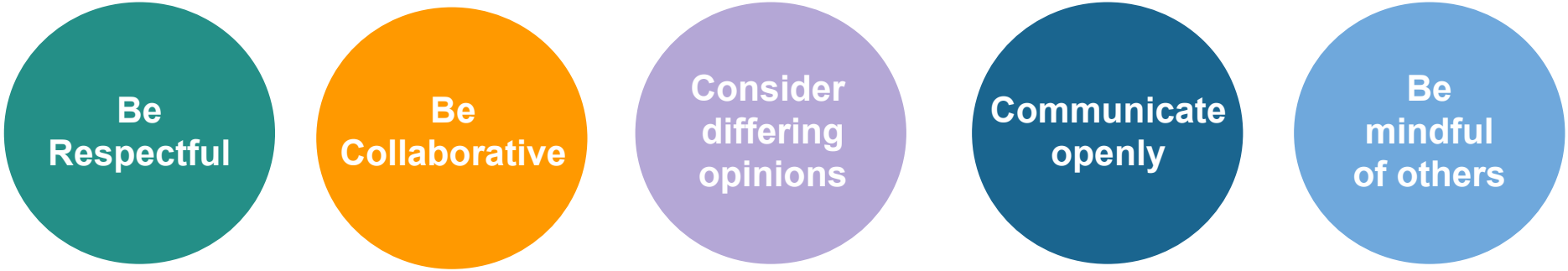
State of the Community Earth System Model Project

David Lawrence
CESM Chief Scientist

Welcome

Reminder on UCAR Code of Conduct



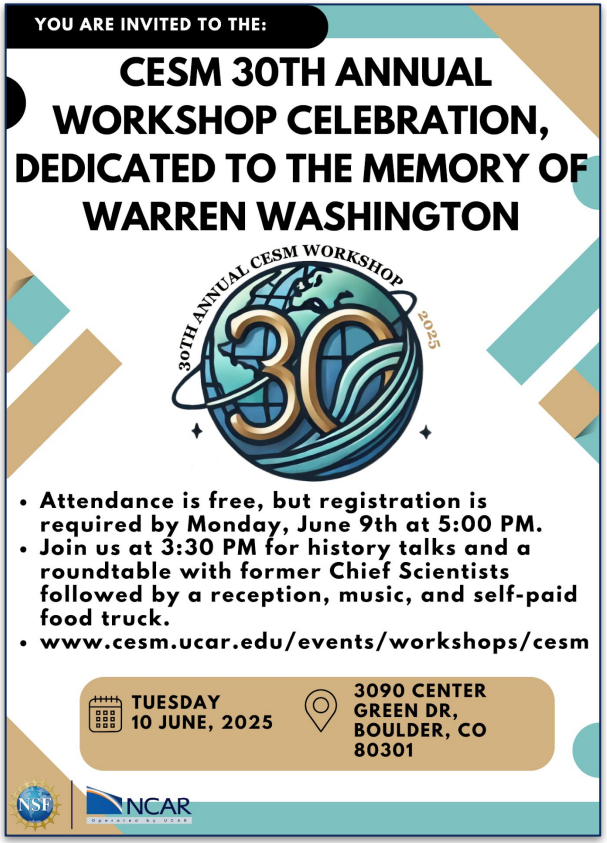
In-person or Conduct Issues: Reach out to Dave or Elizabeth or cesm-workshop-support@ucar.edu (also for any technical issues)

Nursing Room: 2668
All-gender restrooms: 2024, 3048, 3052
Quiet Meeting Rooms: Check at front desk

Some workshop logistics

In addition to the oral science sessions

- Group photo: Monday afternoon break, in the lobby; photo booth in lobby
- Poster session and reception this evening
- Faculty Network for Teaching with CESM meeting Tuesday lunchtime, Center Bay
- 30th Annual Workshop celebration Tuesday, open to anyone, including family and friends
- Cross working group sessions on Wednesday morning on AI/ML and High Resolution CESM
- **Wed. 4:15-5:00pm summary session**
  - Open session, mainly focused on community comments, questions, and discussion



Quiet Spaces

Outdoor Seating

Walking Path

Thanks!

U.S. National Science Foundation

Workshop organization and support

- Elizabeth Faircloth
- CGD Admin team
- UCAR Multimedia and Events services

CESM Use and Impact Survey

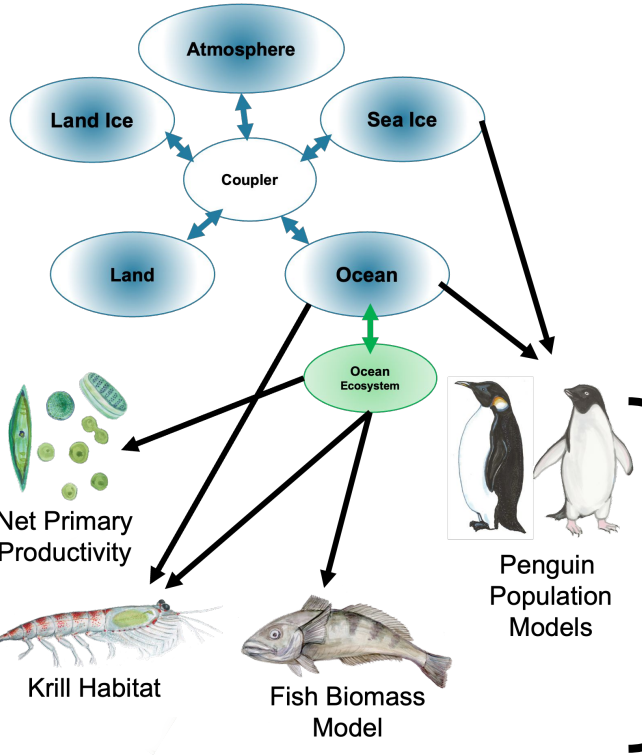
https://forms.gle/U5LeUQF6V7X35Gib6

As we celebrate the 30 year anniversary of CESM, we are seeking to characterize the ongoing value of the CESM activity, which includes the model, data, and support that is provided for its use.

We are especially interested in how the activity supports users and stakeholders and how it is delivering impact for science and societally-beneficial applications.

CESM is informing international Antarctic conservation initiatives

CESM2 – Large Ensemble



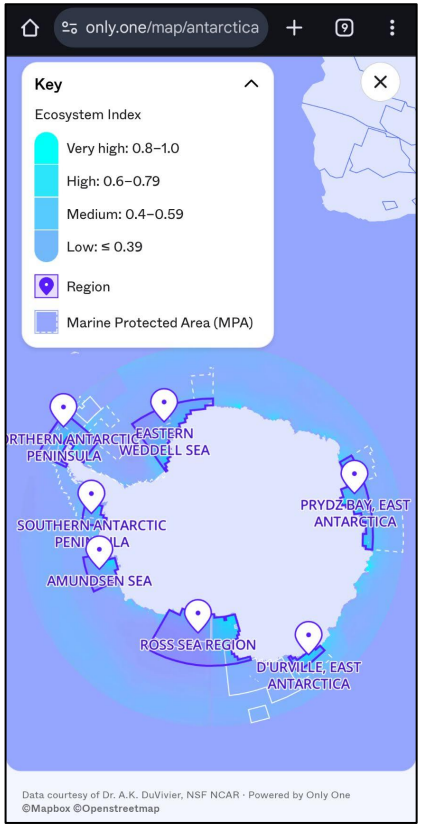
Non-Governmental Organization (NGO) partners

THE PEW CHARITABLE TRUSTS

Antarctic and Southern Ocean Coalition

Only One

NGO developed Web-App



Alice DuVivier

Laura Landrum, Kristen Krumhardt, Marika Holland + external University and NGO collaborators

(Re)Insurance industry (Willis Towers Watson, QBE)

Time horizons:

1 **2 – 10** **10+**

Insurance industry interested in frequency and intensity of weather events
- material to loss
- outliers, tails, not the mean (though in context that mean is changing)
  CESM Large Ensembles, especially CESM1(HR) are used

Hurricane Otis, Mexico, Oct 2023. Image: NOAA

Companies are using CESM data when creating policy relevant platforms

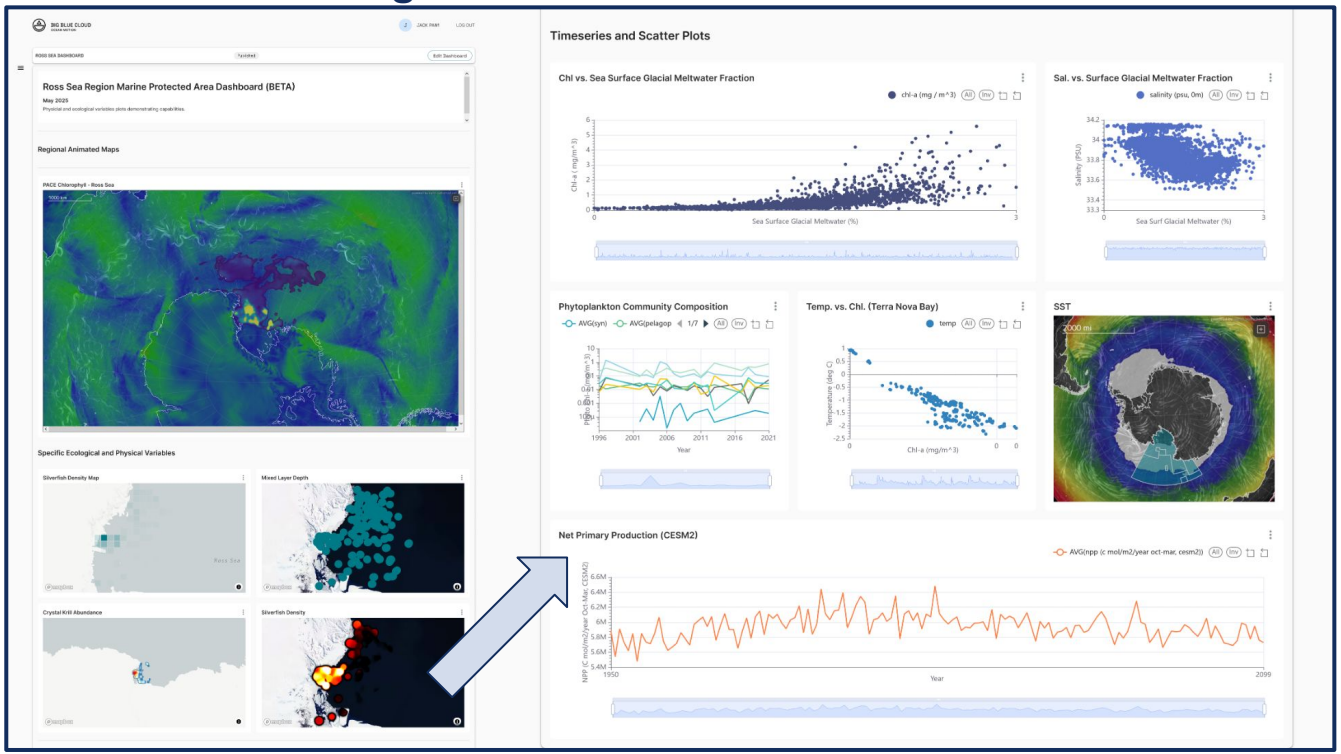
Ocean Motion

https://www.oceanmotion.tech/

Creating data tools requested by U.S. and international policy makers that are relevant for Marine Protected Areas and easy to use.

NSF NCAR partner: Alice DuVivier
+ Jack Pan and Alex Orona at Ocean Motion

Big Blue Cloud Data Dashboard



CESM Use and Impact Survey

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We are especially interested in how the activity supports users and stakeholders and how it is delivering impact for science and societally-beneficial applications.

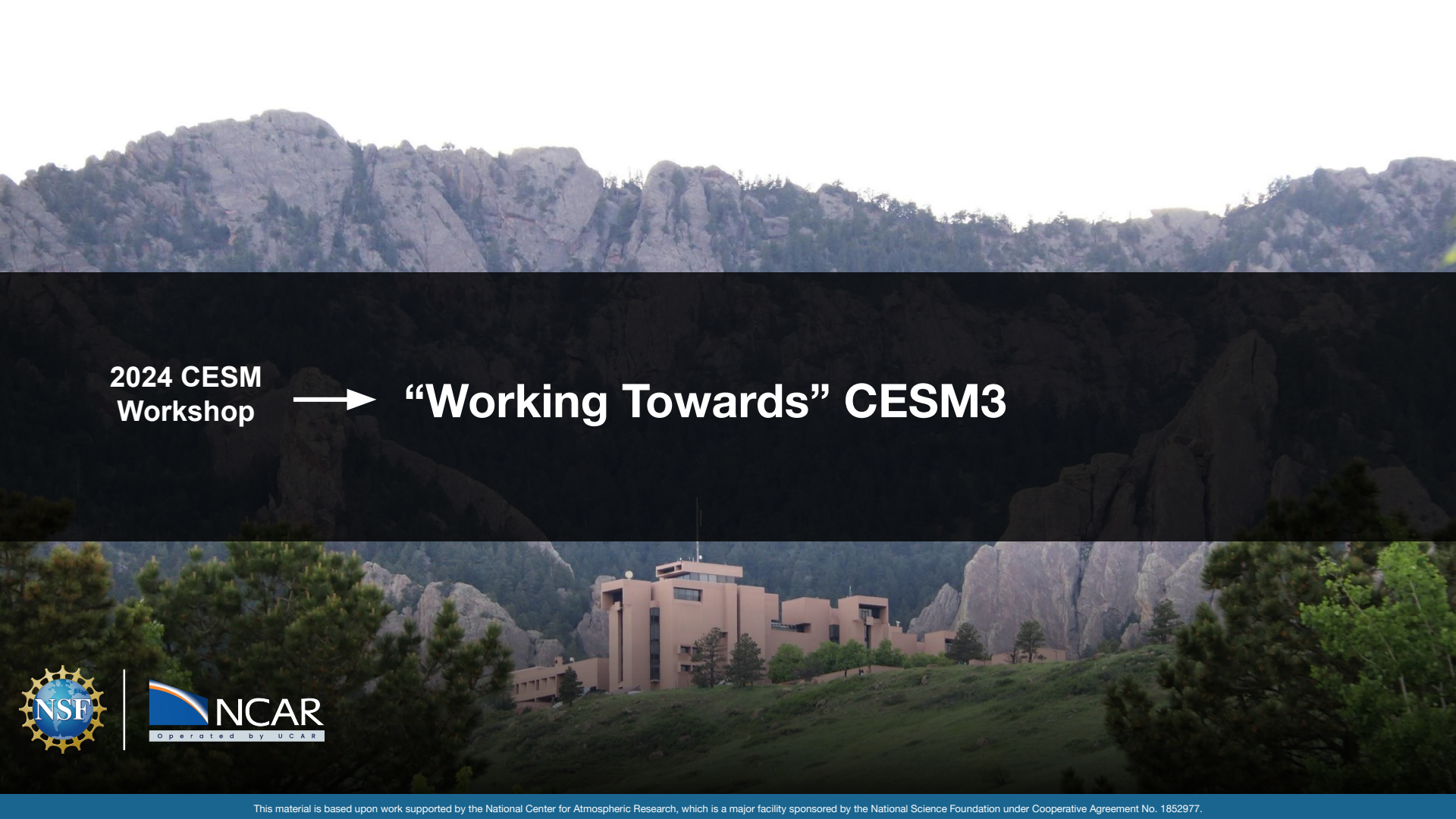
Please share survey link with colleagues, especially colleagues from the private sector, NGOs, or other stakeholders

Faculty Network for Teaching with CESM

Creating a **Faculty Network for Teaching with CESM** to facilitate sharing of information and resources to help faculty best utilize CESM and its component models in their curricula

- Survey to gauge needs/interest
- 70+ faculty responded
- Virtual forums in March, April to gather more feedback
- Meet-up session Tuesday lunchtime at CESM Workshop
- contact Elizabeth Faircloth (fair@ucar.edu)

CESM3



2024 CESM Workshop

“Working Towards” CESM3

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.

Finalizing CESM3

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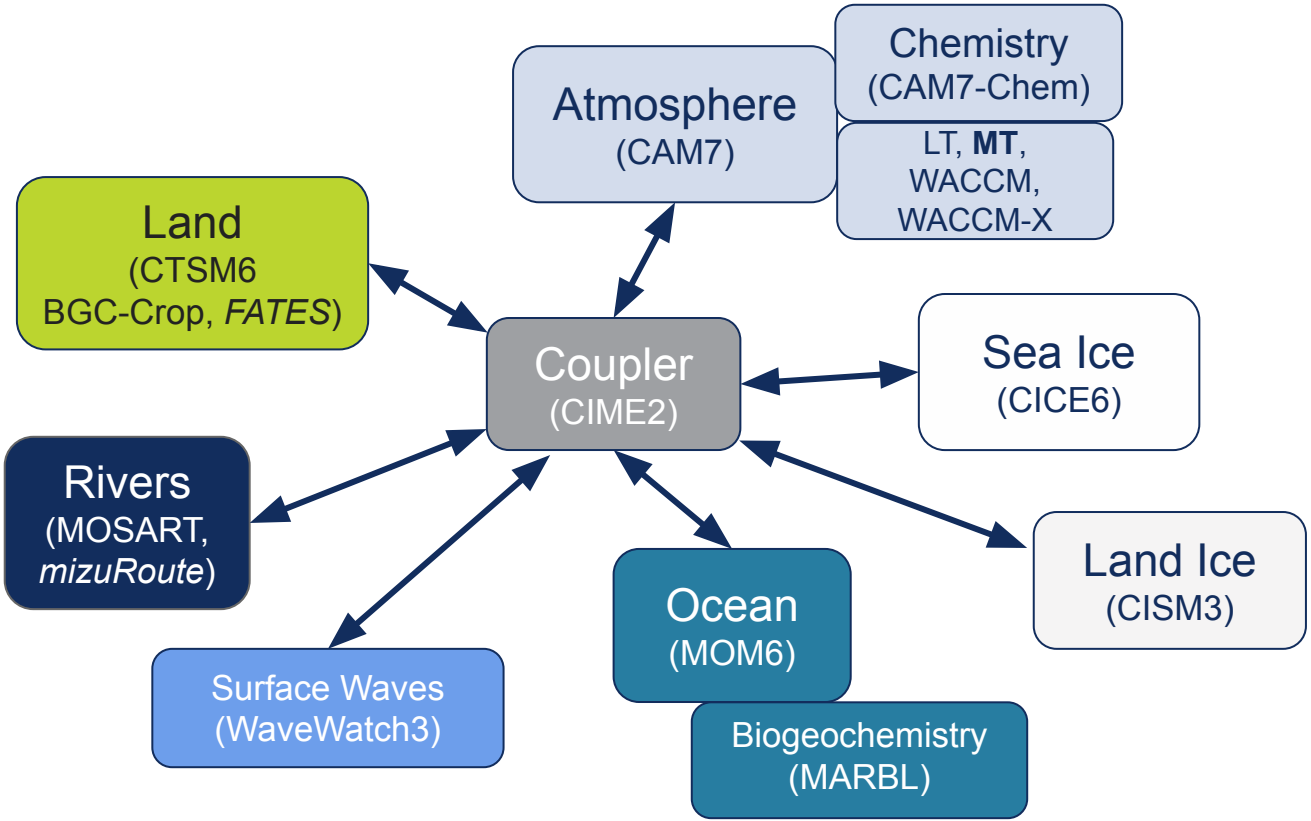
Finalizing CESM3

