initial Conditions




Atlantic Meridional Overturning Circulation



# CESM High-Resolution (CESM-HR) Simulations

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

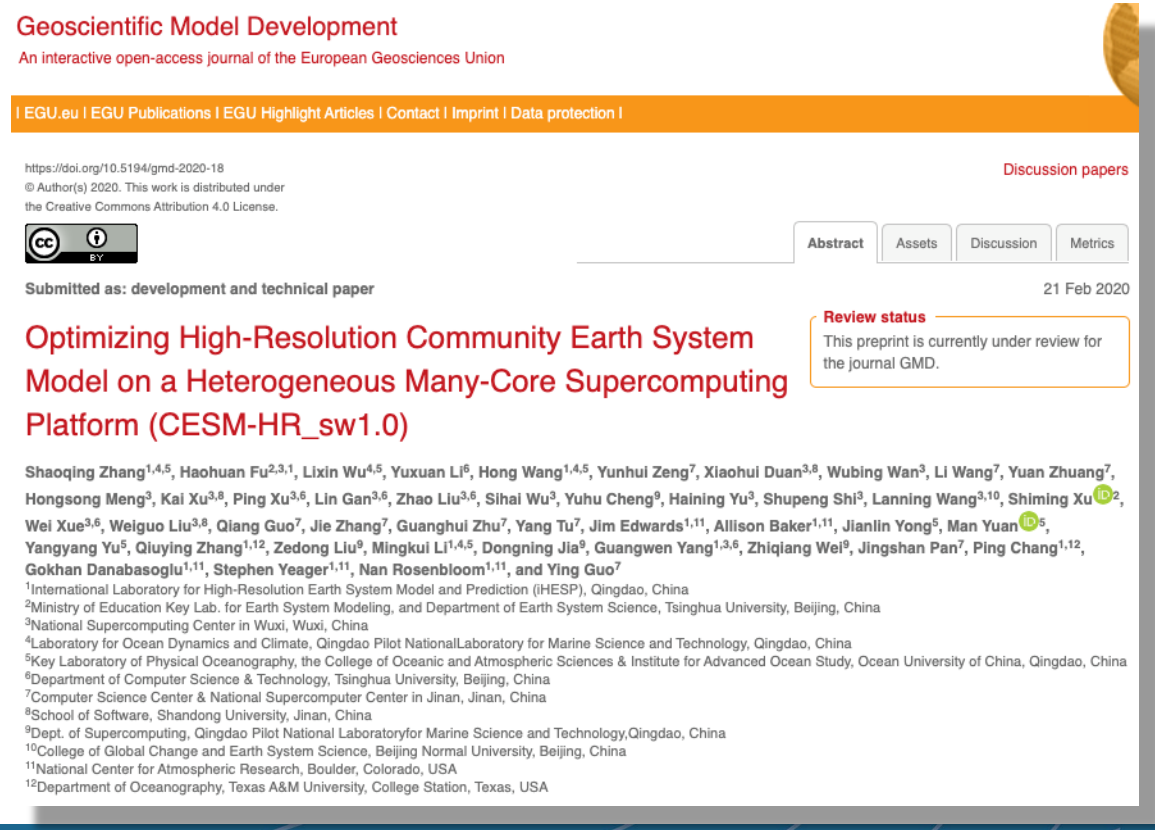
Qingdao National Laboratory for Marine Science and Technology (QNLM)

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

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



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



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]

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[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
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[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

