February 2, 2025

The path towards CESM3 and status of coupled simulations

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AMWG liaison, AMP/CGD

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Road map of this talk

From CESM2 to CESM3

- CESM3 development
- Development simulation database

Challenges during CESM3 development

- Labrador Sea • ENSO • ACC • and many more…

Atmosphere in coupled mode

- Key fields, climate sensitivity, aerosols effect, CMAT and Taylor metrics

Other components

- Sea ice • Ocean • Land

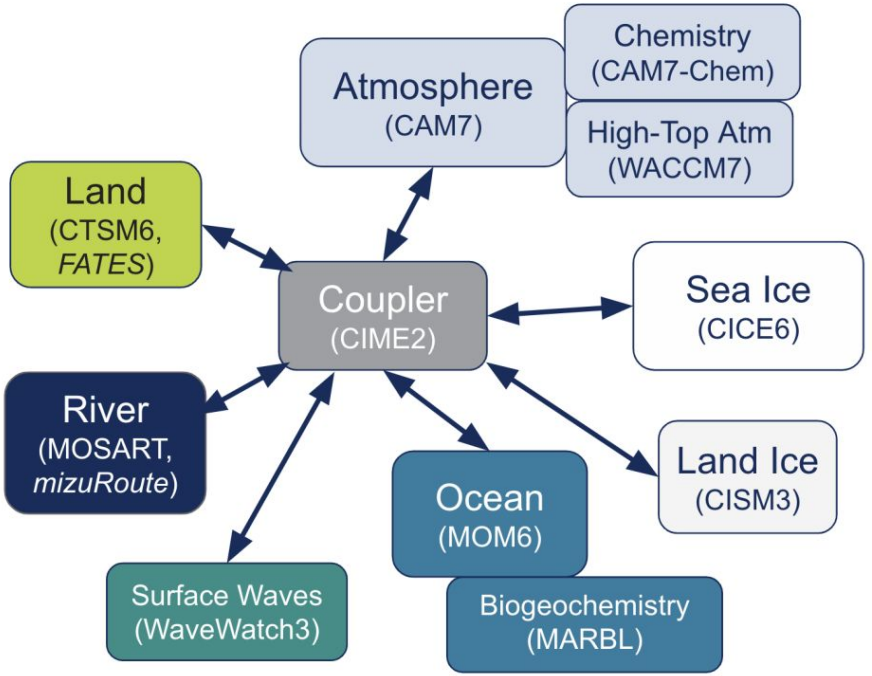
CESM3 Workflow

Components of CESM3

Full list of changes
("what" and "why")

www.cesm.ucar.edu/news/community-earth-system-model-3-cesm3-plans-progress-timelines

Significant updates to all component models



Courtesy of David Lawrence

The CESM development timeline and simulations

CESM2 release: June 2018

- Building timeline: 2010-2018
- 299 configurations

CESM3 release target date: June 2026

- Building timeline: 2018-2026
- 302 configurations so far (as of 2/2/2026 at 9am 😉)