Significant updates to all component models

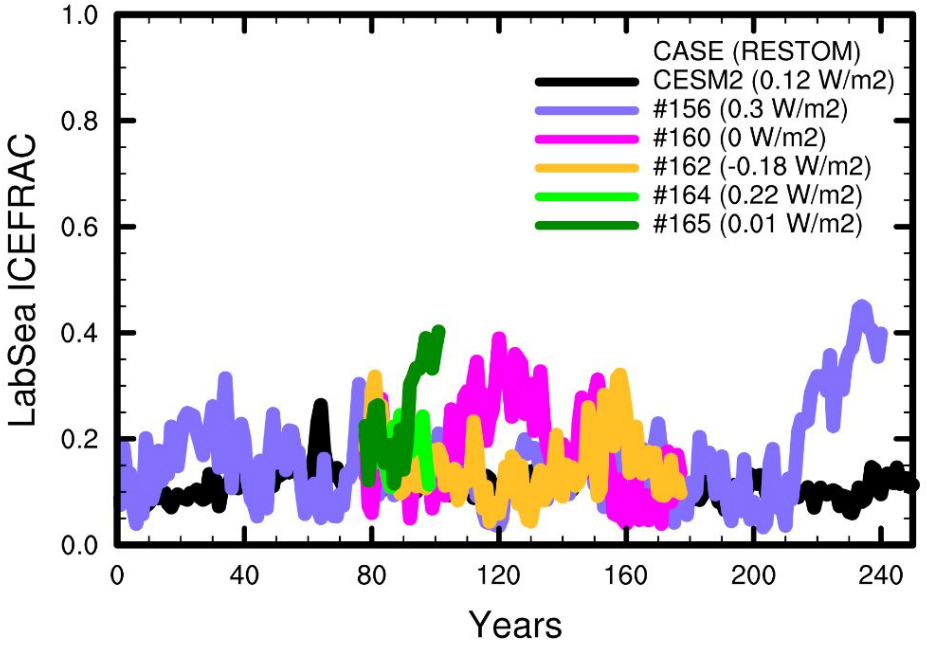
Full list of changes

Details provided during the Working Group sessions

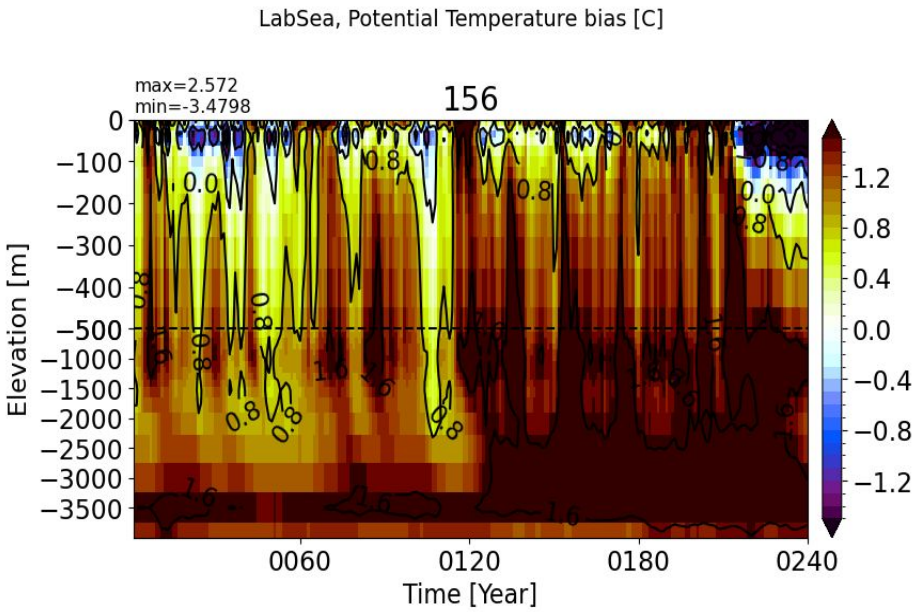


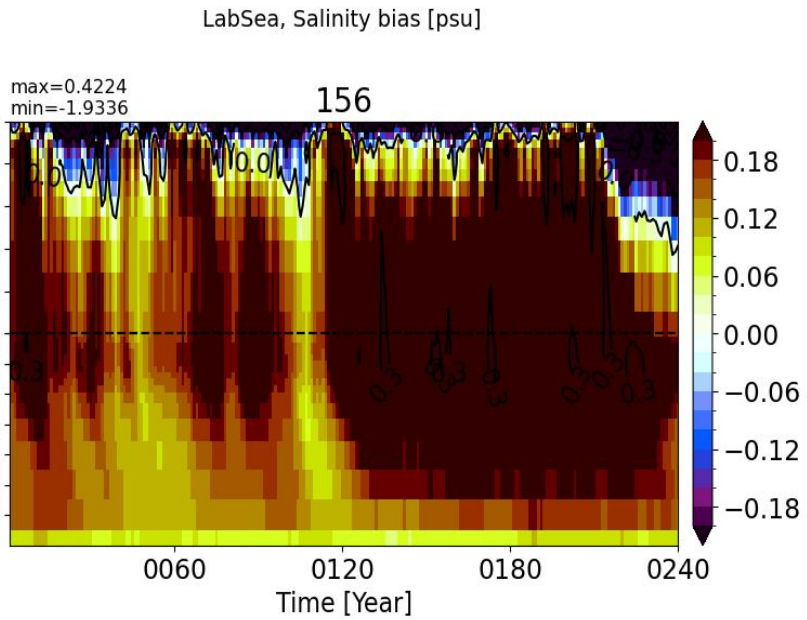
CESM3 Finalization

- Code bases for all component models are complete (‘chilled’, January 2025)
- But, the Lab sea freeze problem came back with that science code chill beta tag
- … which is making it difficult to assess and resolve other issues and biases and to tune

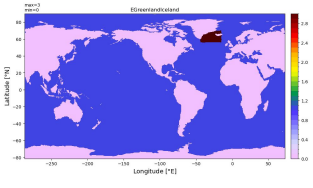


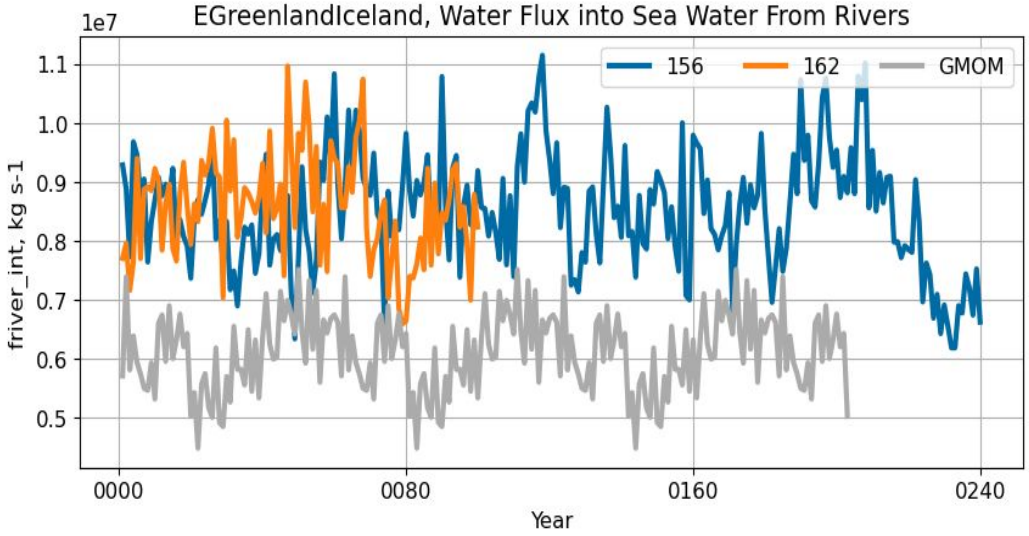
Ocean Plots (156): T & S biases in Lab Sea





Liquid & frozen runoff into East Greenland





- Source of the Lab sea freeze problem *seems* fundamentally to be excess precipitation across the Arctic which manifests as excessive freshwater flux into the region
- CGD-Machine Learning group is starting to explore how/whether AI analysis methods could help us understand the precursor signatures of a Lab Sea freeze

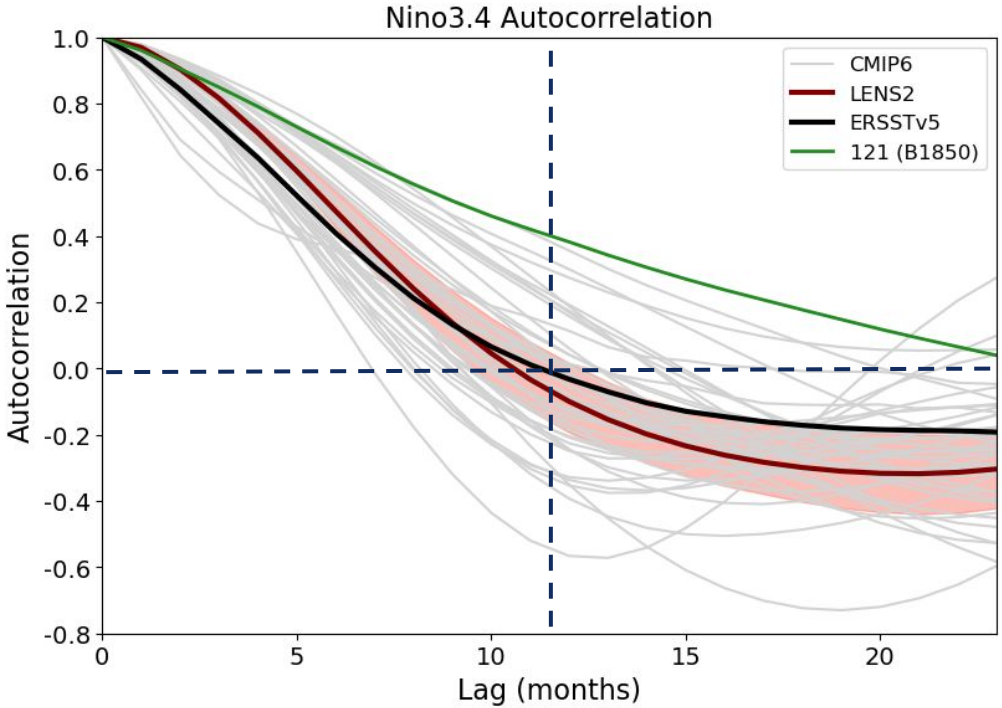
- **Recent run with Bodner sub-mesoscale mixing turned off in Lab Sea region is looking promising**
- **Also testing CLUBB explicit diffusion off, which may help with excess Arctic P**

Some other (non Lab Sea freeze!) issues with CESM3

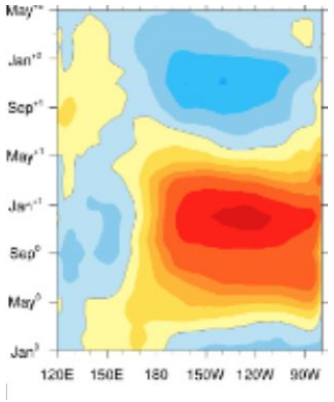
CESM Development team has identified three important biases that we would like to address

1. ENSO issues, especially El Nino to La Nina transitions
2. Amazon and Africa precipitation biases
3. Excessive Antarctic sea ice

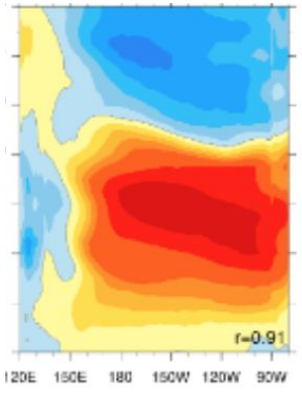
Nino3.4 autocorrelation and transition from El Nino to La Nina



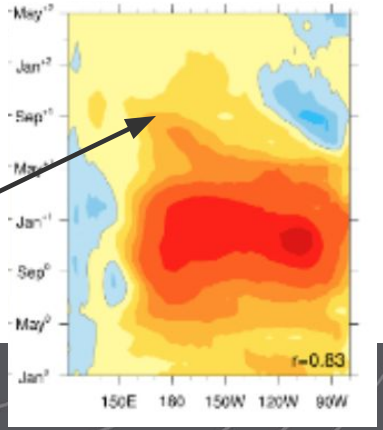
OBS



CESM2

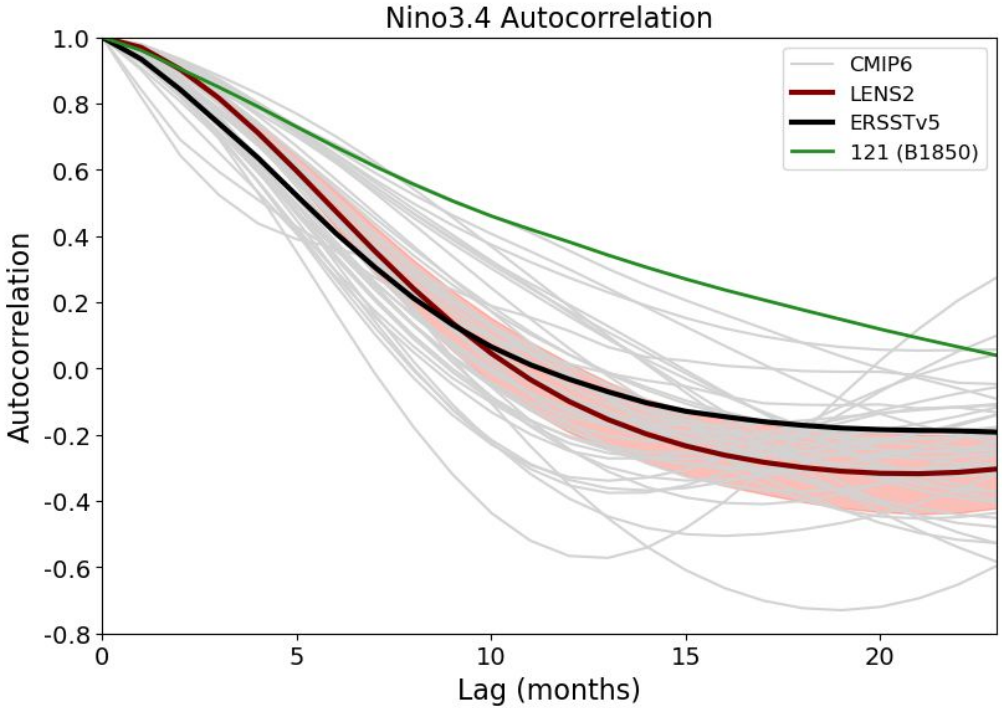


CESM3



It's not transitioning into La Nina after El Nino quickly enough

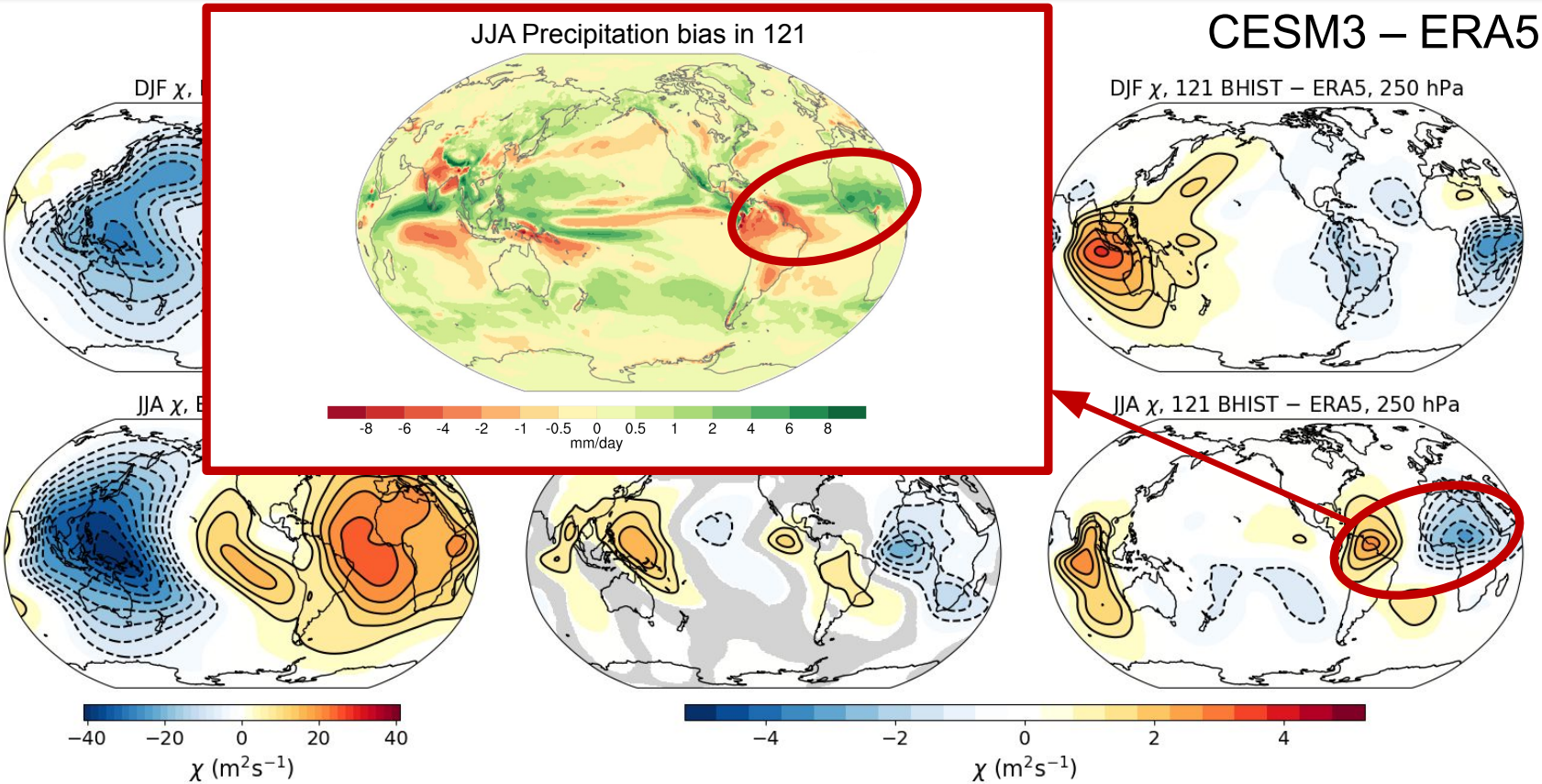
Nino3.4 autocorrelation and transition from El Nino to La Nina



Strategies to resolve issues like this

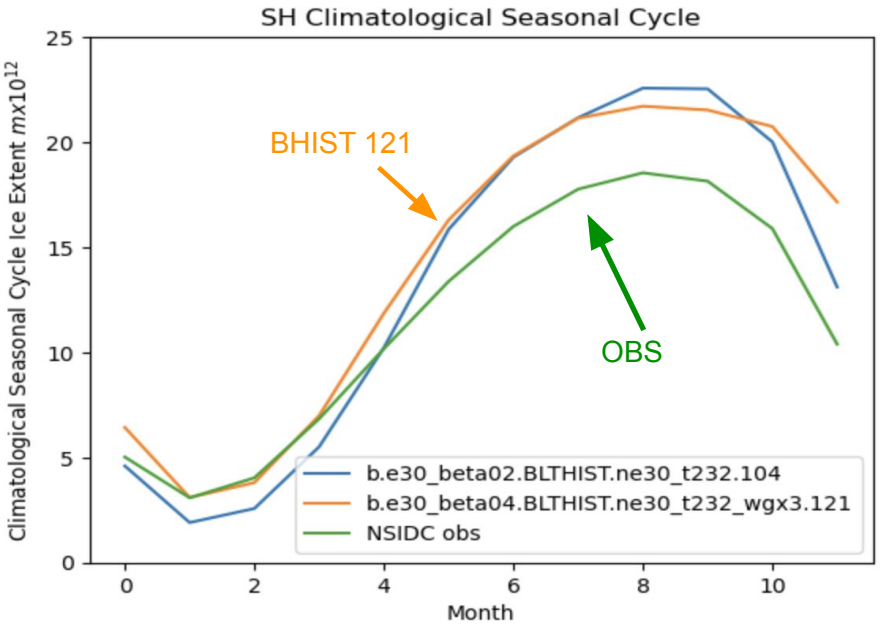
- Salinity-restoring in Lab Sea is enabling long integrations without freezing
- CESM3 initialized predictions; currently setting up to run initialized predictions for 1997/98 El Nino