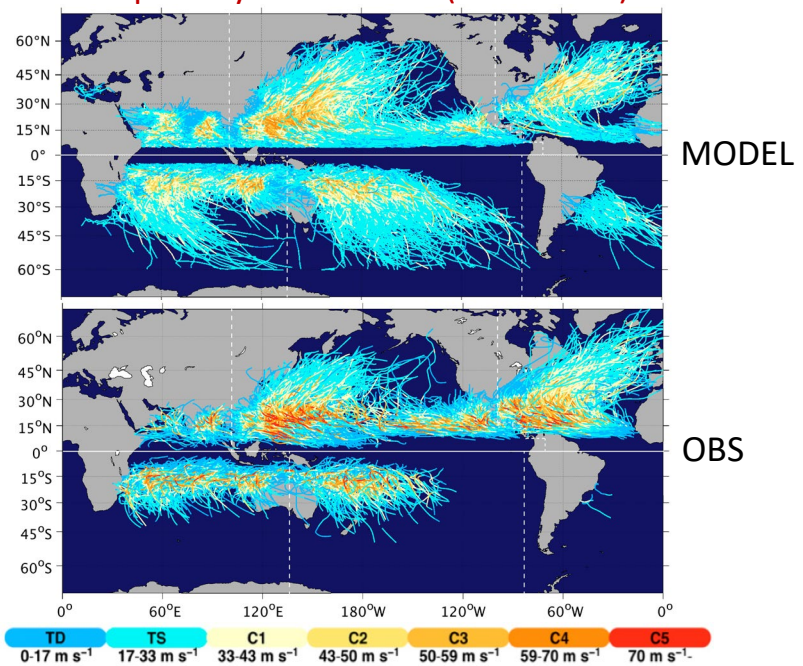
## HighResMIP CESM Contributions

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

+ Low-resolution equivalents for all simulations

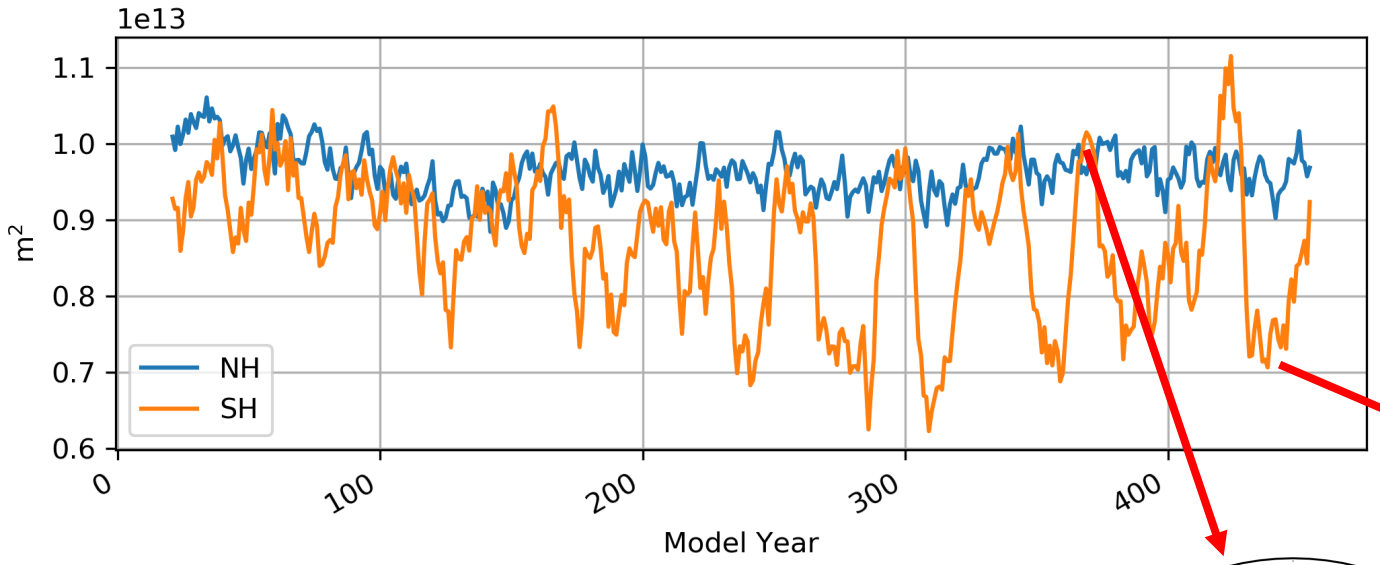
Data sets from coupled HighResMIP and the first 300 years of the PI control were released on 08 June 2020. The rest will be made available by the end of this year.