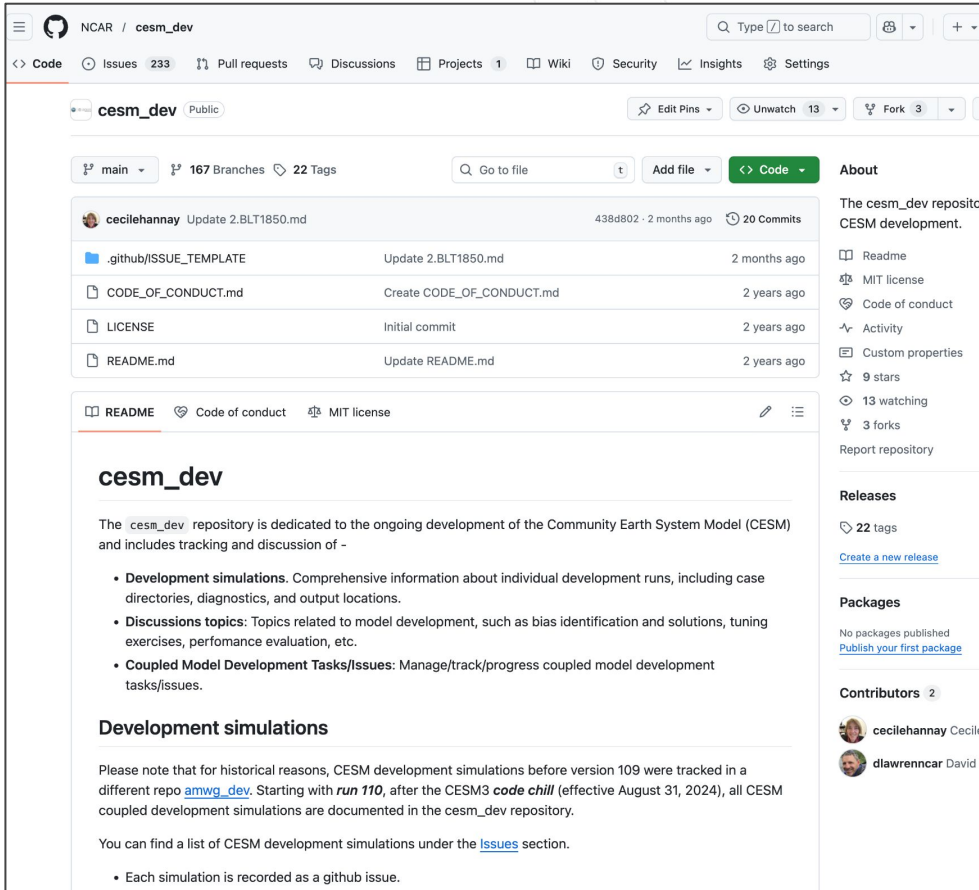
Development run database

cesm_dev database

- We track of **all development simulations** in https://github.com/NCAR/cesm_dev/

What's available in cesm_dev database?

- Info about simulations
- Links to case directories
- Output availability (including some climos)
- Diagnostics
- Related discussions