Amazon and Africa precip biases

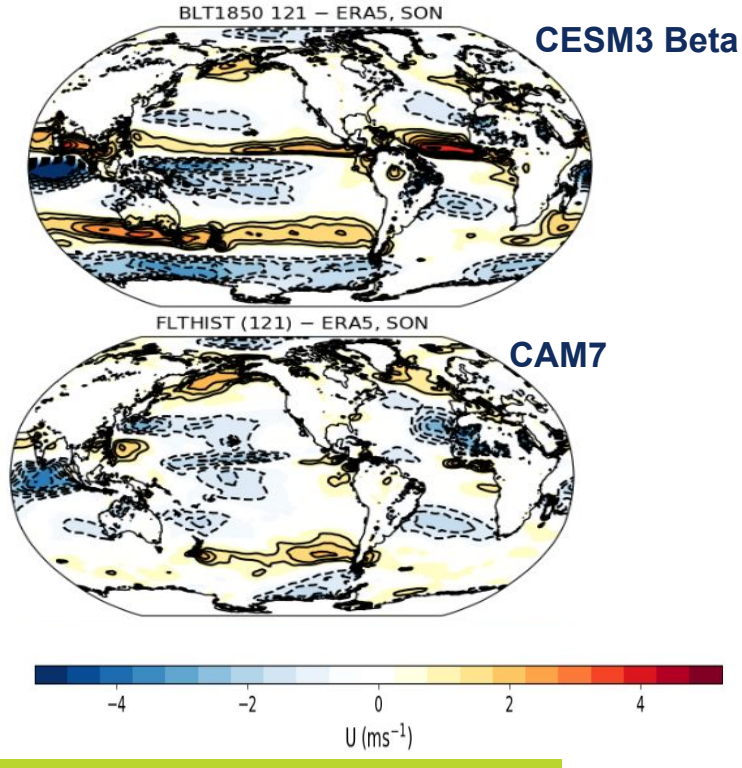


Southern Hemisphere Sea Ice is too extensive

From Alice DuVivier:



950hPa Zonal Wind Biases



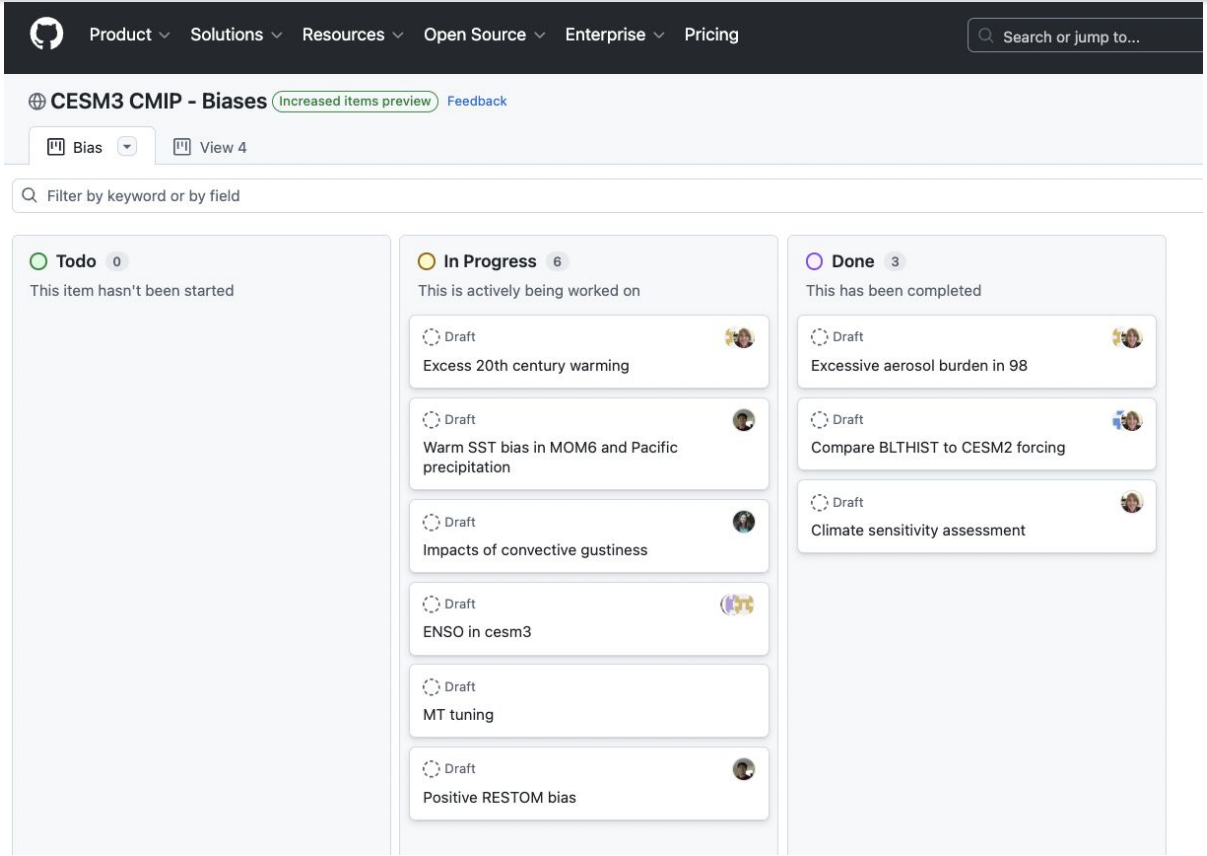
Seems like a coupled problem, some combination of position of jet (run with nudged winds removed 50% of bias) along with ocean mixing

CESM_dev

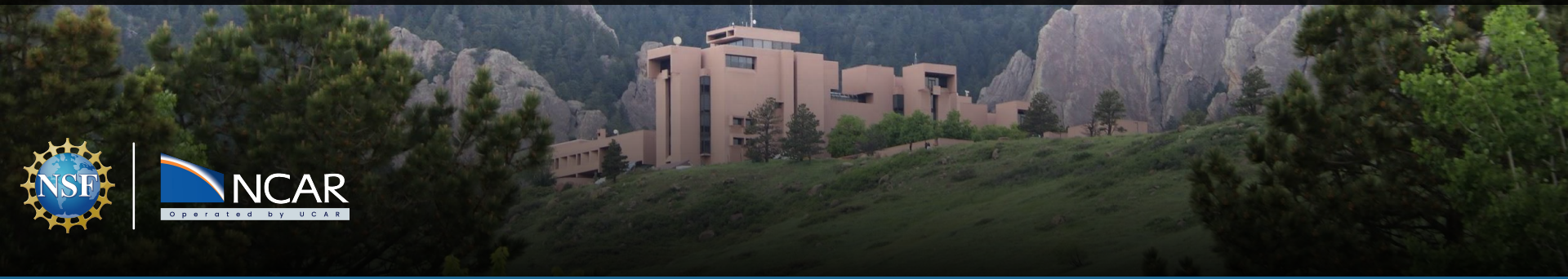
CESM_dev Issues
- Track runs

CESM_dev Discussions
- Discussion of coupled model runs / problems

CESM_dev Project (Biases)
- Tracking of progress for major biases
- Tracking of progress for other configurations (e.g., high res)



Other features of CESM3 beta simulations
(more analysis in Working Group sessions)



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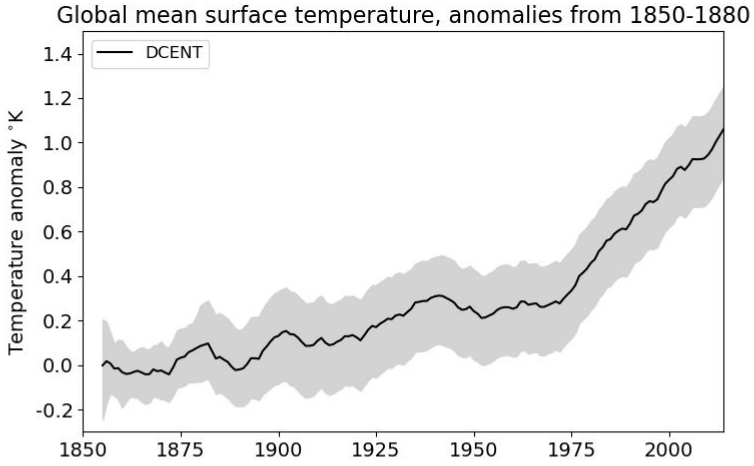
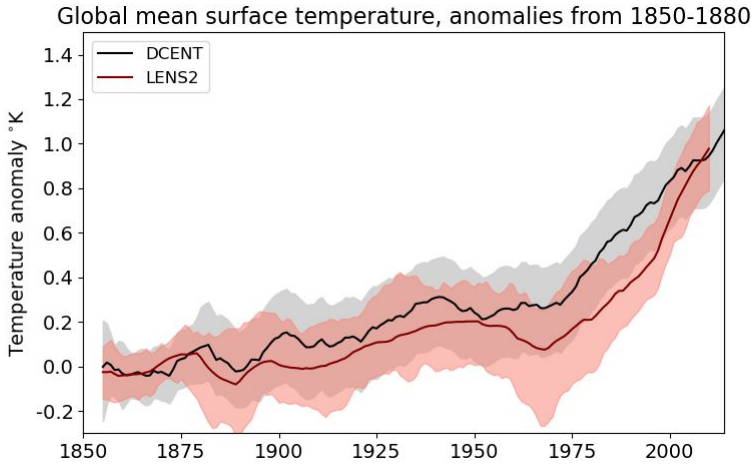
10 year running mean global mean surface temperature



The DCENT observation-based surface temperature
200 member ensemble
(Chan et al. 2024)

10 year running mean global mean surface temperature

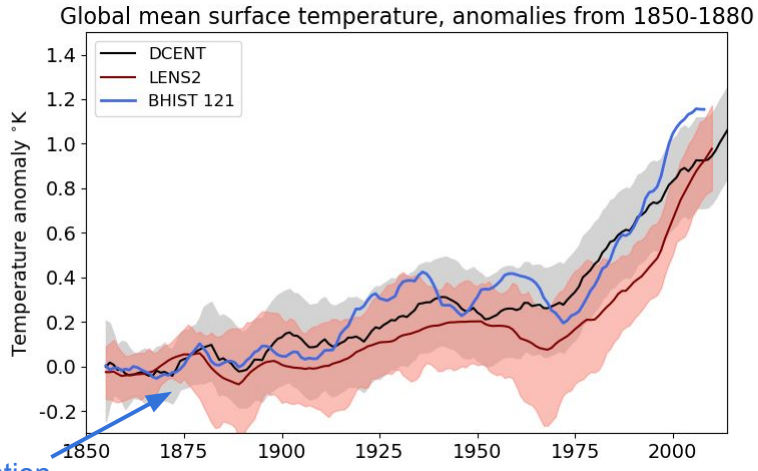


The DCENT observation-based SST 200 member ensemble (Chan et al. 2024)

CESM2 large ensemble (first 50 members) i.e., not smoothed biomass burning

(TREFHT over land, TS over ocean)

10 year running mean global mean surface temperature



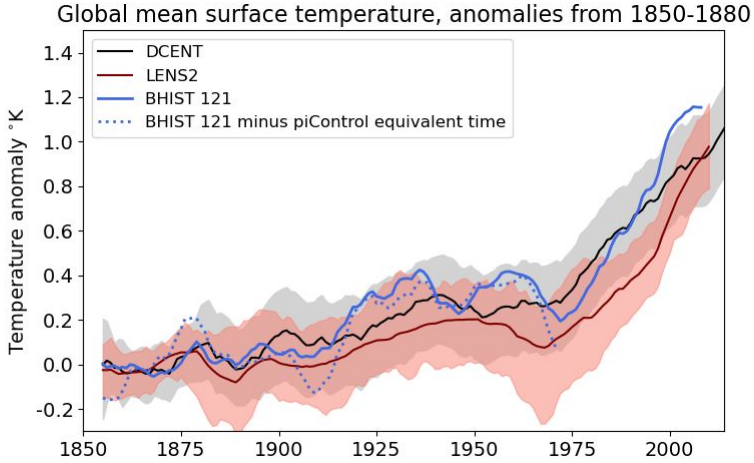
Recent CESM3 development simulation

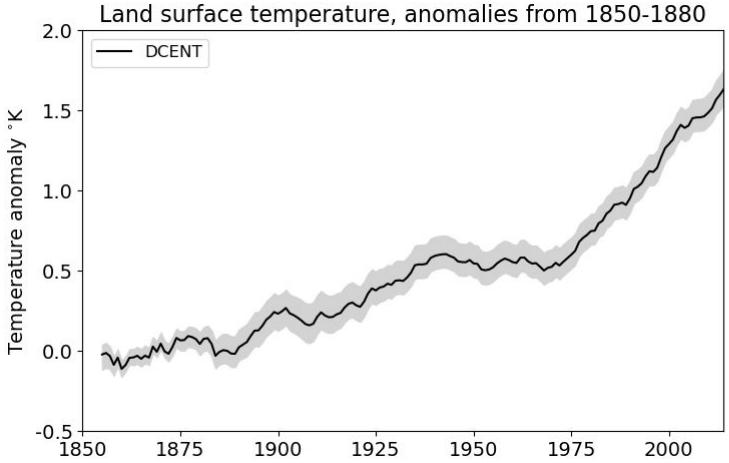
The DCENT observation-based surface temperature
200 member ensemble
(Chan et al. 2024)

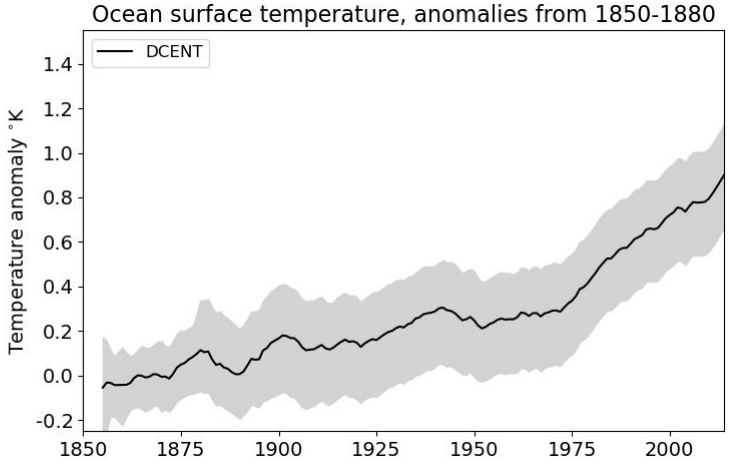
CESM2 large ensemble (first 50 members) i.e., not smoothed biomass burning

(TREFHT over land, TS over ocean)

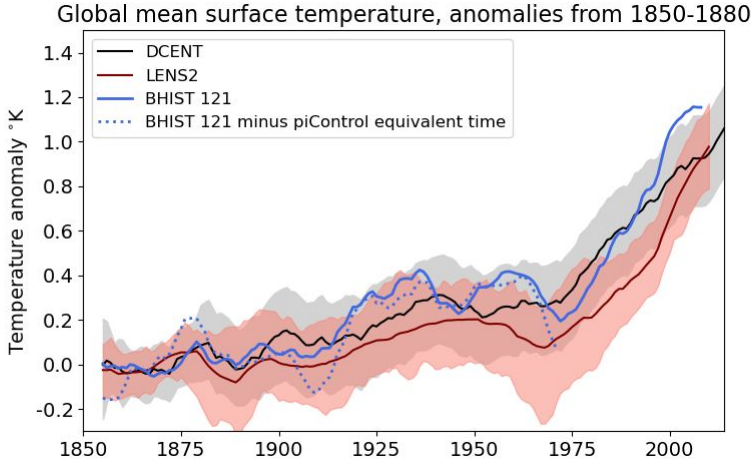
10 year running mean global mean surface temperature



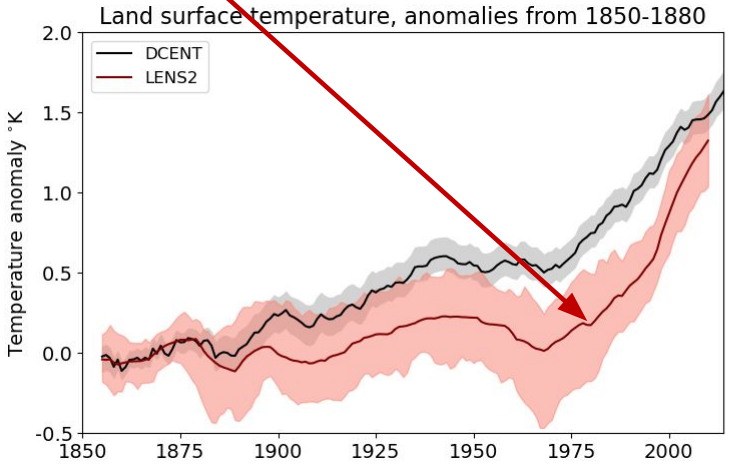


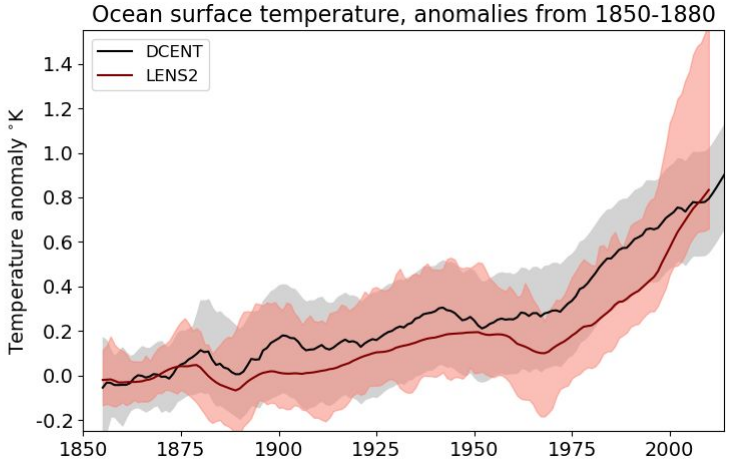


10 year running mean global mean surface temperature

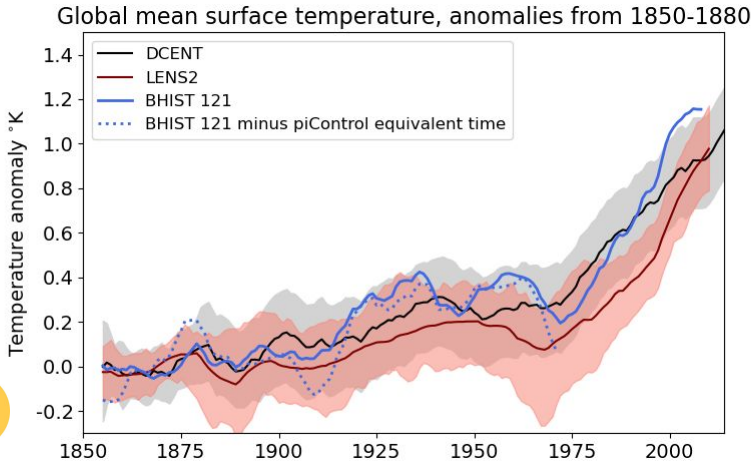


CESM2 didn't warm enough over the land over much of the 20th century





10 year running mean global mean surface temperature

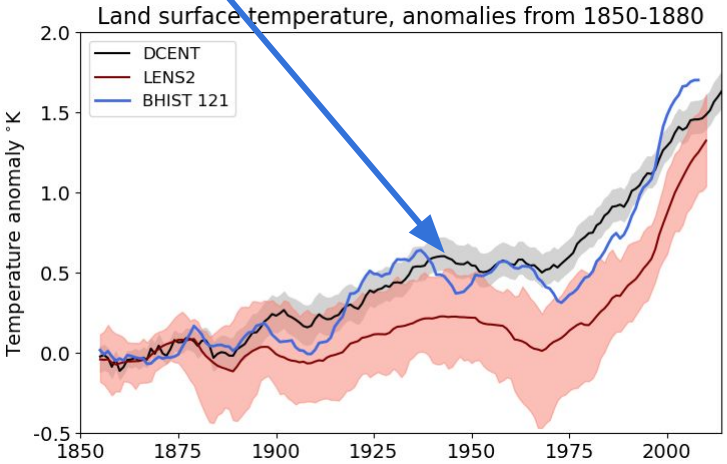


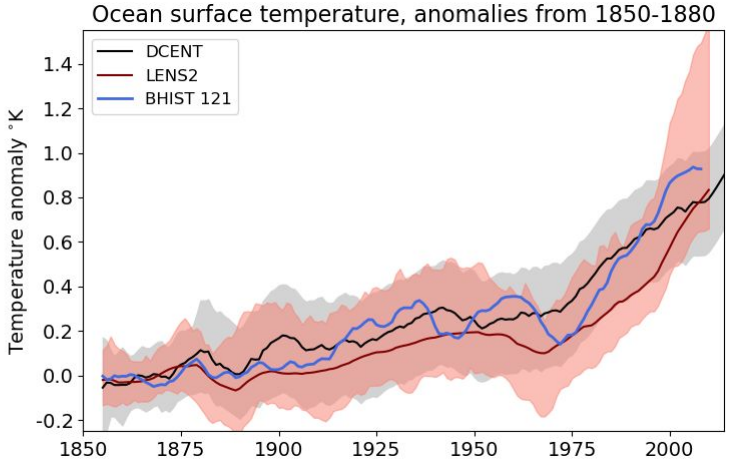
We suspect these improvements are related to changes in aerosol effects.