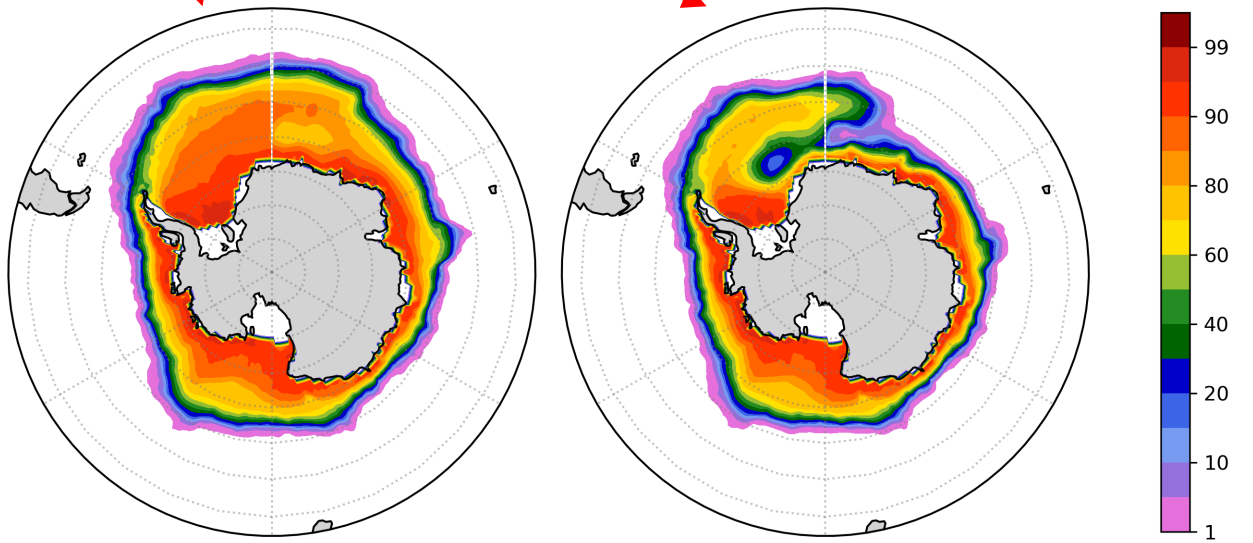
Tropical Cyclone Tracks (1950-2018)




Courtesy of Fu and Chang

# Sea-Ice Extent from CESM-HR PI Control



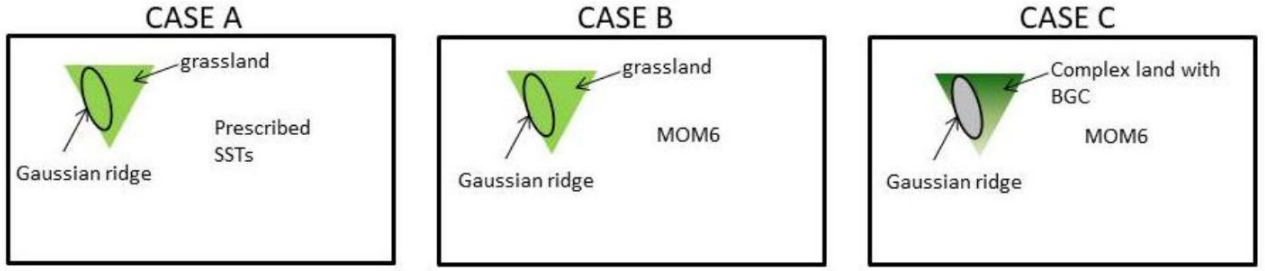

SON Averages

Ping et al. (2020, JAMES, in preparation)

# Towards CESM3

# A 3-year project to develop coupled idealized modelling toolkits

Cyberinfrastructure for streamlining coupled, simplified climate modelling within the Community Earth System Model, Funded by NSF CSSI (PI's: Bachman, Simpson. Co-I's: Vertenstein, Danabasoglu, Collaborators: Clement, Armour, DiNezio, Sacks.




We will:

- 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.

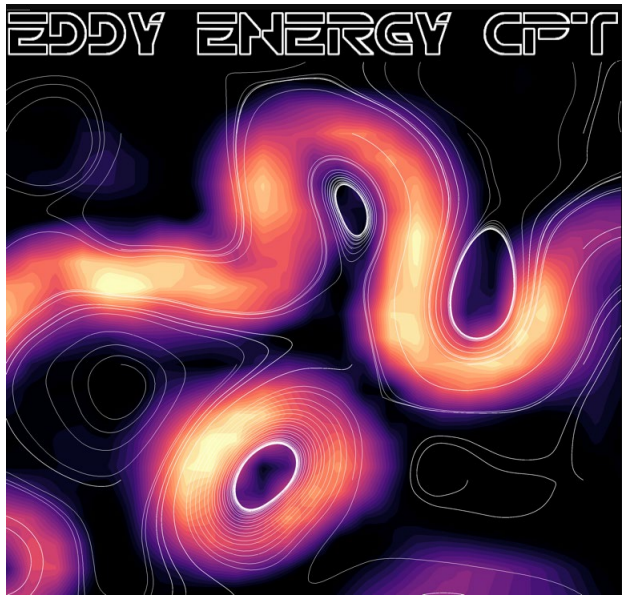
# Climate Process Teams (CPTs)