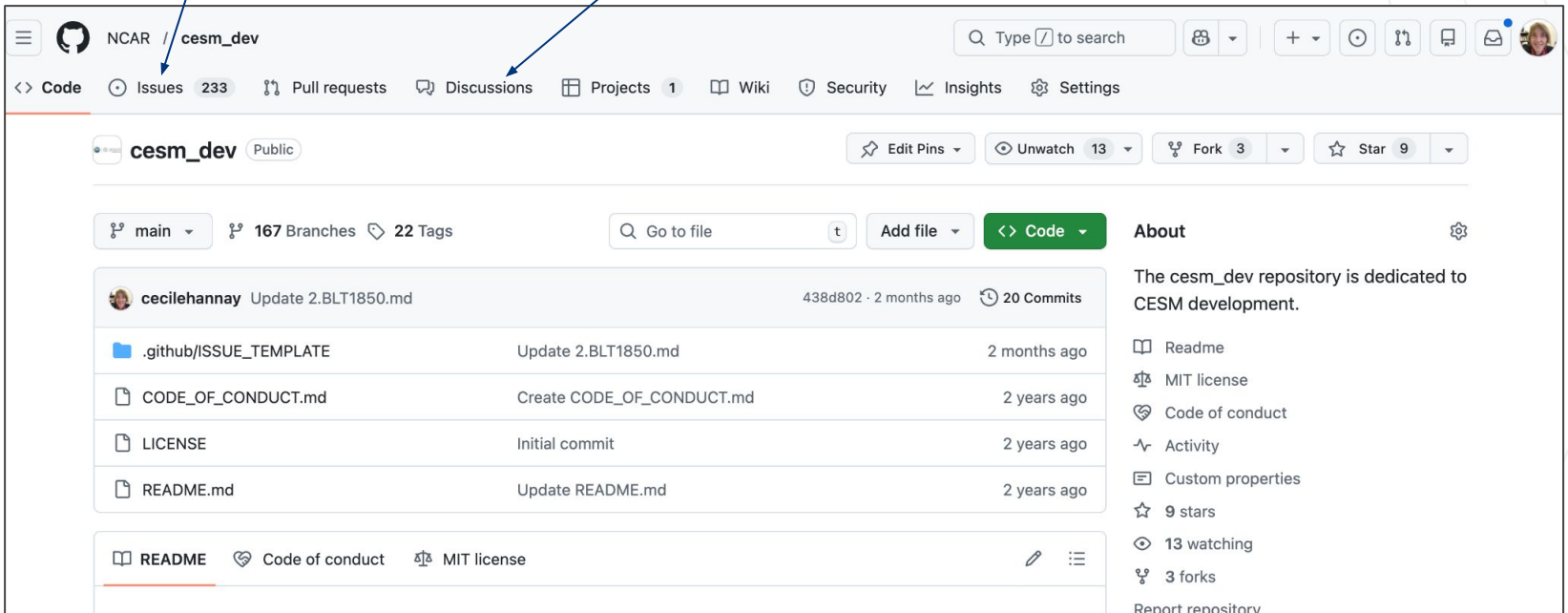
cesm_dev database

One issue = one simulation

- info about case directory, tag, diags
- Posts about plots, bug, etc…

Discussion

- discussion about specific issues
- Ex: Analysis of historicals, …



Challenges during CESM3 development

What has been slowing us down on the scenic highway to CESM3 (*)…

- The Labrador Sea Freeze

  => This talk

- ENSO characteristics

  => See Isla's talk

- Antarctic Circumpolar Current (ACC) transport

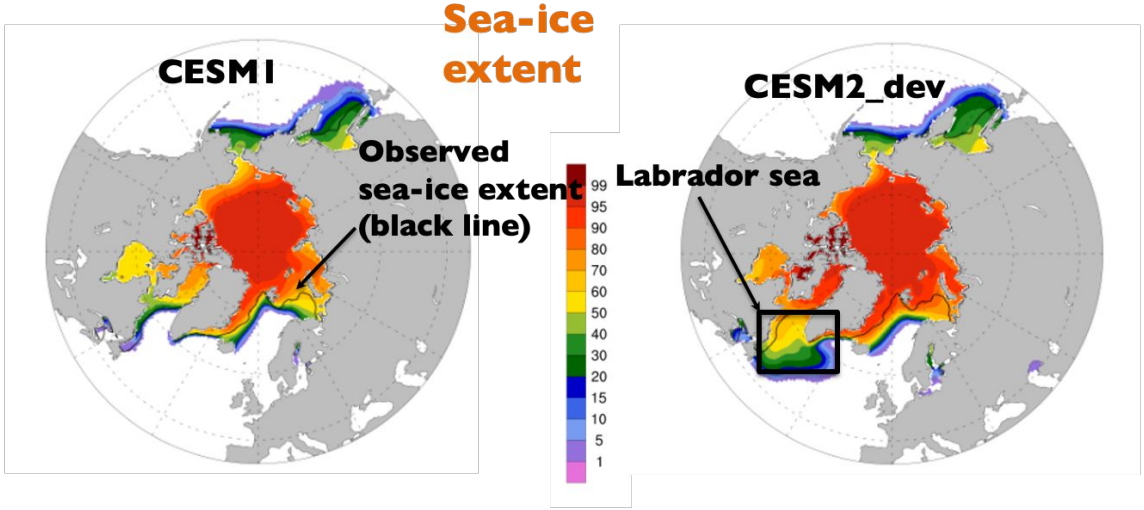
  => This talk and more at OMWG Thursday

(*) List not exhaustive

The lab Sea Freeze: a sticky challenge in CESM

The Labrador Sea issue (CESM2 development, 2016)

- The Labrador Sea was freezing in CESM2_dev.



Sea-ice extent is close to obs.
Labrador sea is ice free

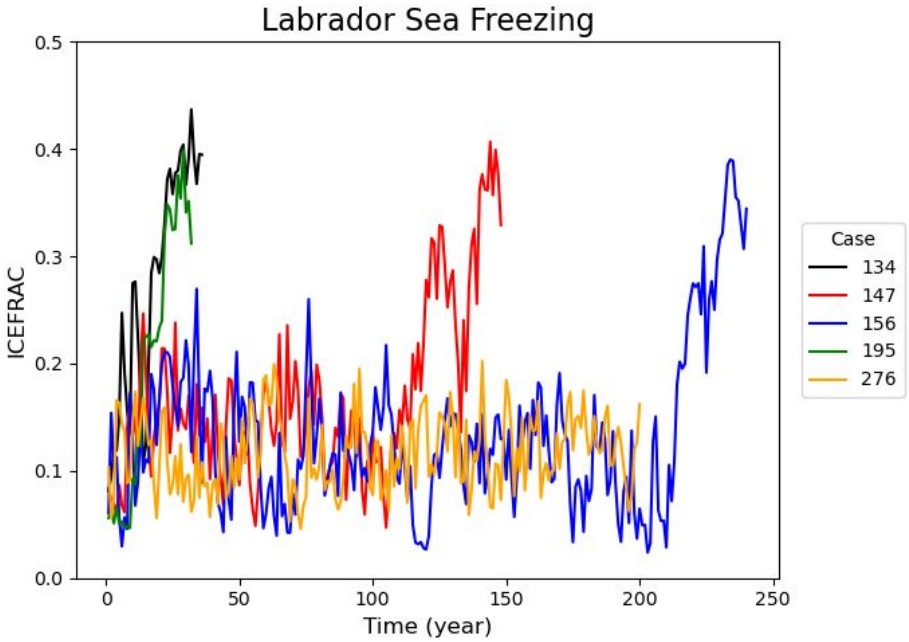
Labrador sea is ice-covered.