Aerosol Radiative Forcing:

-1.65 In CESM2 (Medeiros et al. 2020)
-0.5 in a beta version of CESM3 (though assessed in version before new dust emissions)

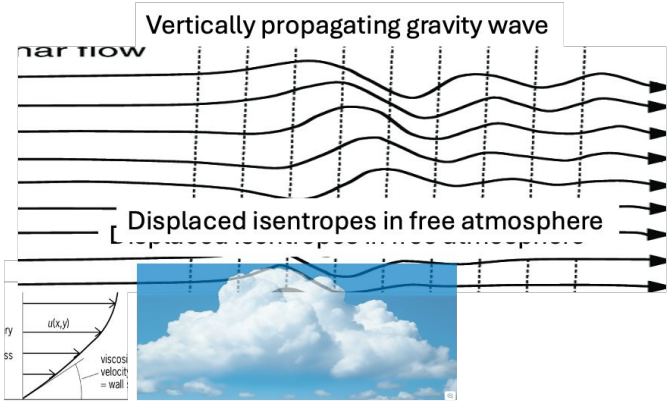
CESM3 development run is much better!



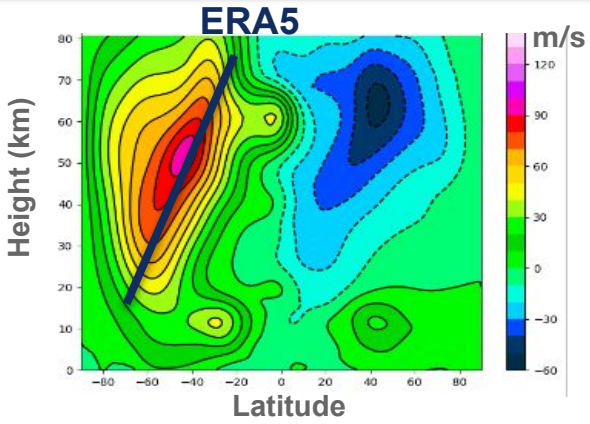


Improvements to stratospheric jets with “moving mountains” GW param

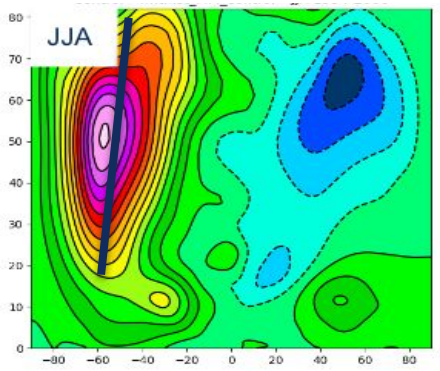
New source of gravity waves (“moving mountains”)

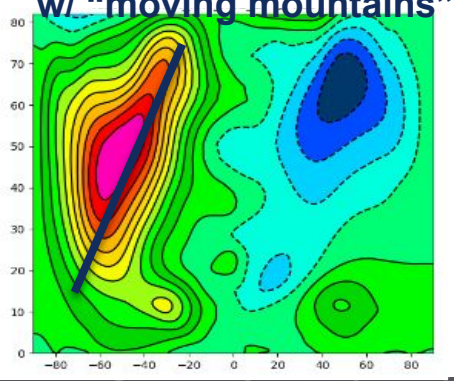


Convection/eddy in sheared PBL flow acts like an obstacle to flow in free atmosphere



zonal wind



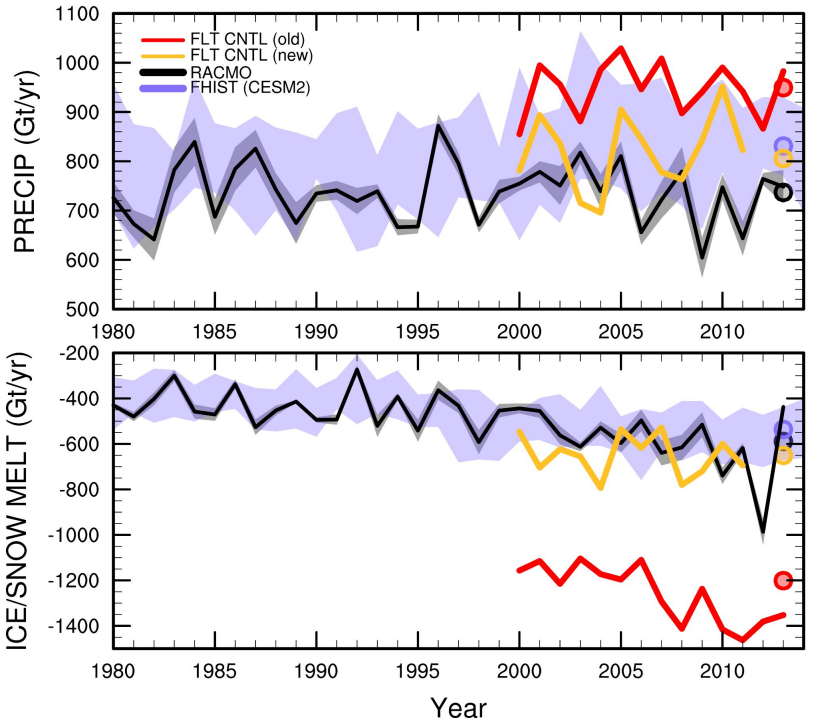


Greenland Surface Mass Balance (SMB)

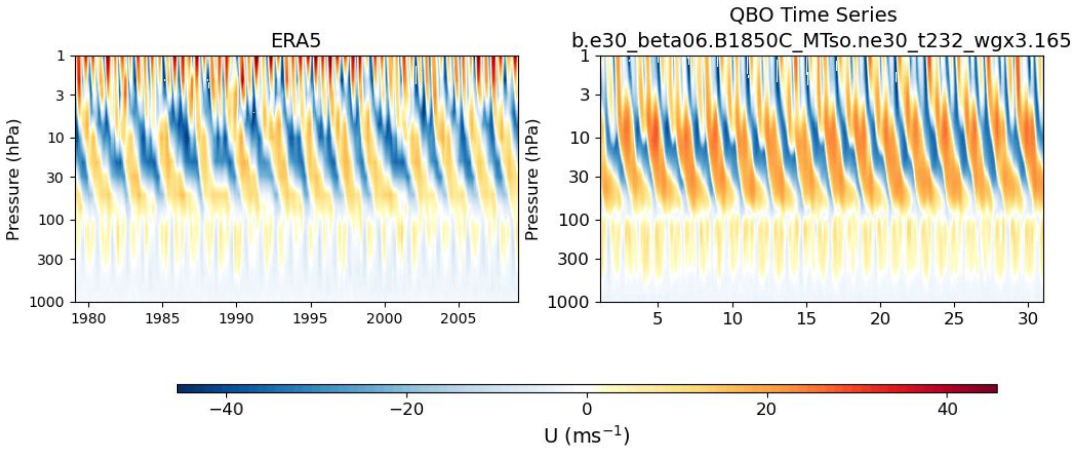
Improving biases in precipitation and melting over the Greenland Ice Sheet

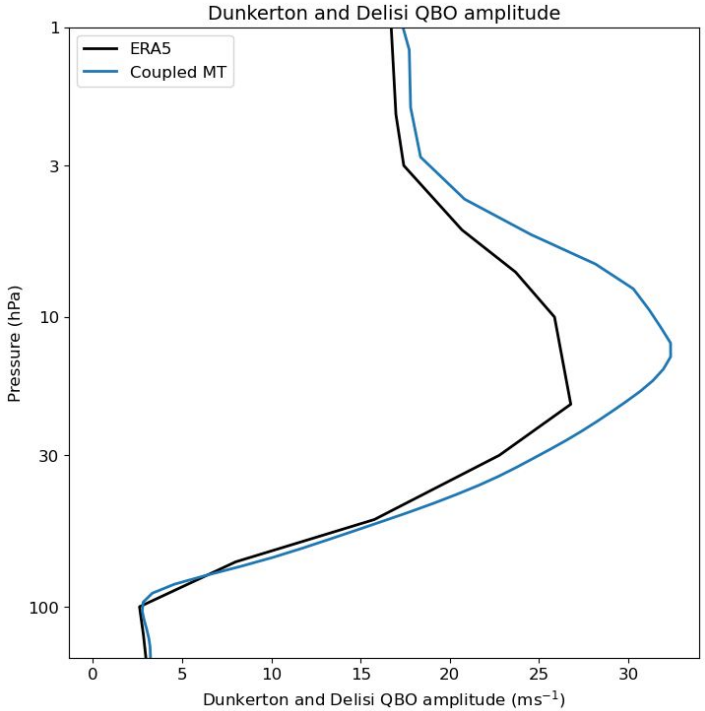
- Reasonable SMB required to enable interactive ice sheet simulations
- As in CESM2, artificially enhance sub-grid orography along the Greenland coasts ***reduces excessive precipitation***
- ***Reduced excessive melting*** through switching back to the Jordan snow conductivity scheme, just over ice sheets

Ice Sheet-wide precipitation and ice+snow melt



Highlights of first coupled CESM3(MT) run

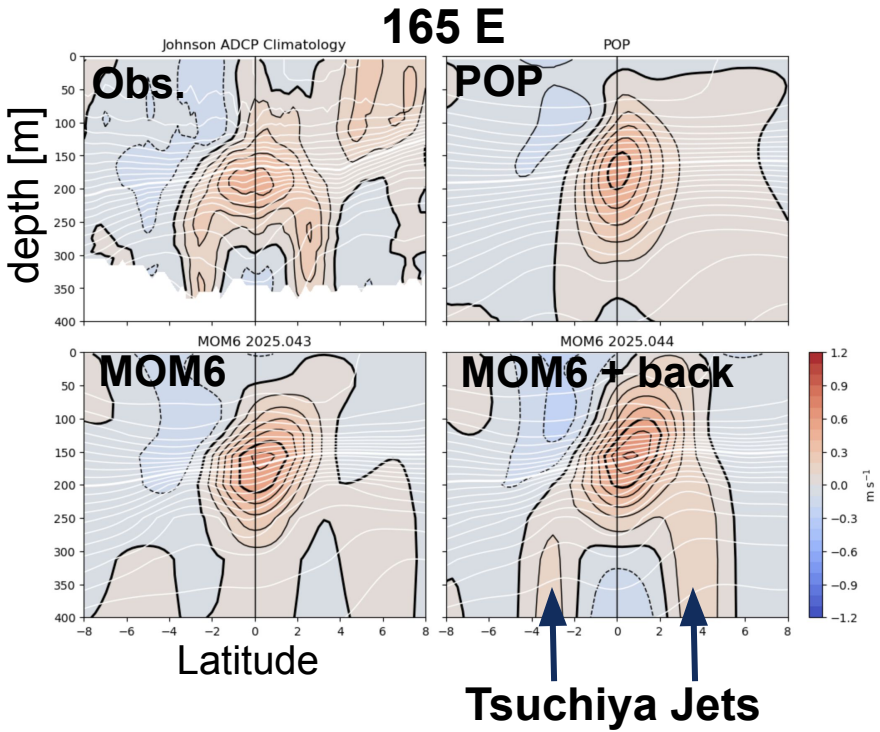




- QBO amplitude in good agreement with ERA5, especially below 30hPa
- QBO period too fast and westerly phase too strong; tuning?

Improved Equatorial Ocean Processes via Kinetic Energy Backscatter

Transects of zonal velocity



- Emergence of **Tsuchiya jets** when backscatter is applied
- These jets reduce biases in the extent of oxygen minimum zones (not shown), critical for ocean BGC

ECS / microphysics commentary manuscript

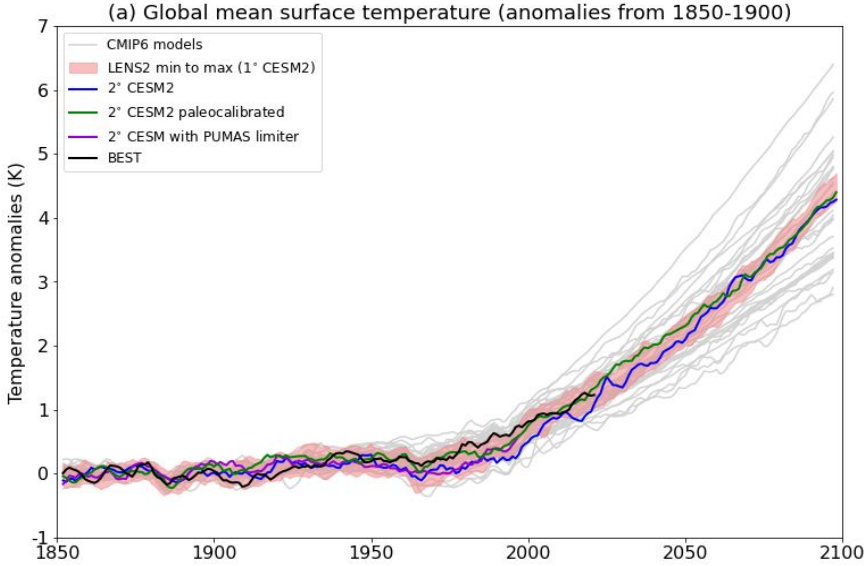
Is the high ECS in CESM2 degrading transient climate change projections over the 21st century?

Margaret L. Duffy[1,2], Isla R. Simpson[1], Christina S. McCluskey[1], Brian Medeiros[1], Jiang Zhu[1], Adam R. Herrington[1], Andrew Gettelman[3], Bette L. Otto-Bliesner[1], John T. Fasullo[1], Peter H. Lauritzen[1], Richard B. Neale[1], Hui Wan[3], and David M. Lawrence[1]

Key Points

- CESM2's high Equilibrium Climate Sensitivity (ECS) and too-cold simulation of ice age climate have raised questions about its skill.
- Changes to CESM2's microphysical representation that improve its ice age climate and ECS ***do not impact its Transient Climate Response***.
- ***CESM2 is appropriate for studies of the historical climate and 21st century warming,*** and we provide guidance on how to use CESM2 for studies of other climates.

Submitted to JAMES, frist reviews received

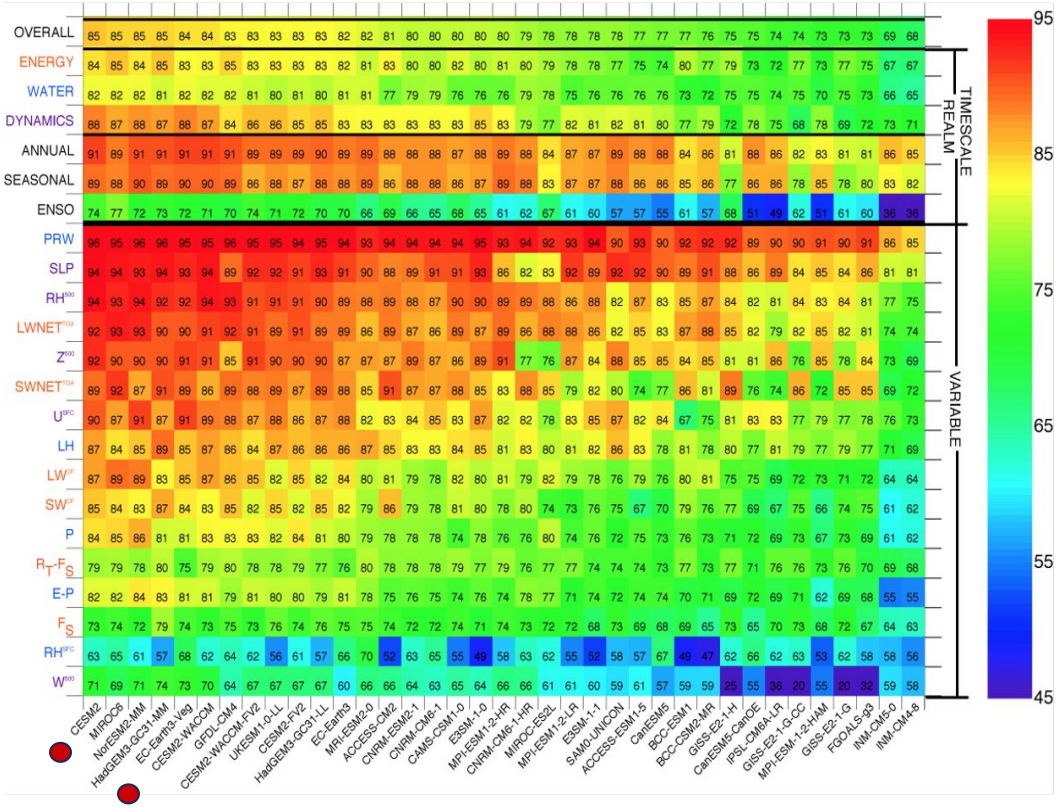


Note that CESM3(beta) shows ECS of about 3.8°C and also 'passes LGM test'

CESM3 assessment and tuning

As we finalize the science configuration, resolve issues, and tune the model, we will continue to evaluate against broad set of metrics

… but, CESM2 was/is a pretty good model, so … we'll see



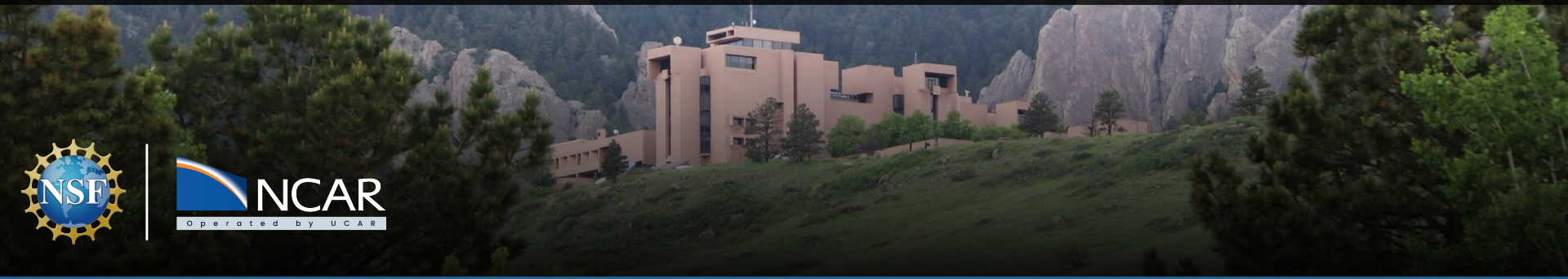
Scores for pattern correlations, seasonal contrasts, and ENSO teleconnections

CESM2 versions

better agreement with obs

CMAT analysis, Fasullo et al., 2020

CESM3 Tools



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.