CPTs bring together observationalists, theoreticians, process modelers, and climate model developers (modeling centers) to work very closely on improving representation of a particular process in multiple global climate models with an ultimate goal of reducing (persistent) biases.

Five CPT Projects started in 2019:

1 ocean; 2 atmosphere; and 2 land

New Ocean CPT led by L. Zanna (NYU)



# Supplemental NSF Funding for CESM Atmospheric Modeling

## Atmospheric Modeling Priorities

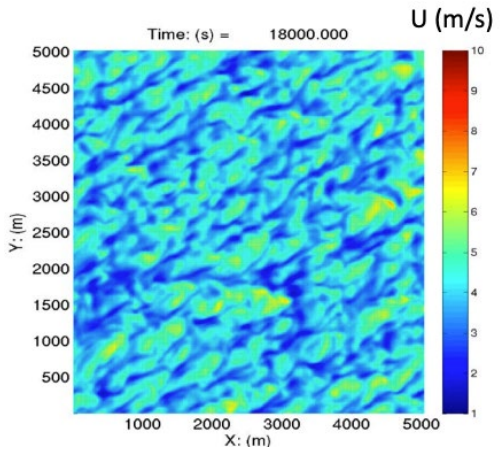
- Framework for understanding cloud-aerosol and climate sensitivities in CAM6 (LES)
- Alternative approach for developing and validating new (and existing) physics (also w/ LES)
- Consistent workflow to support a model hierarchy
- Infrastructure for improving accessibility and participation

6 positions …. Three positions have been already filled.

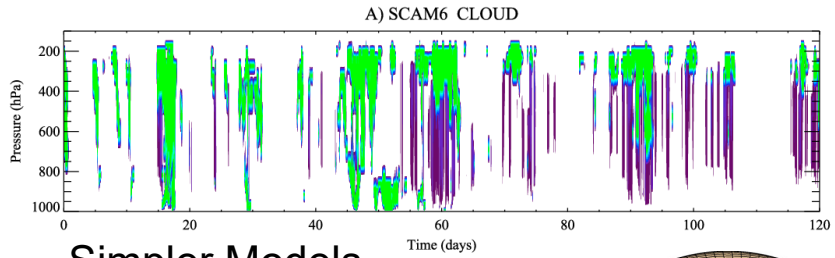
New positions are coming soon:

- Ladder Track Scientist
- Two Software Engineers

*Contact Rich Neale (rneale@ucar.edu) if interested or look out for the announcements on cesm-jobs@cgd.ucar.edu*

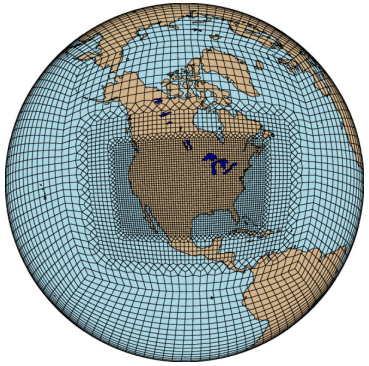



Large Eddy Simulation (LES)




Simpler Models


Accessibility



Regional Modeling Workflows

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

Task Team: Isla Simpson (chair), Bacmeister, Caron, Davis, Garcia, Hannay, Jablonowski, Lauritzen, Medeiros, Neale, Polvani, Richter, & Tilmes