The frozen Lab Sea Issue re-emerges in CESM3

Frozen lab sea is difficult problem

- Freezing can occur after long periods
- Freezing timing is unpredictable (can happen after 20, 100, or even 200 years)
- Once frozen, the Lab Sea stays frozen (*)

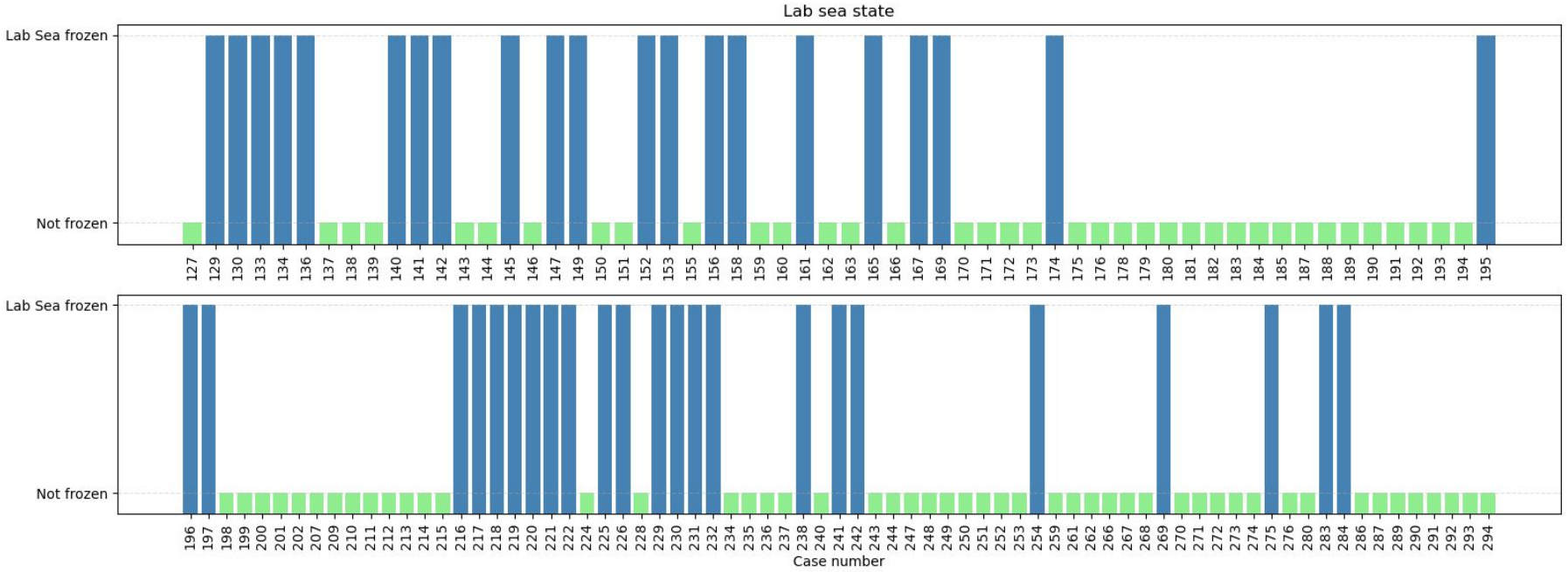
(*) this was true until …
(stays awake, it is coming in a couple of slides)



How often the lab sea freeze?

Key findings

Lab sea freeze in 30% of our development runs.
In the remaining 70%, all we could say: the lab is not frozen … yet.



How did we fix the lab sea issue?

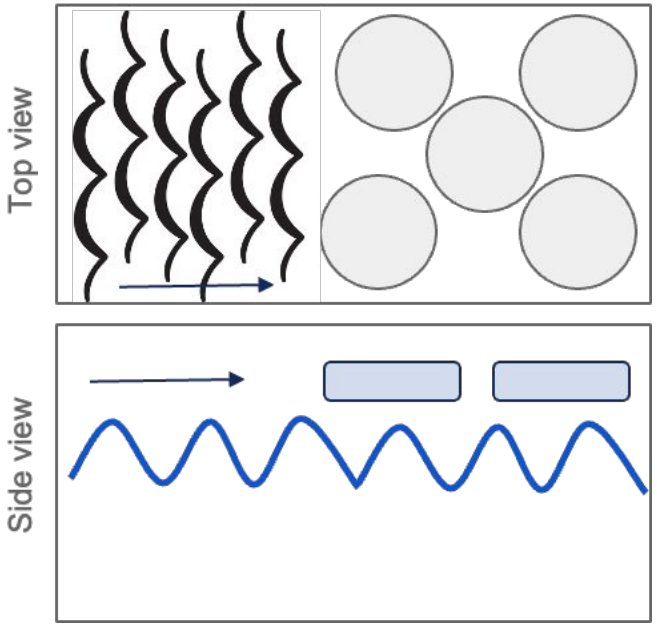
Only three things helped:

- The floe size distribution (FSD) parameterization
- Turn Bodner off in the lab sea
- Apply salinity restoring (not desirable - not covered here)

The prognostic floe size distribution (FSD)