CMIP7 Forcings

CMIP7 Datasets

- **Raw datasets**: Location on glade
- **CESM-ready forcing**: Tracking processing
- **Scripts:** Github repository (in development)

Dataset			Raw Datasets			Processing (making datasets "CESM ready")			Testing (running cases)	
Name	**Contact**	**Github**	**Status**	**Glade Location** dir = /glade/campaign/cesm/cesmdata/input4MIPs_raw/input4MIPs/CMIP6Plus/CMIP	**Comments**	**Status**	**Scripts location**	**Comments (including Expected date).**	**Status**	**Case directory**
Anthropogenic short-lived climate forcer (SLCF) and CO2 emissions	Louisa, Rebecca, and Ben	link	Preliminary dataset	PNNL-JGCRI	There are 2 dates, only processing the latest (CEDS-CMIP-2024-11-25) /glade/derecho/scratch/gaubert/cmip_outputs/f09/model_ready/	Done		Datasets are done but only tested for period 2010-2020 - didn't process airfracft emission yet	Done	/glade/derecho/scratch/gaubert/archive/f.e2 .FCnudged.f09_f09_mg17.slh.bb.2000.cmip 7.voc_ant.finn.001/atm/hist
Open biomass burning emissions	Louisa, Rebecca, and Ben + Nan (smoothing present-day emissions)	link	Preliminary dataset	DRES/DRES-CMIP-BB4CMIP7-1-0	Fasullo expect CMIP to have smoothed emissions by the end of Feb. /glade/derecho/scratch/gaubert/cmip_outputs/f09/model_ready/	In progress			Done	/glade/derecho/scratch/gaubert/archive/f.e2 .FCnudged.f09_f09_mg17.slh.bb.2000.cmip 7.voc_ant.finn.001/atm/hist
Land use	Peter	link	Preliminary dataset	UofMD/UofMD-landState-3-0	https://github.com/PCMDI/input4MIPs_CVs/discussions/141#discussioncomment-12208440	Unknown			Unknown	
Greenhouse gas concentrations	Doug Kinnison & Jun Zhang	link	Preliminary dataset	CR/CR-CMIP-0-4-0	This data set has mole fraction LBCs for Greenhouse gases. I also includes the halogens (CFCs, HCFCs, Bromine). OCS is also included.	In progress			Unknown	
CO2 isotopes	TBD (check with Will)	link	In preparation			Unknown			Unknown	
Stratospheric volcanic SO2 emissions and aerosol optical properties	Simone, Ilaria	link	Preliminary dataset	uoexeter/UOEXETER-CMIP-1-1-3 uoexeter/UOEXETER-CMIP-1-2-0 uoexeter/UOEXETER-CMIP-1-3-0 uoexeter/UOEXETER-CMIP-1-3-1 (latest)	Simone had an issue with the files and was touch with the CMIP group. The new files have been posted. They changed the injection height. and Ilaria has had problems processing it with the new heights.	In progress	/glade/u/home/iquaglia/injection_files.ipynb	The python script first produces a csv file that can be read with Mike's scripts, and continues with the creation of the netcdf emissions. The pythion output has been compared with Mike's ncl output. In addition to Mike's script here you can choose between a vertically uniform or gaussian injection.	Unknown	
Ozone concentrations		link	In preparation		We don't need those (datasets created with MT then used for LT). Need to discuss next time. Will be derived from 2degree WACCM6 simulations with CMIP7 forcings.	In progress		Simulations will start 1st week of March.	Not started	

Strategy for testing

- **Test in CESM2-WACCM** *(in progress)*
  - B1850 + CMIP6 forcing: Done
  - B1850 + CMIP7 forcing: Done
  - BHIST + CMIP6 forcing: Running
  - BHIST + CMIP7 forcing: Start this week
- If no issues arise, **test in CESM3-beta**

MIP Workflow (Input data, MIP prep, Production, Post-process, CMORization, Publication)

Prerequisites

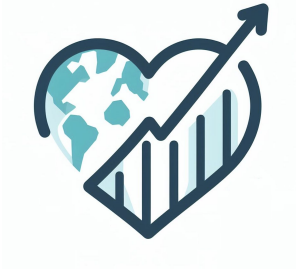
CMIP7 forcing

- 🔁 raw -> CESM-ready
- 🔁 forcing testing

MIP prep

- ✅ Data request -> CESM variables
- ✅ Volume calculator
- 🔄 Storage

CESM Unified Postprocessing and Diagnostics (CUPiD)



Workflow

Production

- ✅ Database
- ⏳ Scripts development

Postprocess

- 🔁 Timeseries Tools
- 🔁 CUPiD

CMORization

- 🔁 CMOR tool

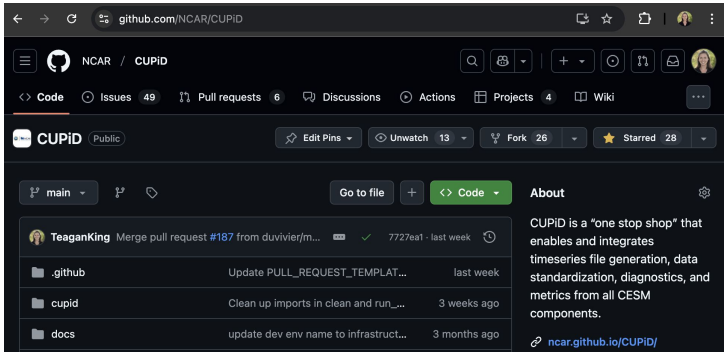
Publish

Legend

- ✅ → **Done**
- 🔄 → **In Progress**
- ⏳ → **Not Started**

CUPiD (CESM Unified Post-processing and Diagnostics package)

- [x] Key metrics for most components which can run in parallel
- [x] Internal and External diagnostic packages
- [x] Command line arguments
- [x] Common environment
- [x] Documentation
- [x] Part of CESM Workflow
- [ ] Support for machines other than Casper / Derecho
- [ ] Include additional packages (CVDP / MDTF)



CUPiD Update

External Diagnostic Packages

Search

Atmosphere

Link to ADF output

Land

Link to ILAMB output

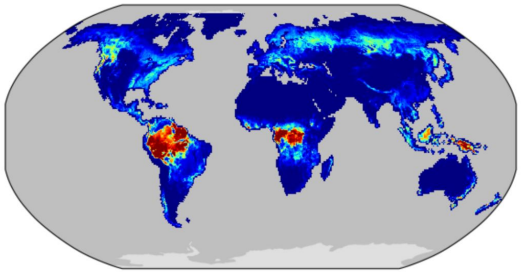
Link to Full ILAMB output

Key Metrics from ILAMB

Some important things to look at from ILAMB:

▶ Show code cell source

```
../../examples/external_diag_packages/ILAMB_output/EcosystemandCarbonCycle/Biomass/ESACCI/Be
```



ILAMB Benchmarking

Overall Score

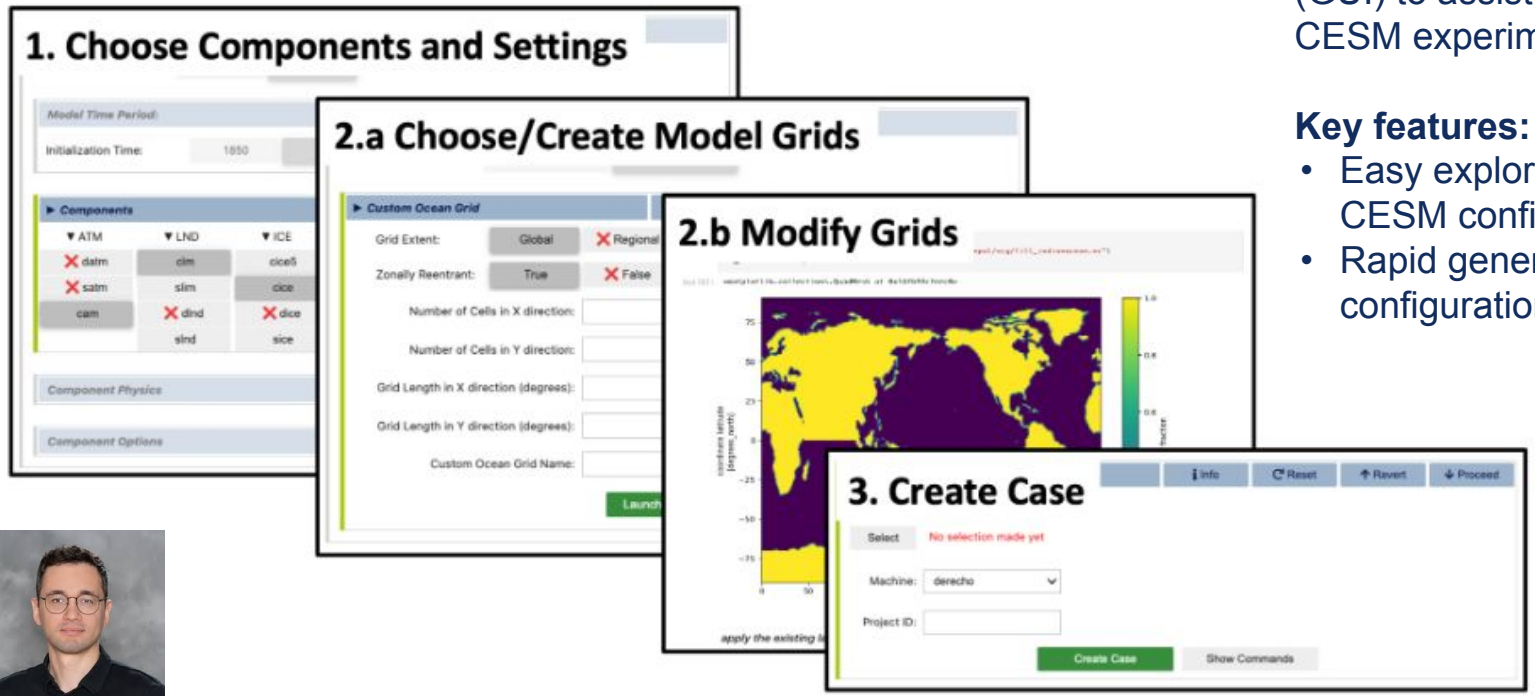
Global - Land

	CTSM51
Ecosystem and Carbon Cycle	
Biomass	
Burned Area	
Carbon Dioxide	
Gross Primary Productivity	
FLUXNET2015	
FLUXCOM	
WECANN	
GBAF	
Leaf Area Index	
Global Net Ecosystem Carbon Balance	
Net Ecosystem Exchange	
Ecosystem Respiration	
Soil Carbon	
Nitrogen Fixation	
Hydrology Cycle	
Evapotranspiration	
Evaporative Fraction	
Latent Heat	
Runoff	
Sensible Heat	

CUPiD is now included in the ccs_config_cesm workflow. This is available in beta05 enabling CUPiD to be run directly within CESM workflow (in testing).

visualCaseGen released

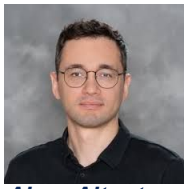
A typical visualCaseGen Workflow



A user-friendly graphical interface (GUI) to assist users in creating CESM experiments

Key features:

- Easy exploration and setup of CESM configuration options
- Rapid generation of custom configurations:



Alper Altuntas,
Sam Levis, Isla Simpson, Gokhan Danabasoglu, Scott Bachman, Brian Dobbins

https://esmci.github.io/visualCaseGen/

CESM3 Release Timing

- Need to finish CESM3 for many reasons; enabling new science, setting new baseline for CESM3-MLe and High Resolution configurations, MIPs
- CESM Working Group co-chairs, SSC, and CAB is working towards a plan to finalize CESM3
- Likely will include firm deadlines and accepting that some biases cannot be resolved

How to resolve the "final mile(s)" coupled development problem?

- Idea from arising from CESM2 development to couple early and often hasn't solved all our problems
- New strategies to emphasize: AI/ML assistance? Initialized predictions?

Other CESM activities

Forces driving the future of Earth System modeling

- Urgent need for actionable climate change information (climate risks, consequences of intervention/mitigation)
- *Earth System* prediction across timescales (ESPAT), S2S → S2D → 30-yr projections (ideally, seamless)
- Increasing demand for high-resolution (~0.25°) and ultra high-resolution (km-scale) configurations in modeling hierarchy
- Growth and potential of machine learning, hybrid modeling, and emulators to transform models
- Changing computing architectures → need for code modernization
- Calls for improved accessibility of ESMs and output (e.g., to global south)

Ima

CESM high-resolution (HR) simulations

CESM1.3(HR): 0.25° atm/lnd, 0.1° ocn

500-year PI control

1%CO_2, 4xCO_2

10-member 1850-2100 transient (RCP6, RCP8.5)

All HighResMIP Coupled and AMIP

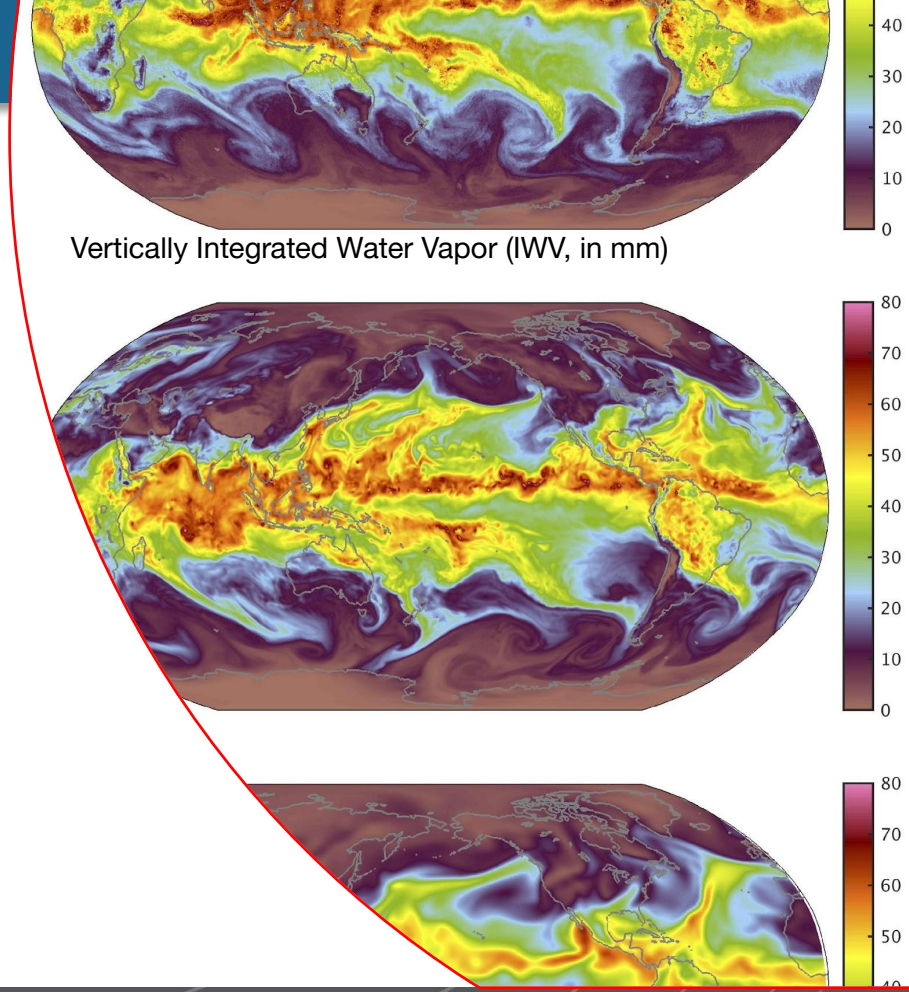
5 cycles of 1958-2018 OMIP (w/ BGC)

3-member 1970-2020 Ozone withholding

3-member 1950-2014 AMIP

Decadal Predictions (1980-2023)

PaleoCWG: 60-year high- and low-CO_2 past periods

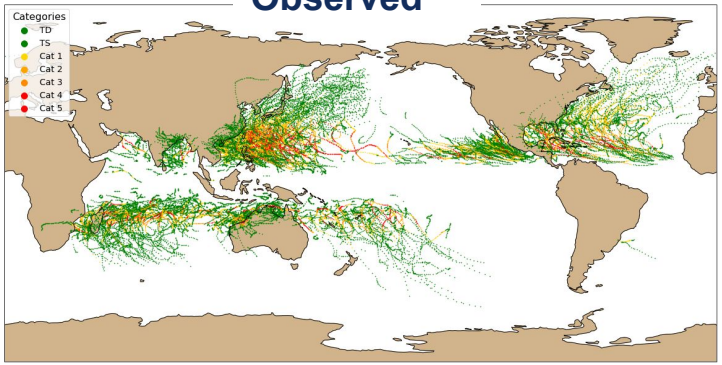


Vertically Integrated Water Vapor (IWV, in mm)

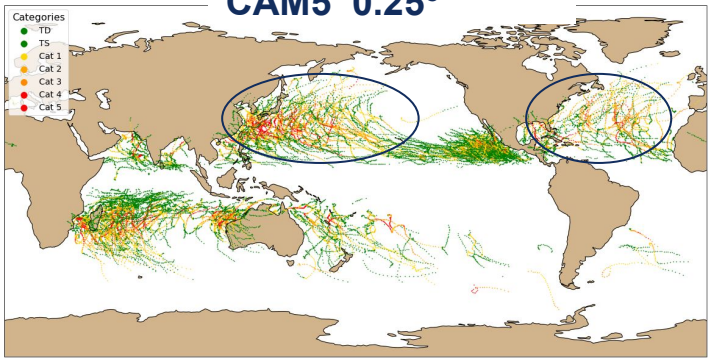
Chang et al. (2020, JAMES)

Preliminary work towards a CESM3 HR configuration (CAM7 simulations)

Observed



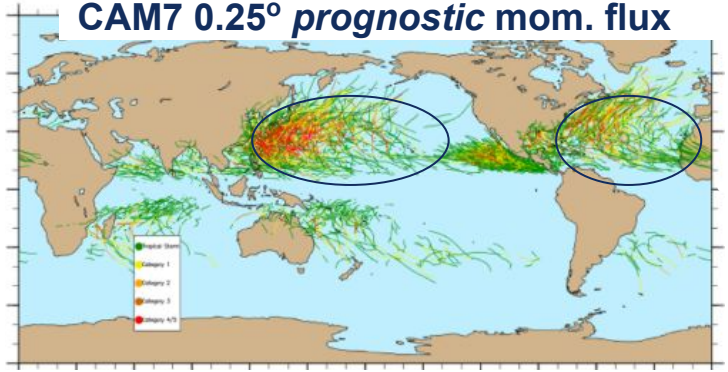
CAM5 0.25°



Tropical Cyclone tracks (2000-2010)