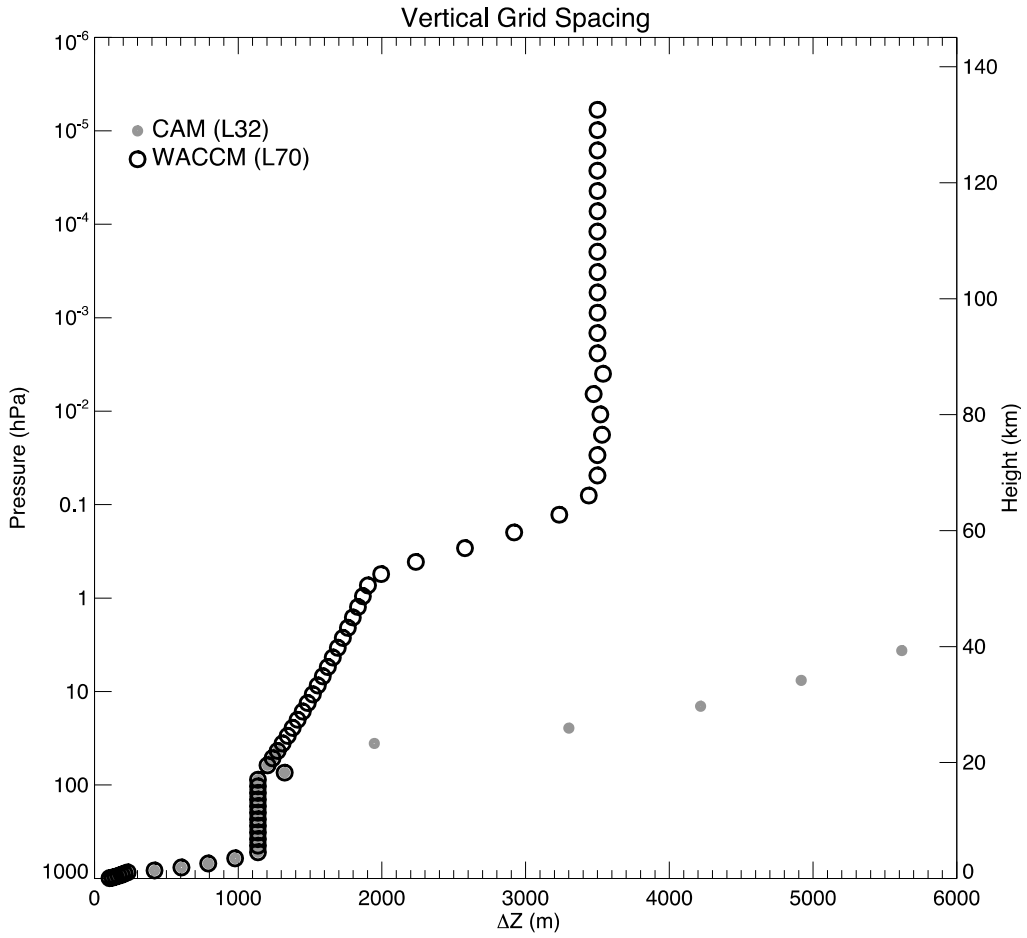
Investigate possible vertical grid configurations and model tops for the next generation, workhorse atmospheric model version of CESM.

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.

- Recommend a specific number of levels (expectation ~80), along with their spacing, with justification
- Recommend a specific top height with justification (expectation ~80 km)
- Recommend a ”mid-level” height and resolution for cheaper simulation/tuning purposes. (secondary)

# Motivation

- Avoid running both WACCM and CAM for the CMIP exercises;
- WACCM still doesn't have a high enough vertical resolution to adequately represent the QBO;
- Extra-tropical stratospheric variability and change have an important influence on the troposphere and CAM is too low to have confidence in its stratospheric representation;
- WACCM is difficult to initialize, given that the top is higher than reanalysis products that are often used for initialization;
- Other reasons to increase resolution in the boundary layer and lower the lowest model level.



# New Atmospheric Dynamical Cores in CESM

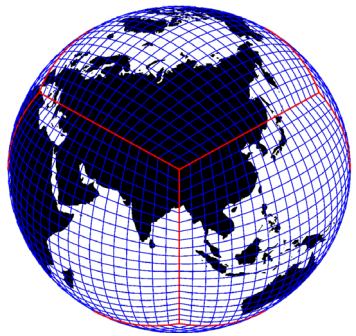
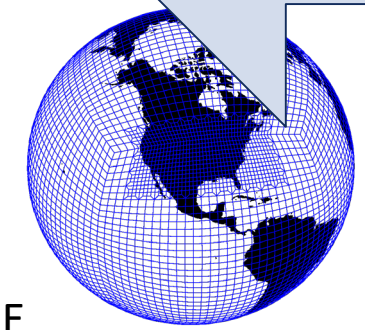
The following dynamical cores have been or are being integrated i the CESM:

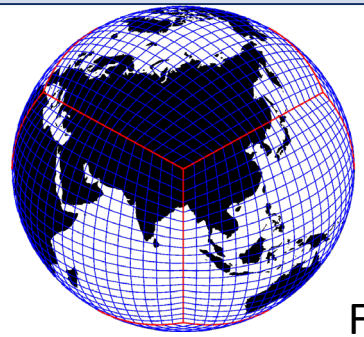
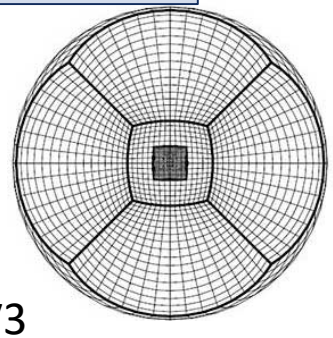
- **SE** dynamical core with option for accelerated transport s
  - highly scalable hydrostatic dynamical core with flexible
  - capability of running physics on a separate (coarser) g
- **FV3**: GFDL's dynamical core used by NCEP for globa
  - scalable finite-volum dynamical core (currently u available)
- **MPAS**: NCAR's
  - non-hydrostat allows for flexible mesh-refinement

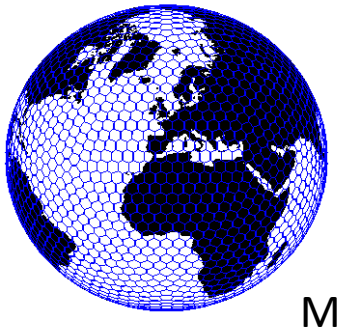
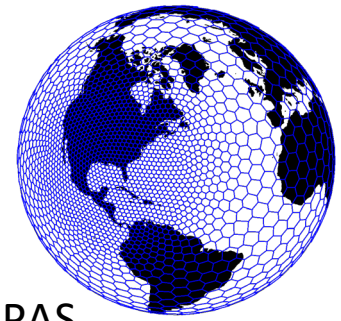
**RELEASE WITH CESM2.2**
**See J. Bacmeister's talk in the AMWG for more details**

**RELEASE WITH CESM2.2**
**See J. Bacmeister's talk in the AMWG for more details**

**IMPLEMENTATION IN PROGRESS**
**Status: testing CESM simpler models with MPAS**



SE



FV3



MPAS

Peter Lauritzen

# New Atmospheric Dynamical Cores in CESM

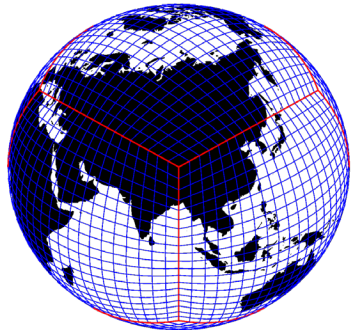
The CESM Scientific Steering Committee (SSC), in consultation with the community, will be choosing a workhorse dynamical core for CESM3

Work has been completed to check many details of physics-dynamics coupling and verified that the new dynamical cores have been coupled to CAM physics correctly (mass conservation, thermodynamic consistency, etc.)

Simpler models as well as fully-coupled simulations are used. Things that are looked at:

- conservation properties: mass, total energy, angular momentum, preservation of shape (monotonicity), correlation preservation, ...
- computational performance in standard CAM, WACCM and CAM-Chem configurations (scalability, cost, ...)
- mean climate in AMIP-style and coupled configurations

For more details on idealized dycore comparison see AMWG talk by Lauritzen: http://www.cgd.ucar.edu/cms/pel/papers/L2018AMWG.pdf