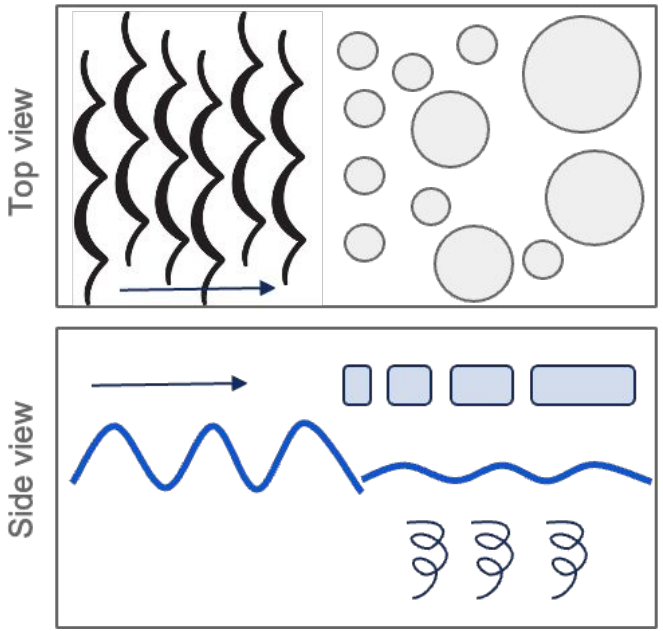
CESM2

Constant floe diameter: 300m
Ocean waves **not** damped by sea ice
Ocean mixing **not** impacted



CESM3

Prognostic joint floe size and ice thickness distribution
Ocean waves **are** damped by sea ice
Ocean mixing **is** impacted by waves



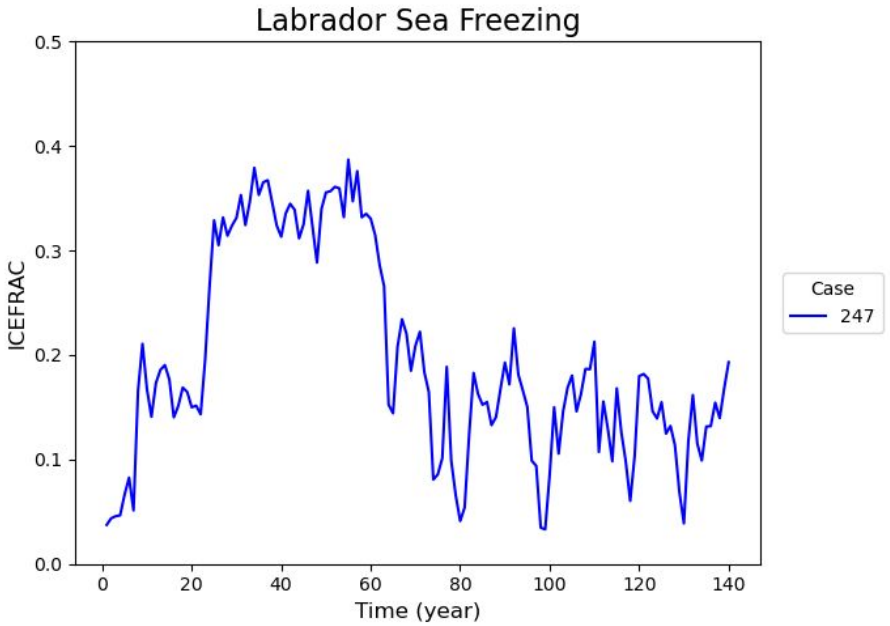
Impact on Ice

Wave breaks sea-ice
↓
More lateral melt
↓
More open water
↓
More waves

The Lab Sea with the Flow Size Distribution (FSD)

Typical behavior with FSD

- The model starts from a non-spun-up state
- Freezing occurs during spin-up
- De-freezing happens after spin-up
- ~~Once frozen, the Lab Sea stays frozen~~



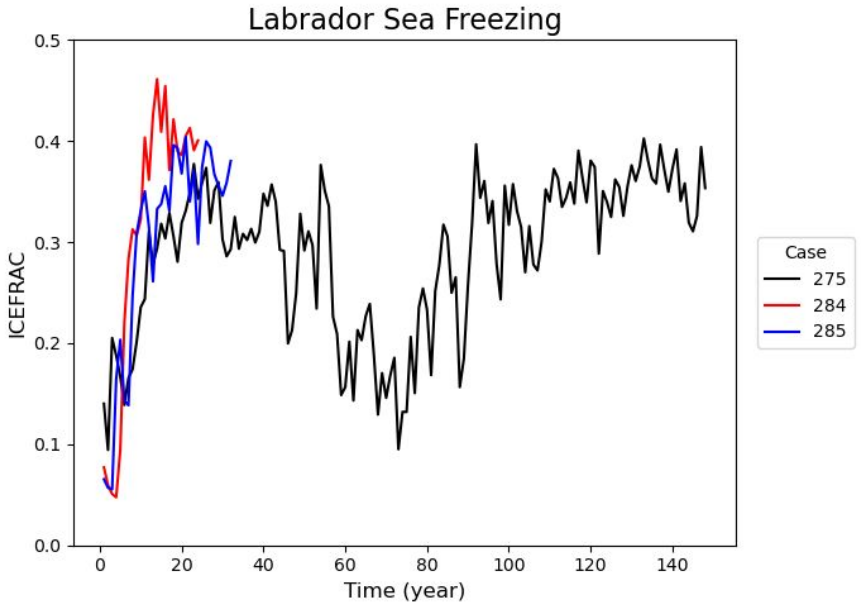
Impact of Bodner parameterization on lab sea

What is Bodner parameterization (2023)?