- Action is shifted west and south w/resp to what it was in CAM5
- Recurvature is better in CAM7
- Implies landfall/impact statistics might be better in CAM7
- TC counts too high: ~160% of obs

CAM7 0.25° *prognostic* mom. flux

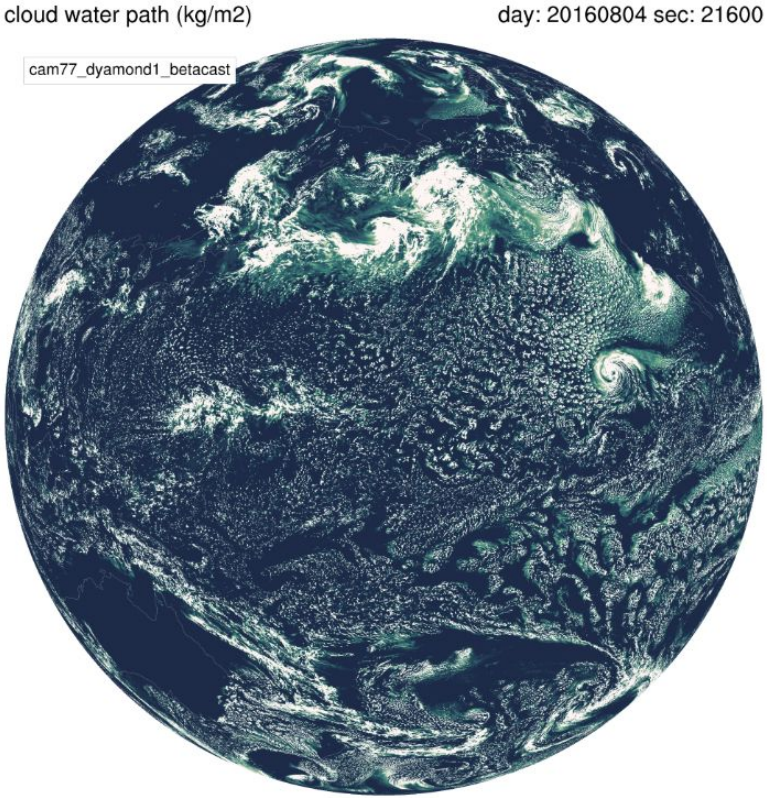


On-going work:

- Exploring sensitivity to convective time scale
- NH focused variable resolution domain (⅓ cost)
- Recent results in excellent agreement w/ NH TC counts ~50/year

Julio Bacmeister, Ben Stephens, Cecile Hannay (CGD), Colin Zarzycki (PSU)

CESM km-scale capabilities



Joint effort:

CSEG, SIMA, Earthworks, StormSPEED

CGD, CISL, MMM

Km-scale efforts are a cross-lab, cross institution, activity

CAM-MPAS DYAMOND simulations

DYAMOND = DYnamics of the Atmospheric general circulation Modeled On Non-hydrostatic Domains

- Provides a framework for the intercomparison of global storm-resolving models (Stevens et al., 2019)

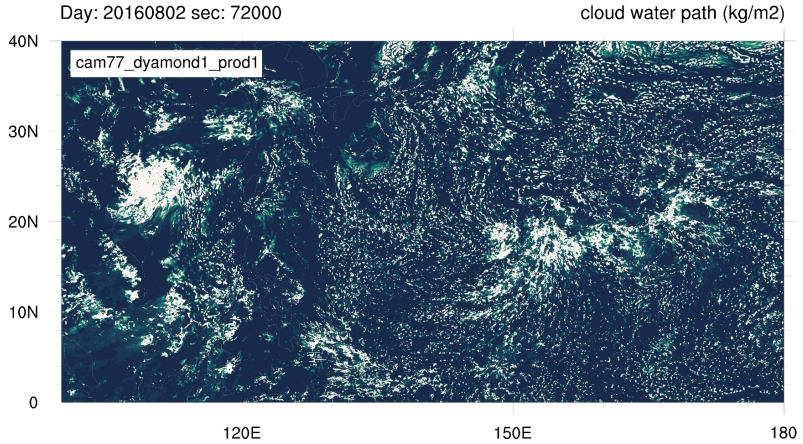
- DYAMOND1 (summer) 40-day run starting on 1 August 2016
  - Completed
  - Bug in diagnostic pressure field, add'l sponge layer diffusion
- DYAMOND2 (winter) 40-day run starting on 20 January 2020
  - 30 of 40 days completed
  - Snow depth bug in CLM
- DYAMOND3 (annual) 1-year run starting on 1 March 2020
  - NSC allocation awarded (A. Herrington, Y. Tian, H. Li, D. Leung, P. Lauritzen, F. Judt)
  - Plan to start in the winter, after a tuning & calibration effort

Huge thanks to Brian Dobbins, Adam Herrington, and many others in EarthWorks, SIMA, and StormSPEED projects to make this happen

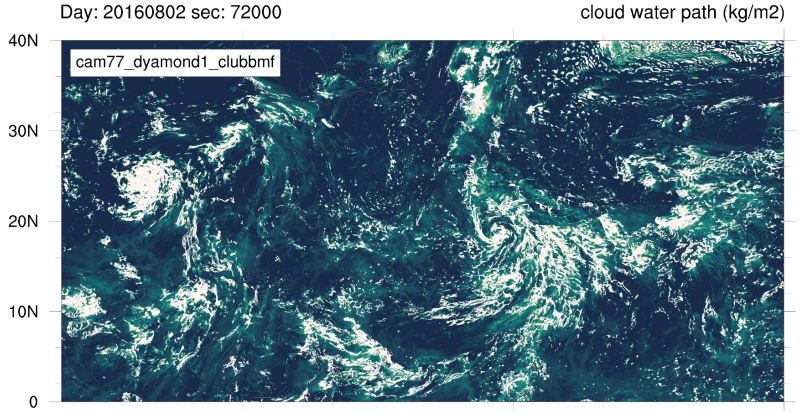
CLUBB+MF in km-scale CESM3

Using *CLUBB+MF in 3.75 km CAM-MPAS improves transitional cumulus regimes with less ‘patchy’ deep convection and more realistic spectrum of clouds

Simulation 1: CLUBB shallow convection is the only convection scheme active



Simulation 2: Same as 1, but with CLUBB+MF



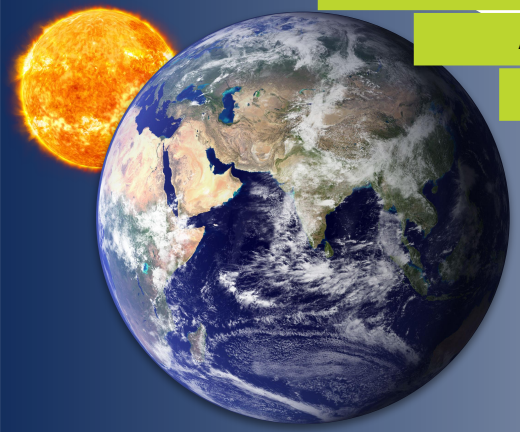
*CLUBB+MF is CLUBB augmented with an ensemble of stochastic mass flux plumes (Suselj et al. 2019; Witte et al. 2022)

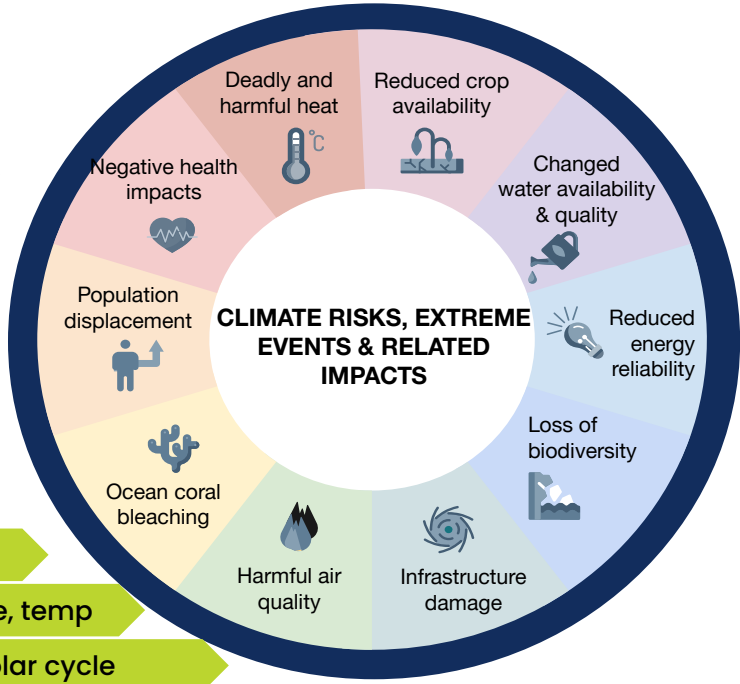
Adam Herrington

NSF NCAR priority: Earth System Predictability Across Timescales (ESPAT)

Guided by societal needs, spanning minutes to centuries

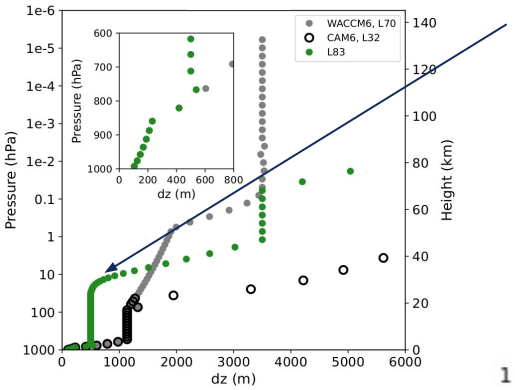
- Tornadoes
- Flooding
- Solar Flares/CME
- Storm Surge
- Wildfires
- Air Quality
- Solar Rossby Waves
- Heat/Cold Waves
- Drought/floods
- Seasonal Temp & Precip
- Sea-ice, land-ice
- Sea-level rise, temp
- Solar cycle





Minutes → Centuries

A new seasonal prediction hindcast suite with high vertical resolution

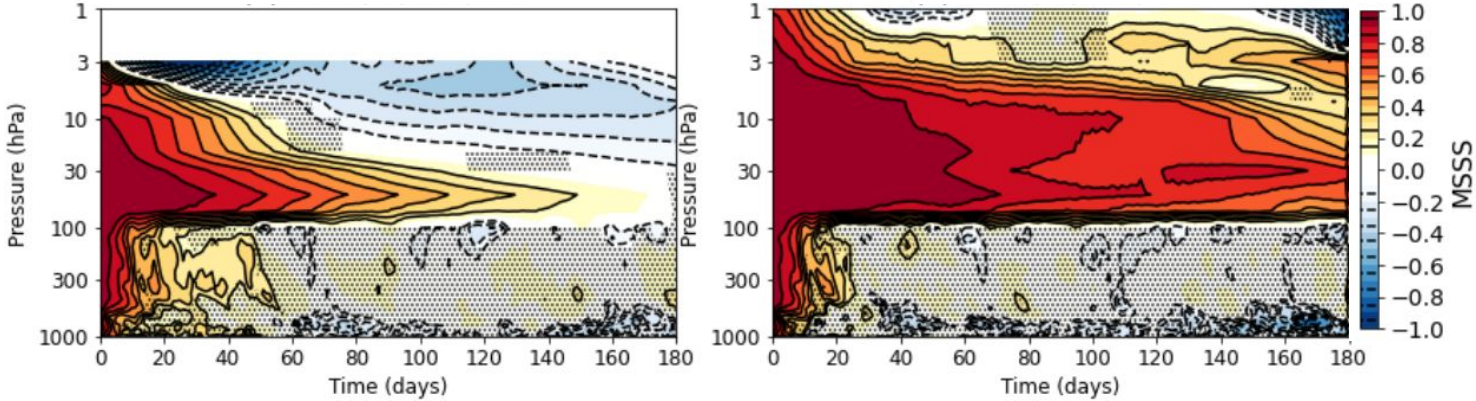


CESM2 but with CESM3's vertical resolution
Initialized Nov 1st, Feb 1st, Sept 1st 1970-2020
6 month long simulations
Standard L32 hindcast suite for comparison

Significantly enhanced skill in the QBO on 6 month timescales with potential influence elsewhere

Standard low vertical resolution

New higher vertical resolution



Mean squared skill score of 5S-5N zonal mean zonal wind

Description paper being finalized. Dataset coming soon.

Land ‘expected’ to be a key source of predictability at subseasonal-seasonal (S2S) timescales …

but CESM2 does not support this hypothesis … why?

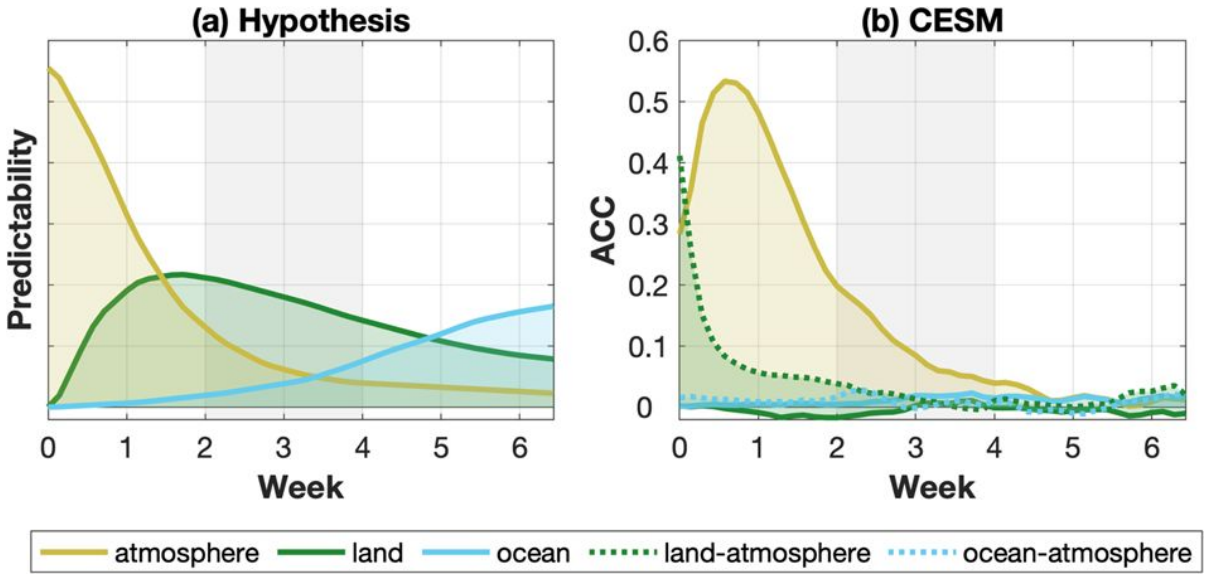


Figure 1 of Richter et al. *(2024)*

L-A interactions in S2S ESPAT Working Group

Workshop next week

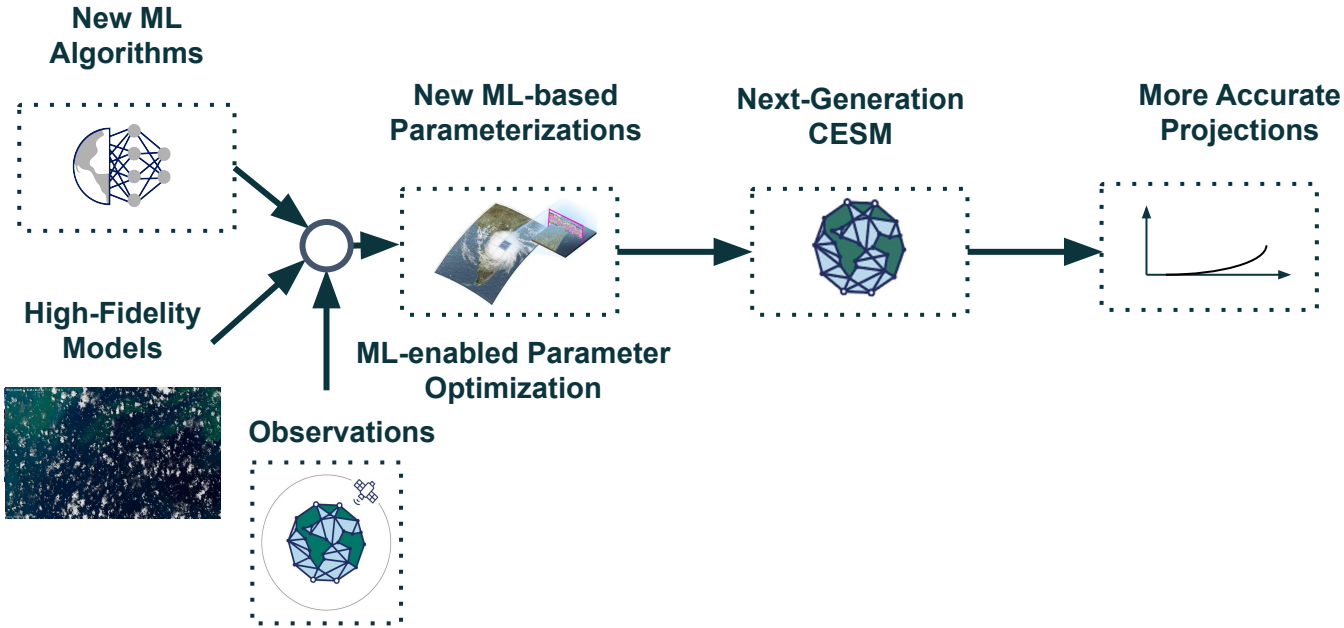
Contact Meg Fowler (mdfowler@ucar.edu) if interested in topic

Towards a machine learning enhanced version of CESM (CESM3-MLe)

LEAP

Learning the Earth with Artificial intelligence and Physics
NSF Science and Technology Center

M^{2}LInES
Schmidt Sciences



Towards a machine learning enhanced version of CESM (CESM3-MLe)