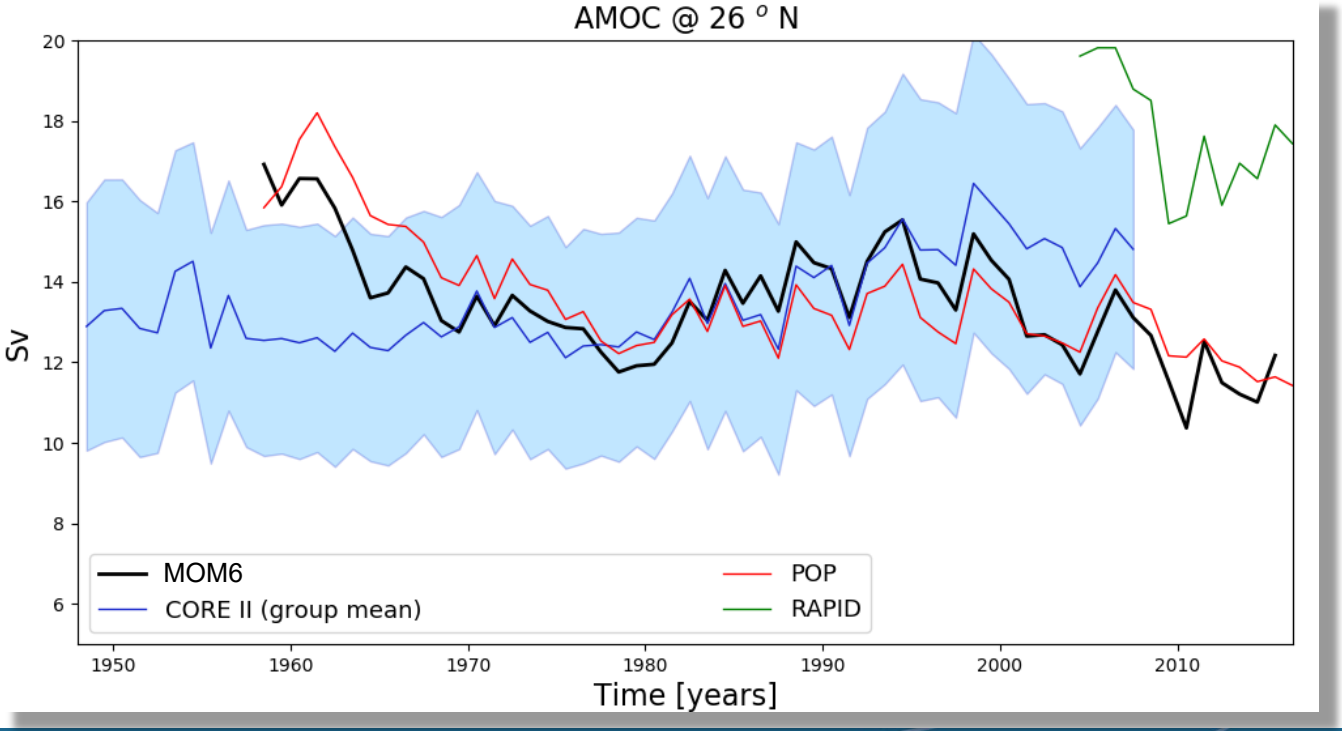
# Modular Ocean Model version 6 (MOM6) in CESM3

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



# Modular Ocean Model version 6 (MOM6) in CESM3

Additional ongoing and planned work include:

- Adaption / replacement of Estuary Box Model; overflow parameterization; etc.
- Port of ocean MARBL BGC (underway)
- Exploring hybrid vertical coordinates
- Additional Resolutions and Configurations: Idealized/simplified-physics template; higher resolutions; regional downscaling