- Bodner is a mixed-layer eddy (MLE) scheme
- It controls how strongly ocean restratifies the ML and it opposes to deep mixing.
- Strength of the restratification increases when the ML depth increases

Why is the lab sea freezing with Bodner on ?

- In the Labrador Sea, mixed layers are very deep
- The restratification becomes too strong
- Convection is suppressed
- Heat stays trapped below
- Surface remains cold → sea ice grows

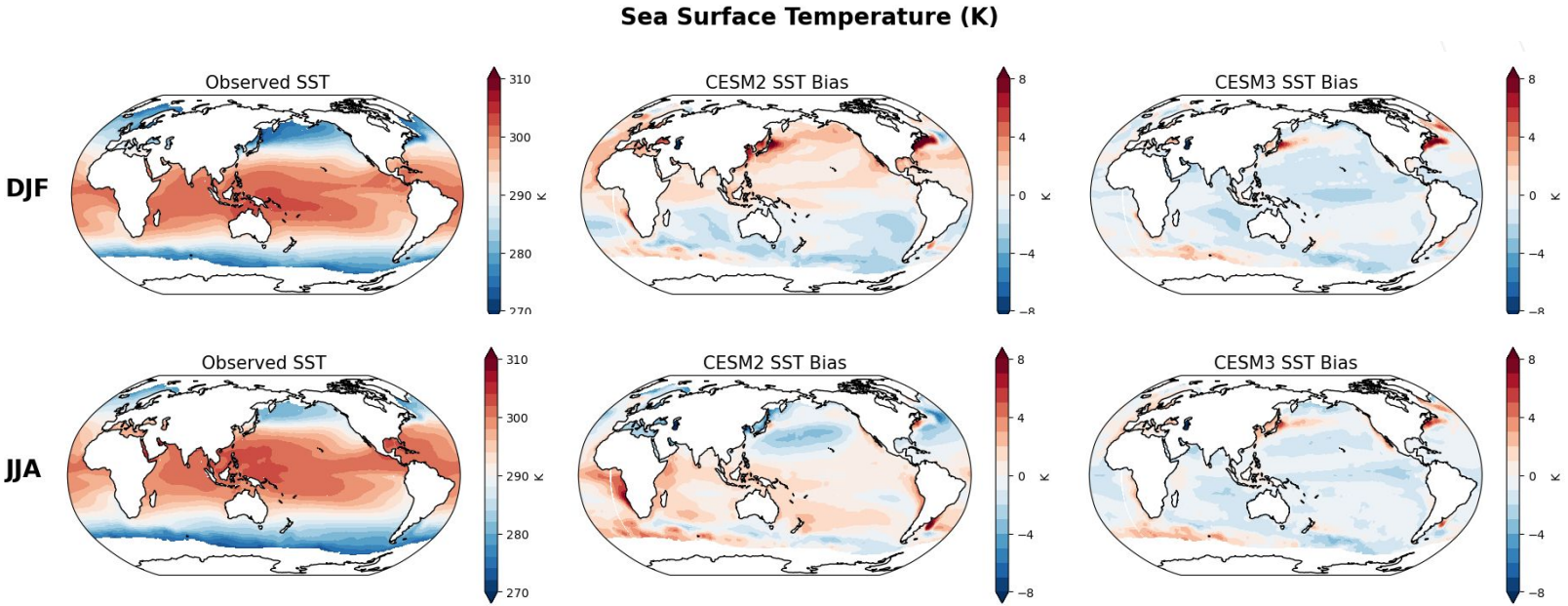


Thanks to Ian Grooms for upgrading my understanding of ocean mixing. Any remaining errors are mine.