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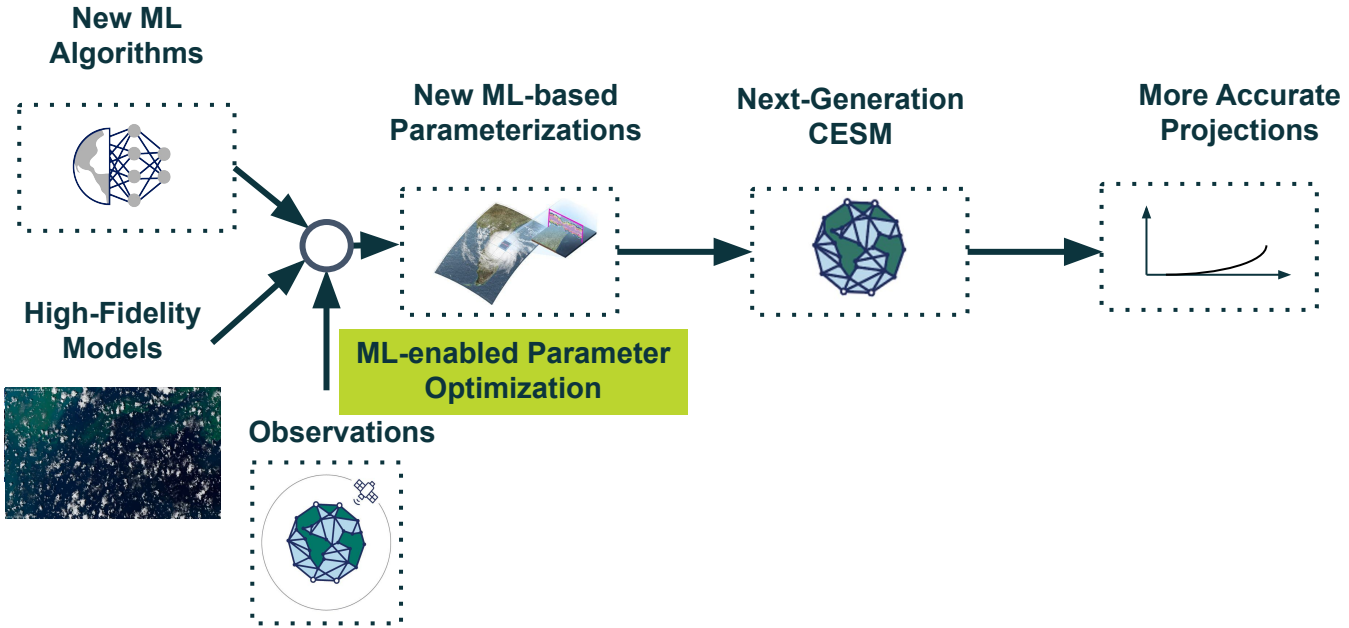
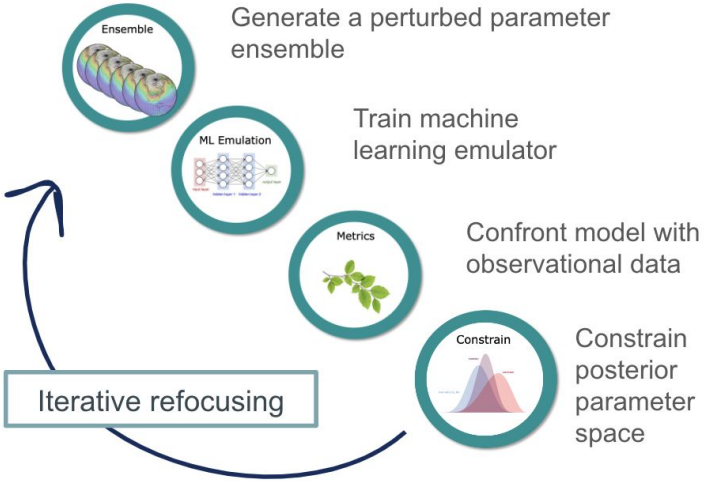


Towards a machine learning enhanced version of CESM (CESM3-MLe)

Parameter estimation methodologies have been developed for land (CLM) and atmosphere (CAM) model components

CLM



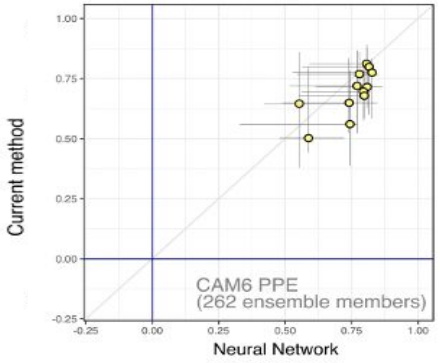
Linnia Hawkins, Daniel Kennedy, Katie Dagon, Dave Lawrence

CAM

Additive Gaussian Process Emulator

Designed for sparse state spaces:

- Additive and simple
- Parameter interaction considered
- Less likely to overfit



Qingyuan Yang, Greg Elsaesser, Brian Medeiros, Addisu Semie, Marcus van Lier-Walqui

Towards a machine learning enhanced version of CESM (CESM3-MLe)

LEAP

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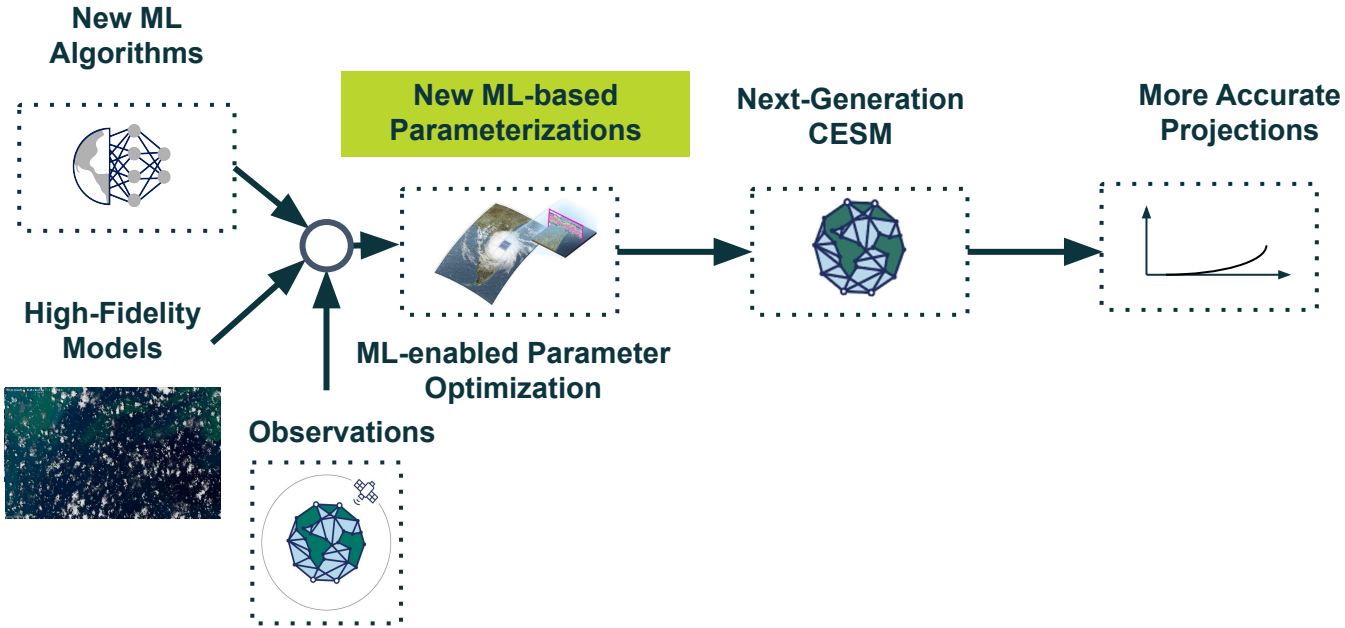
M²LInES
Schmidt Sciences



Candidate ML-based parameterizations and tools for CESM3-MLe

Radiation

Phenology

Pedotransfer functions

Fire

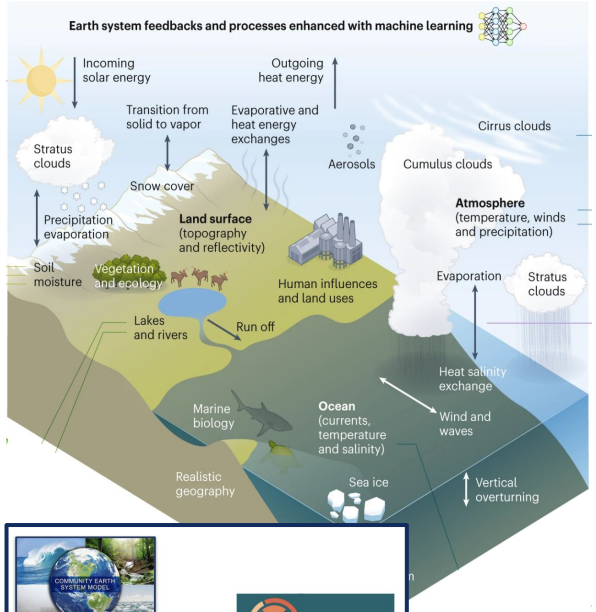
Sea ice heat conduction

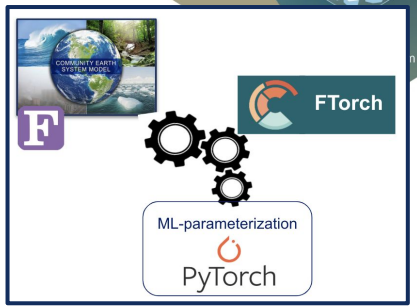
Ice sheet friction

LEAP

M²LInES

ICON, E3SM, lit.





Warm rain microphysics

Ice microphysics

Turbulence

Convection

Cloud cover

Atmospheric Chemistry

Vertical Mixing (KPP)

Ocean Mesoscales

Air-sea turbulent fluxes

Candidate parameterizations for CESM-MLe

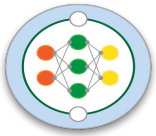
→ **LEAP and M²LInES are enabling** the platform for flexible adoption and experimentation of **ML parametrization & calibration into CESM** from LEAP, M²LInES, and other projects

Figure modified from Eyring, Gentine, Camps-Valls, Lawrence, Reichstein (Nature Climate Change, 2024)

CESM-MLe Integration Team

Identified need

More productive and sustained interactions between LEAP and M^{2}LInES projects and CESM scientists and developers



CESM-MLe Integration Team

Identified need

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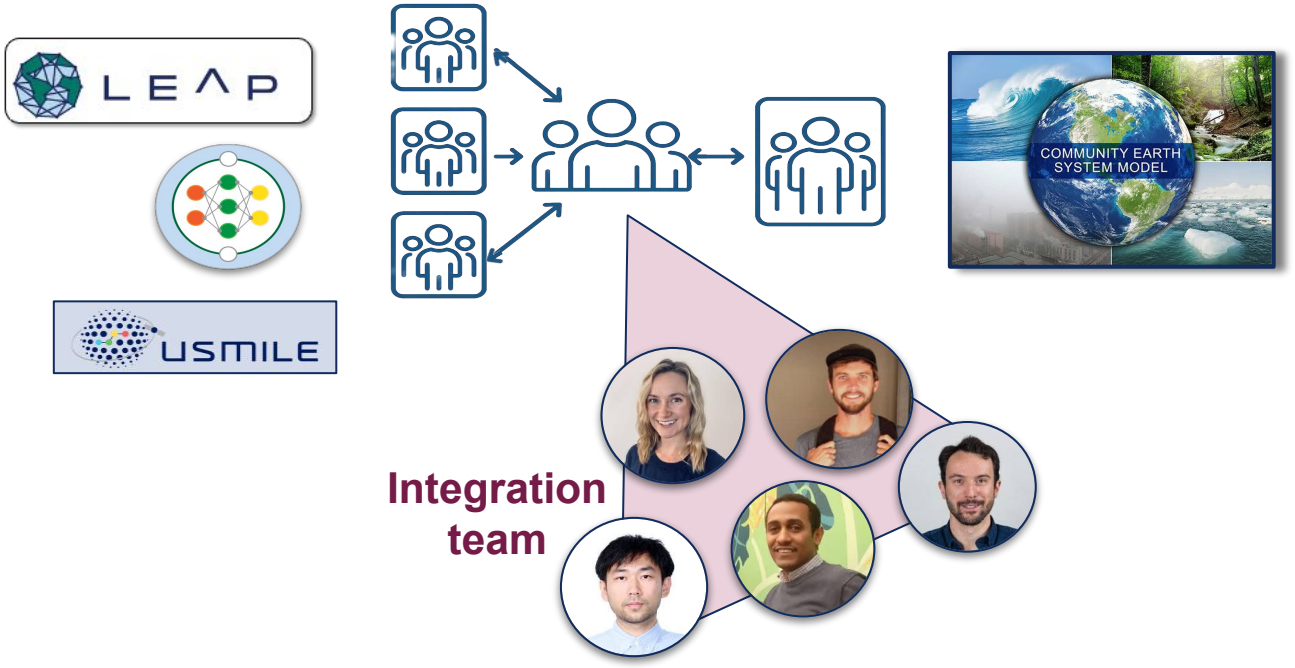


Next-generation Earth System modeling

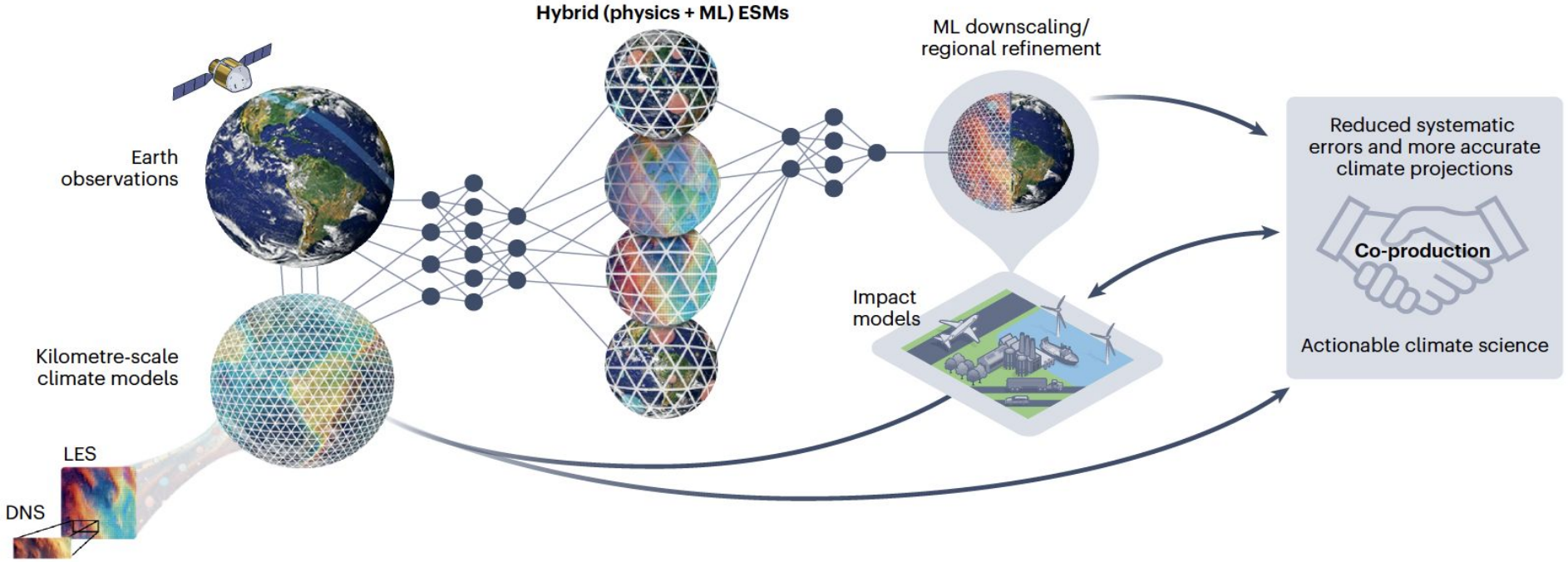
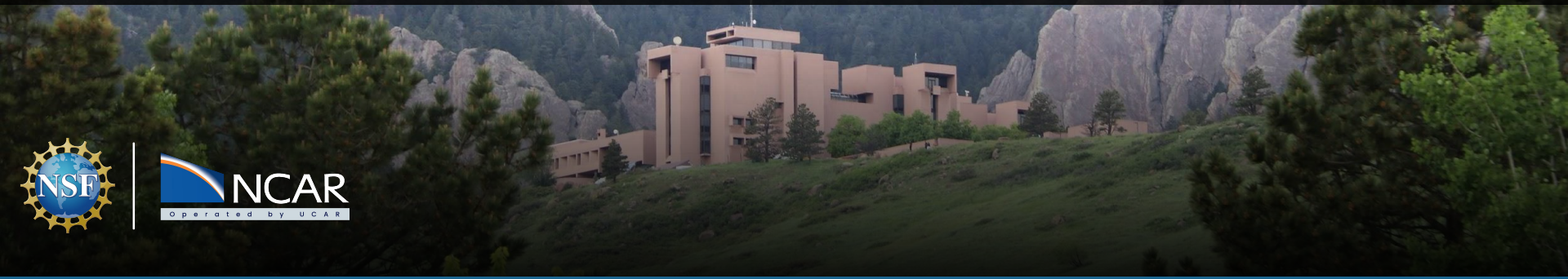


Figure from Eyring, Gentine, Camps-Valls, Lawrence, Reichstein (Nature Climate Change, 2024)

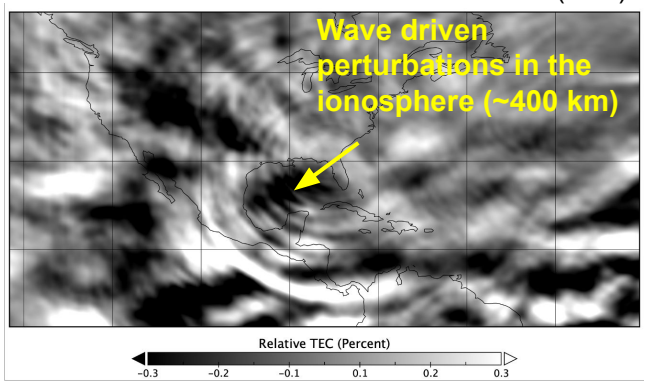
A few recent CESM science highlights



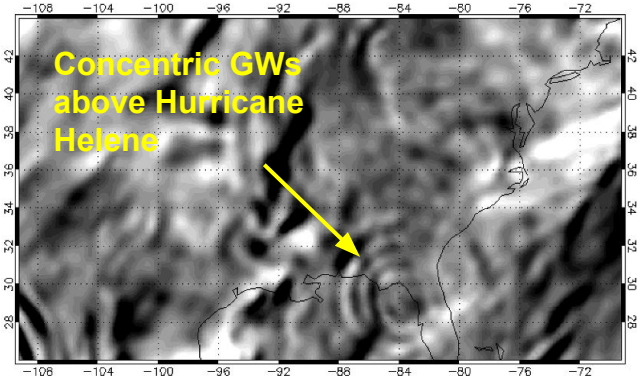
This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

High-resolution WACCM-X simulations of hurricane-induced gravity waves from troposphere to space

WACCM-X Simulated Total Electron Content (TEC)

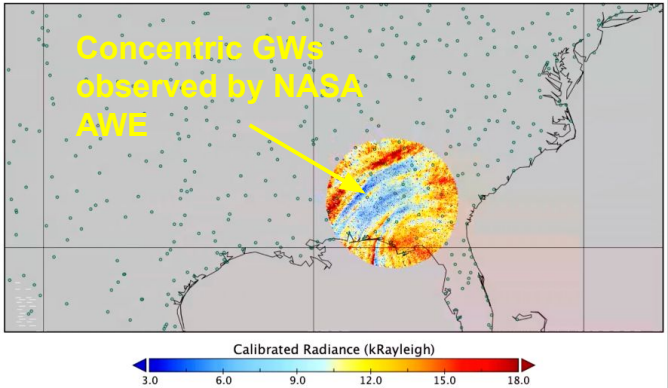


WACCM-X Simulated Vertical Wind (~87 km)



- High-resolution (NE120, 0.25°) WACCM-X simulations of Hurricane Helene show that the hurricane induced gravity waves reach the upper atmosphere (~400 km)
- NASA AWE mission observed concentric GWs near ~87 km altitude similar to the WACCM-X simulations
- Gravity waves generate small-scale perturbations in the ionosphere which can impact communications and navigation signals

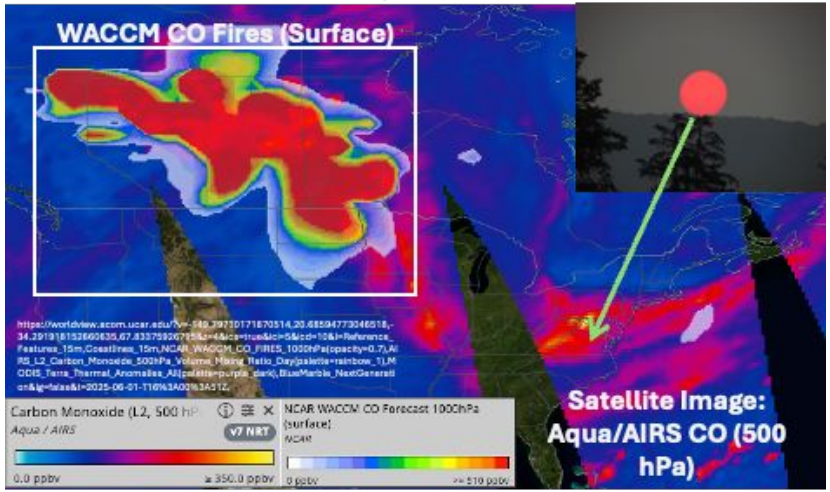
Gravity waves observed by NASA AWE (~87 km)



Hanli Liu (NCAR/HAO) & Jiarong Zhang (Utah State Univ.)