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

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

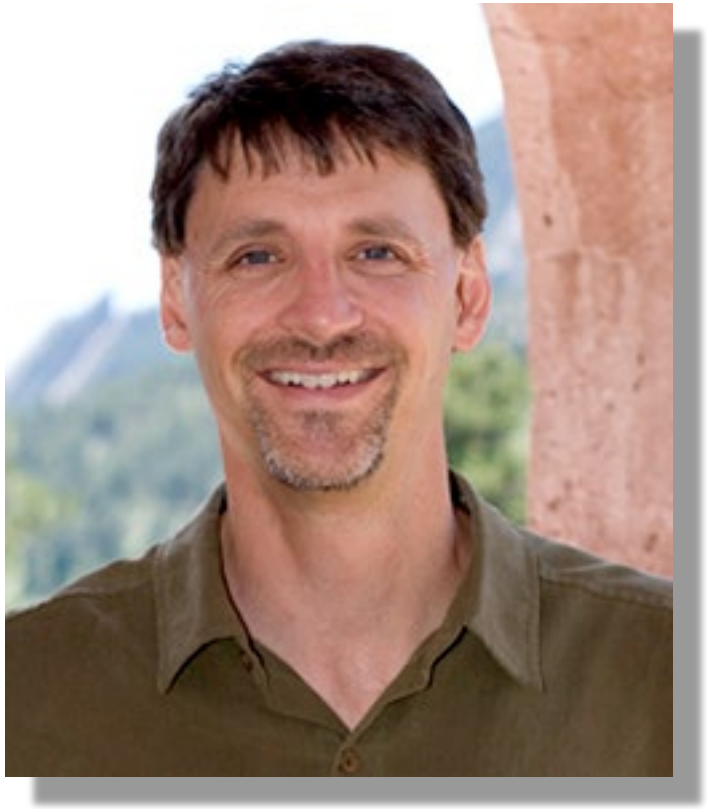
Breckenridge

# Thank You!

Boulder

# CESM Distinguished Achievement Award

## David Lawrence (NCAR)

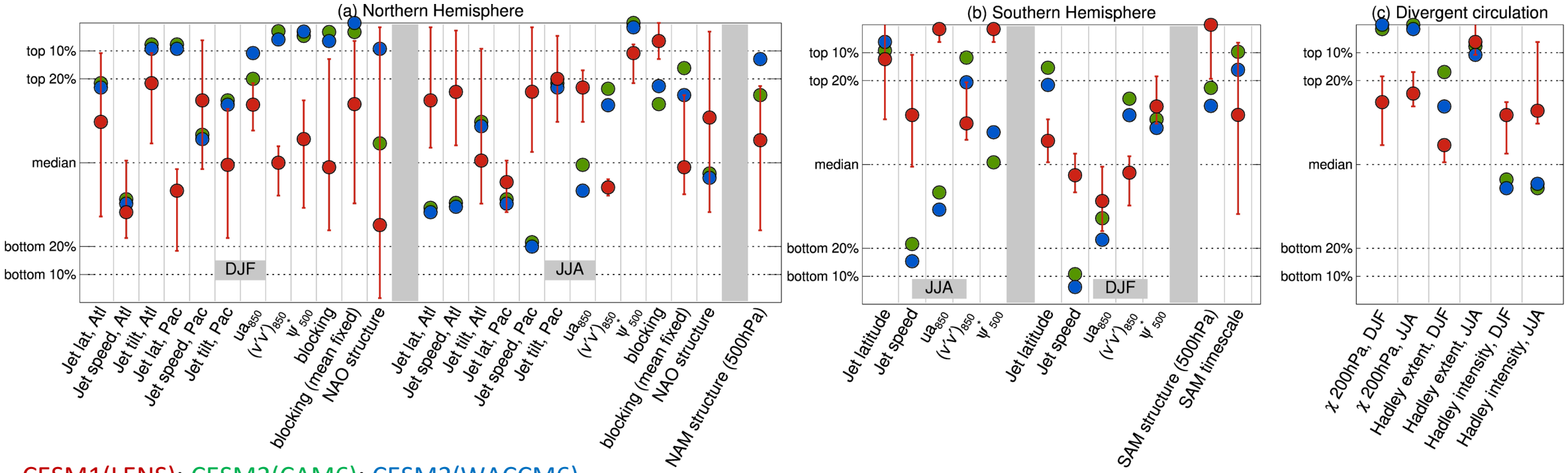


# CESM Graduate Student Award


## Daniel Kennedy

Columbia University / ASP NCAR


# Summary of Large Scale Atmospheric Circulation Metrics




CESM1(LENS); CESM2(CAM6); CESM2(WACCM6)

Ranking relative to other CMIP5 and CMIP6 models; ranked out of 62 models for monthly, 32 models for daily

Red range shows the uncertainty in the ranking based on the minimum to maximum ranking of the 40 CESM1(LENS) members.

Simpson et al. (2020, JAMES)

Improvements in most NH winter aspects. High ranking model in many regards.

Degradations in NH jet metrics but improvements in stationary waves and storm tracks

Degradations in SH jet speed metrics but improvements in storm tracks and a high ranking model in terms of jet location.

Excellent global divergent circulation representation as measured by 200hPa streamfunction.