A few key fields: Sea Surface Temperature (SST)

SSTs

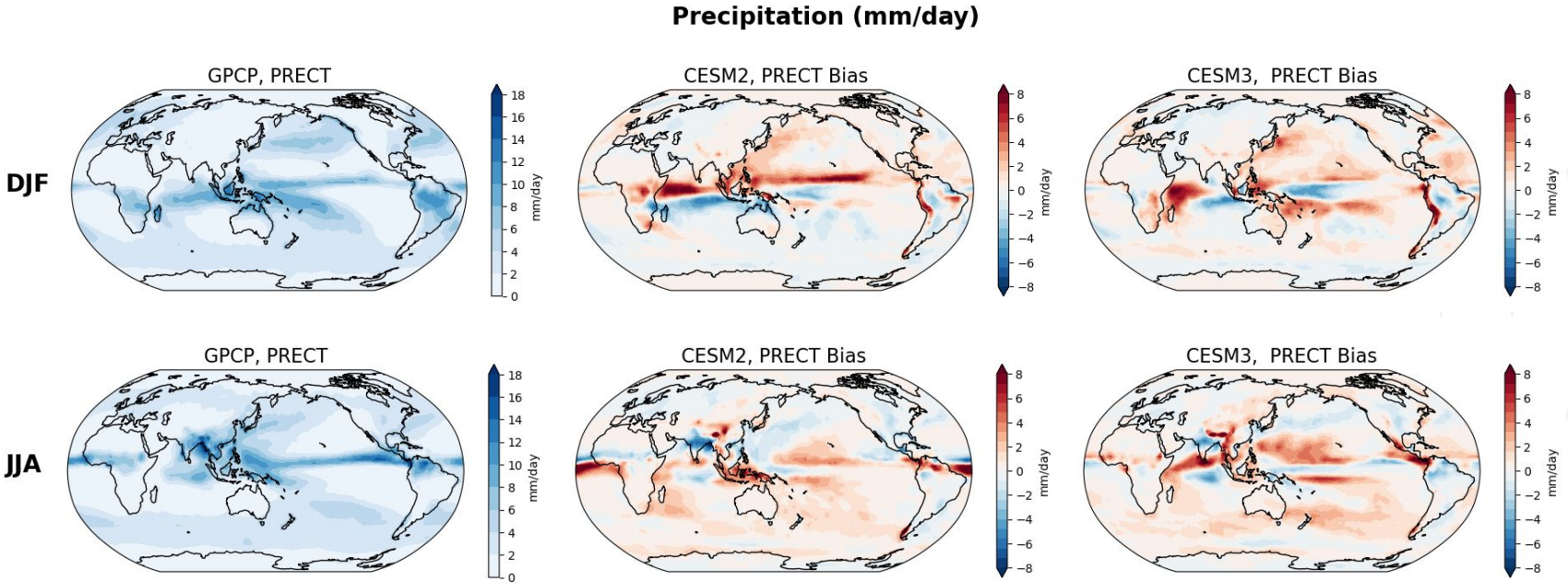
- Observations are from HadSST product (climo years: 1870-1890)
- For CESM, we used 10-year climos of pi control (climo years: 100-110)
- CESM3 pi control is overall colder than CESM2
- The hemispheric seasonal bias present in CESM2 is absent in CESM3.



A few key fields: Precipitation

Total Precipitation (PRECT)

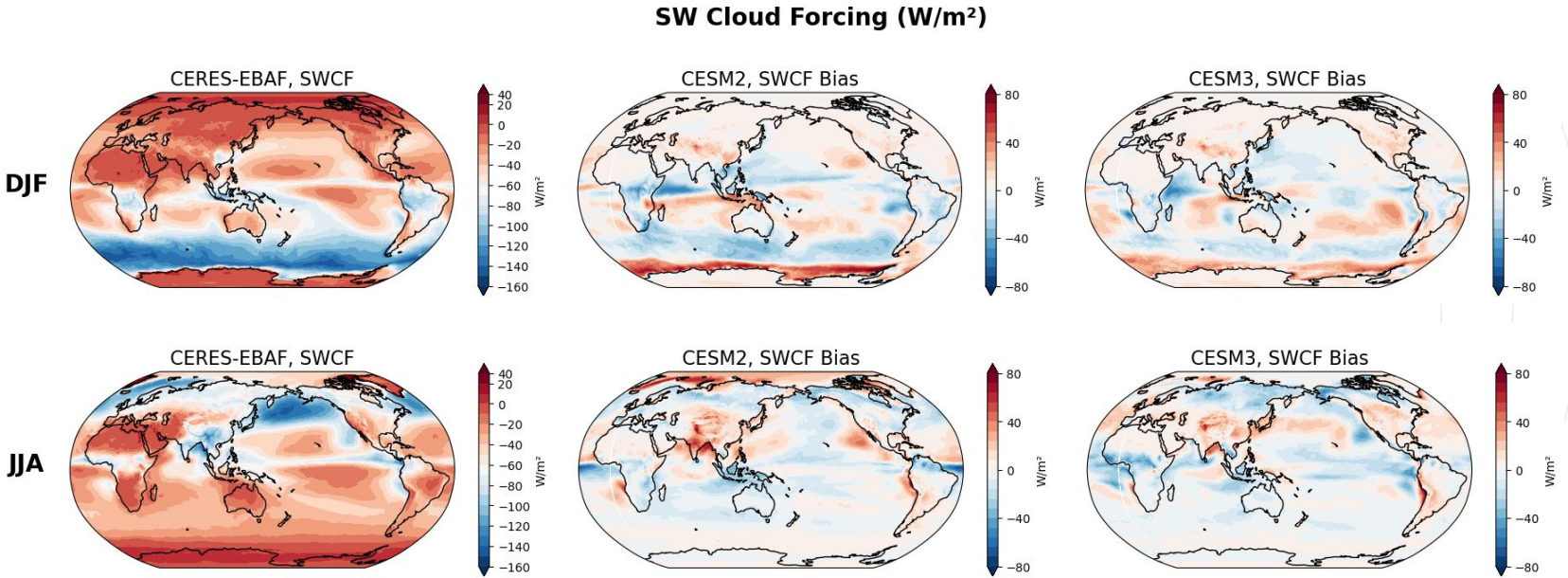
- Observations are from GPGP product (climo years: 2000-2010)
- For CESM, we used 10-year climos of pi control (climo years: 100-110)