The CESM Chemistry Forecast System

Canadian Fires 1 June, 2025 – WACCM Worldview

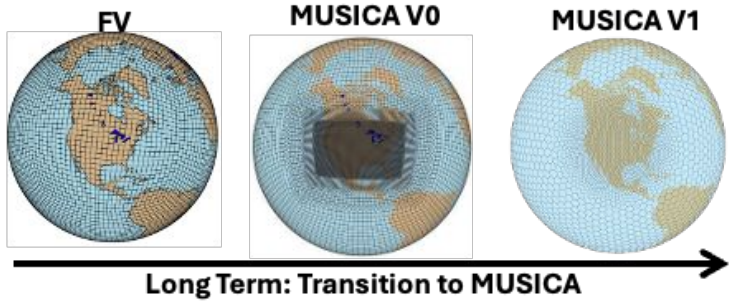


Current Forecast Configuration

- CESM 2.2.2
- FWSD Specified dynamics
- F09 (0.9x1.25) horizontal
- 88 vertical levels
- Meteorology: GEOS-FP
- Emissions: FINN, QFED, CAMS

Future

- CESM 3.x
- FWHIST
- MUSICAv0, MUSICAv1



Forecast Usage Statistics

- ACOM Server:
  - ~17,000 downloads since 2018.
  - Over 1500 User unique registrations since 2019.
- NCAR RDA:
  - ~300 Unique users in 2024
  - 4x increase from 2023.

Shawn Honomichl
Simone Tilmes, Rebecca Buchholz, Louisa Emmons,
Garth D'Attilo, & Carl Drews
NCAR/ACOM

CESM applications for mountain glaciers

Science

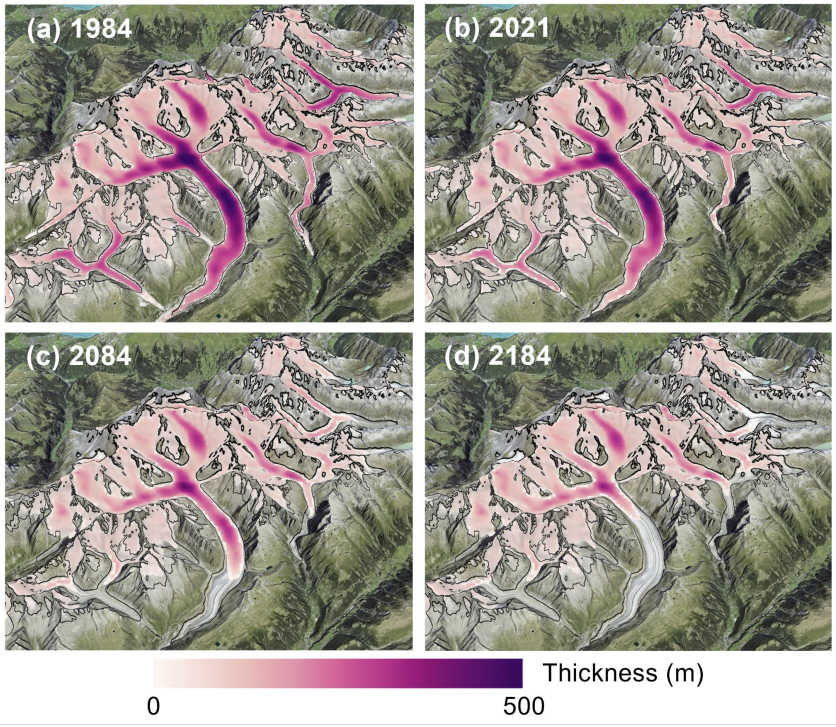
Glacier preservation doubled by limiting warming to 1.5°C versus 2.7°C

- First ESM to include dynamic simulation of mountain glaciers!
- Can now use CESM (CTSM-CISM) for regional glacio-hydrological assessments
- Currently, expanding the work for the North American and Himalaya-Karakoram glaciers

Samar Minallah*, William Lipscomb*, Gunter Leguy, and the GlacierMIP3 team

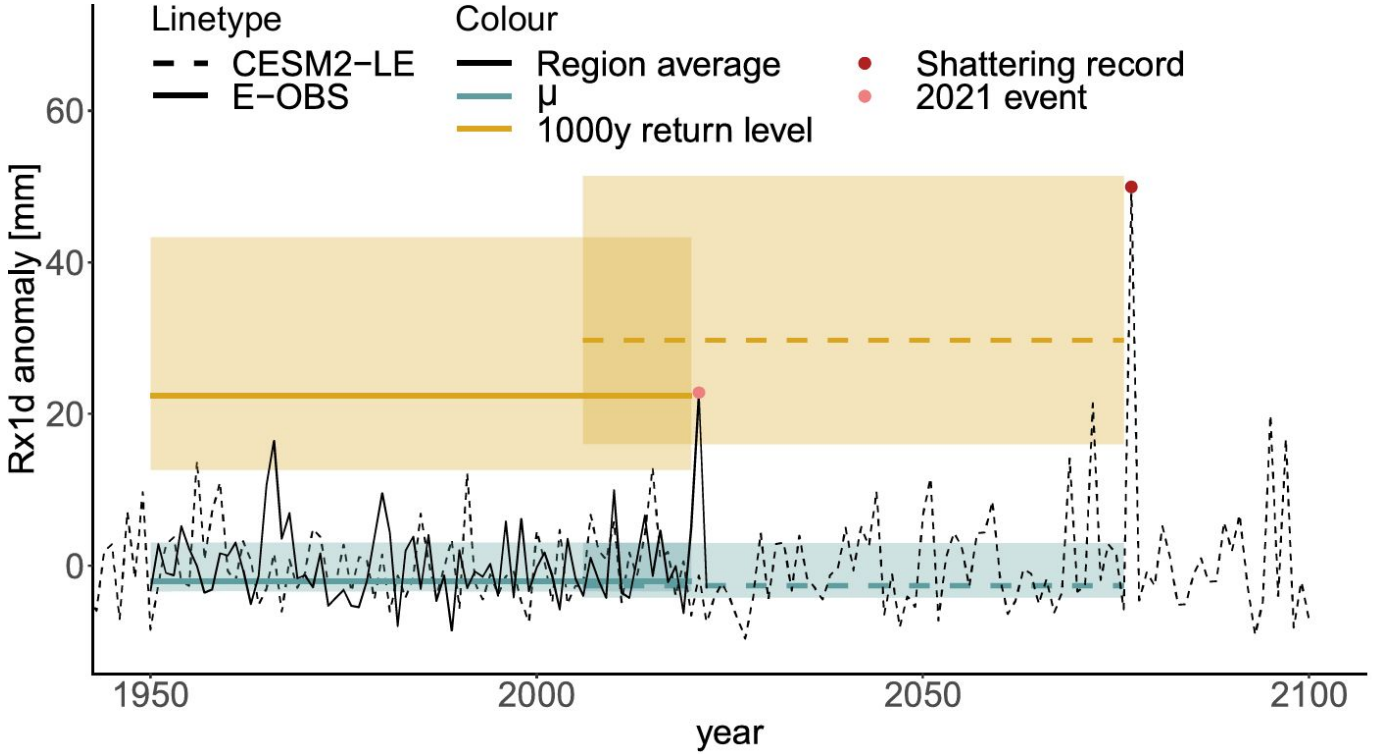
- GlacierMIP paper by Zekollari, Schuster et al. in *Science*
- CISM paper in review at *Geosci. Model Dev.*

Aletsch Glacier in the Bernese Alps
Commitment loss



Record-shattering rain events (Rx1d) (CESM2 large ensemble SSP3-7.0)

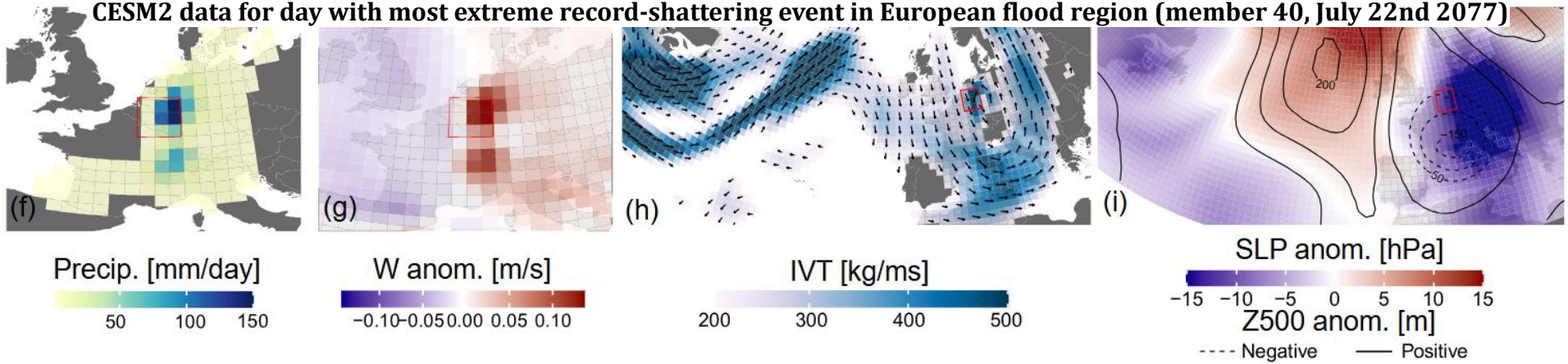
Observed (solid) and simulated (dashed) Rx1d record-shattering in European floods region



Record-shattering rain events (Rx1d) (CESM2 large ensemble SSP3-7.0)

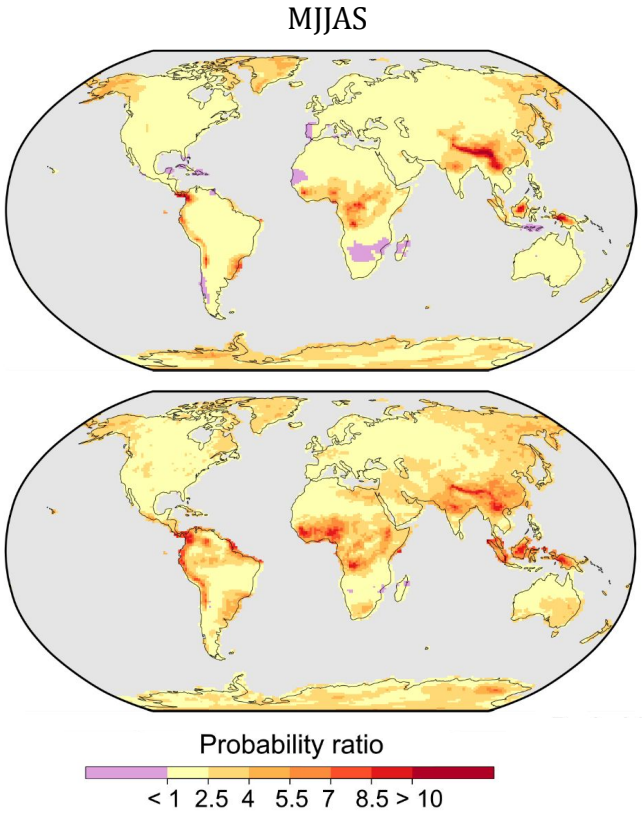
Observation (b,c) & reanalysis (d,e) data for European floods, July 15th 2021

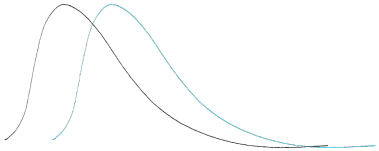
CESM2 data for day with most extreme record-shattering event in European flood region (member 40, July 22nd 2077)



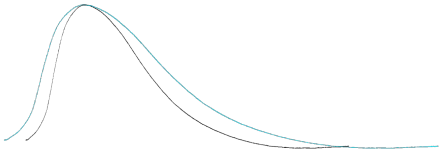
De Vries et al. (2024)

Changes in variability are as or more important than changes in mean





Extreme value distribution shift



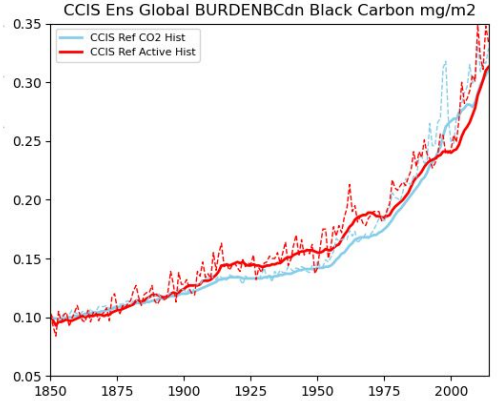
Extreme value distribution widening

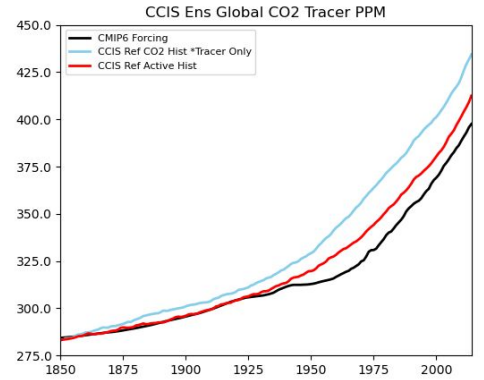
$$\text{Probability ratio} = \frac{P(\text{shatter) in 2100 with climate change}}{P(\text{shatter) in 2100 without climate change}}$$

Novel emissions-driven CESM 2.1.5 configuration simiulation ensemble

- CESM 2.1.5 (LENS2 config)
- **Historical, SSP 1-1.9, SSP 2-4.5 and SSP 3-7.0**
- Active Fire Aerosol Emissions
- Active Biogenic Volatile Organic Compound (BVOC) Emissions
- Marine Coccolithophores in New Ocean BGC – FEISTY Fish Model

- Basis for a range of climate intervention research (SRM, CDR)





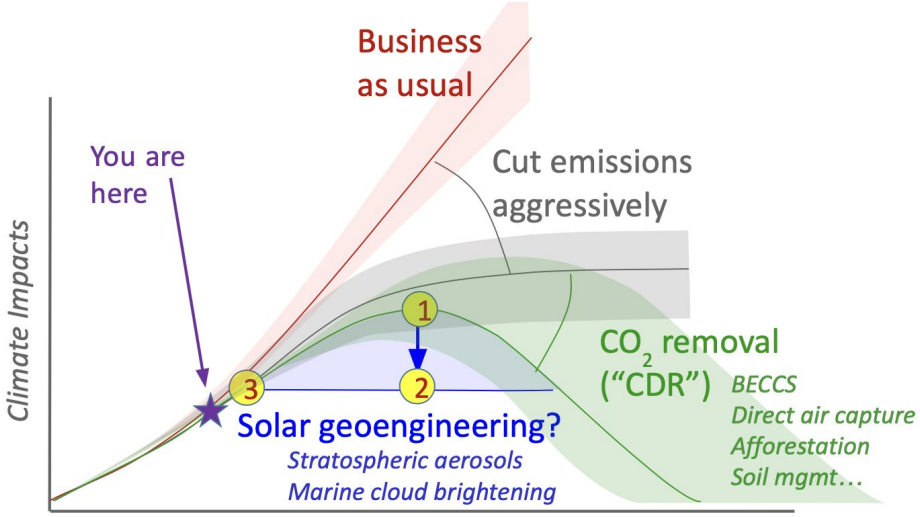
Thank you!

2025 CESM Distinguished Achievement Award

2024 CESM Graduate Student Awards

Climate intervention research

How to protect lives and environment?

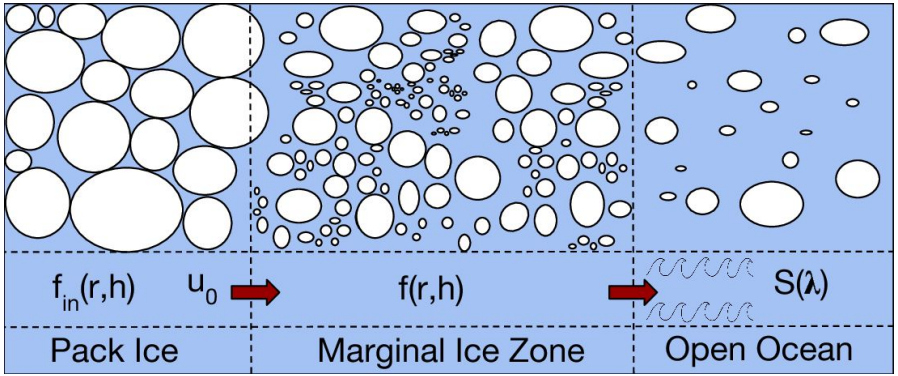


Solar Radiation Management & CDR

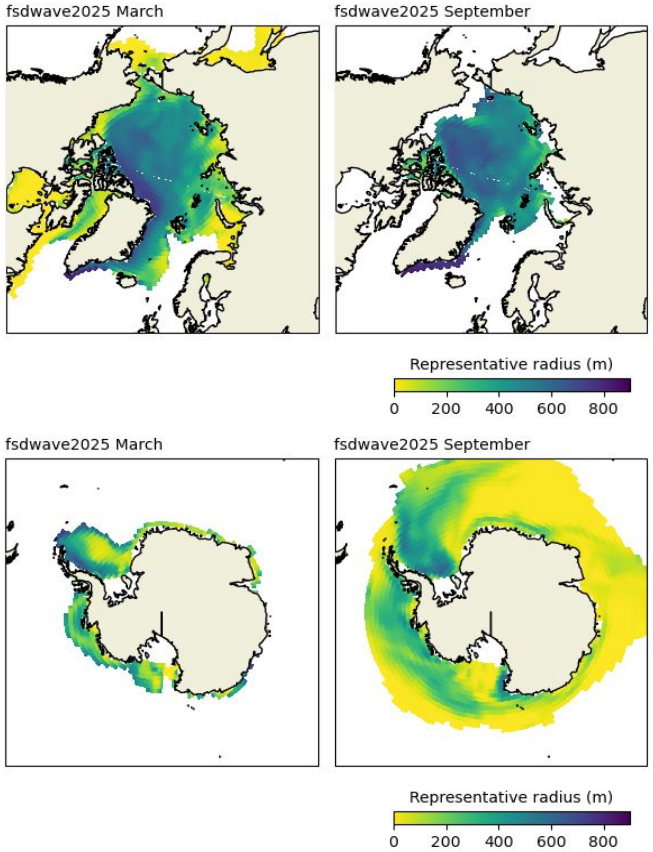
- **Whole Earth System Modeling:** Key to predicting consequences & effectiveness of strategies
- Requires collaboration with **broad research community** for understanding, **impacts assessment** & uncertainty communication

Sea ice floe size distribution in CESM3 will enable science

Joint floe size & ice thickness distribution



- Coupling of ocean wave field affects sea ice floes
  → Fracture of sea ice floes
  → Floe welding
- May impact sea ice predictability
- Will be available in CESM3



PCWG

Special thanks to Lettie Roach, Cecilia Bitz, and David Bailey