A few key fields: SWCF

Shortwave cloud forcing (SWCF) (PRECT)

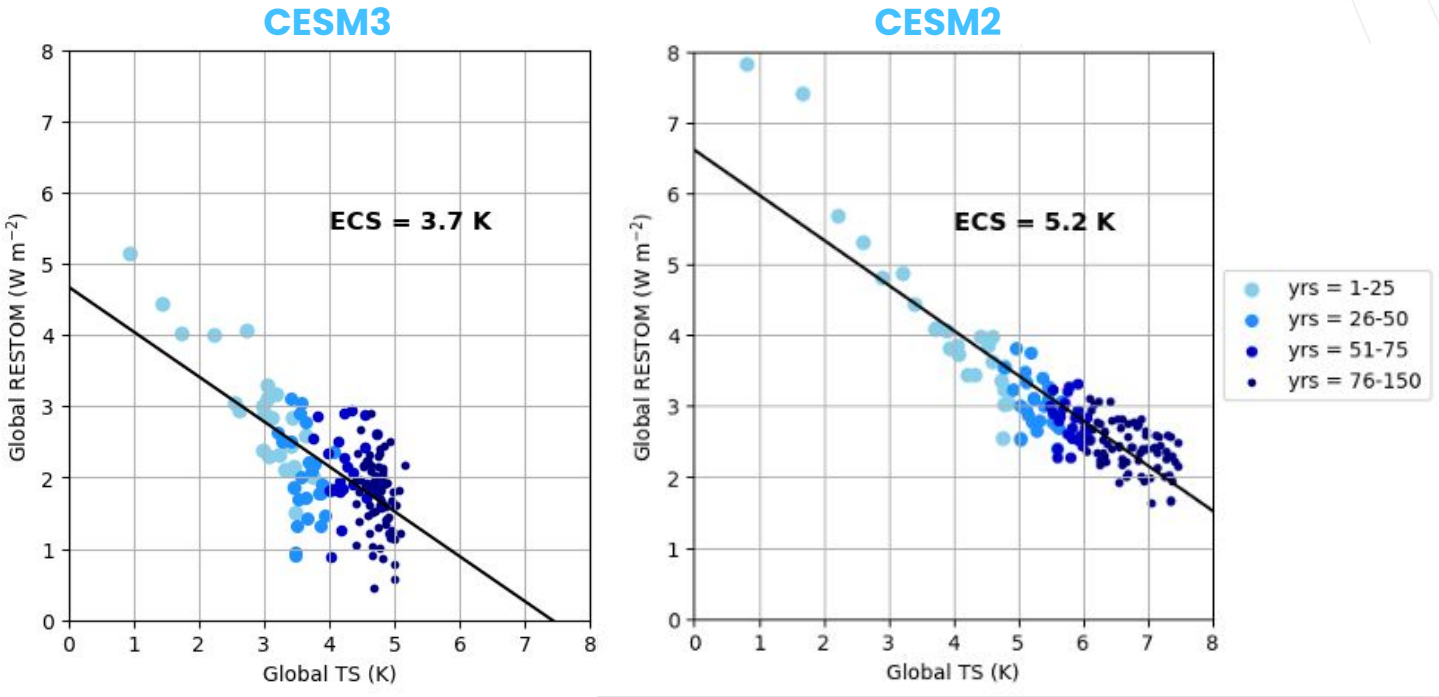
- Observations are from CERES_EBAF_Ed4.1 product (climo years: 2001-2020)
- For CESM, we used 10-year climos of pi control (climo years: 100-110)
- Stratocumulus are quite different in CESM2 and CESM3



Equilibrium Cimate Sensitivity (ECS)

ECS is reduced in CESM3 compared to CESM2

Attributed to MG2->PUMAS: Remove inappropriate ice number limiter + improvements (missing processes, …)



Aerosol Effects

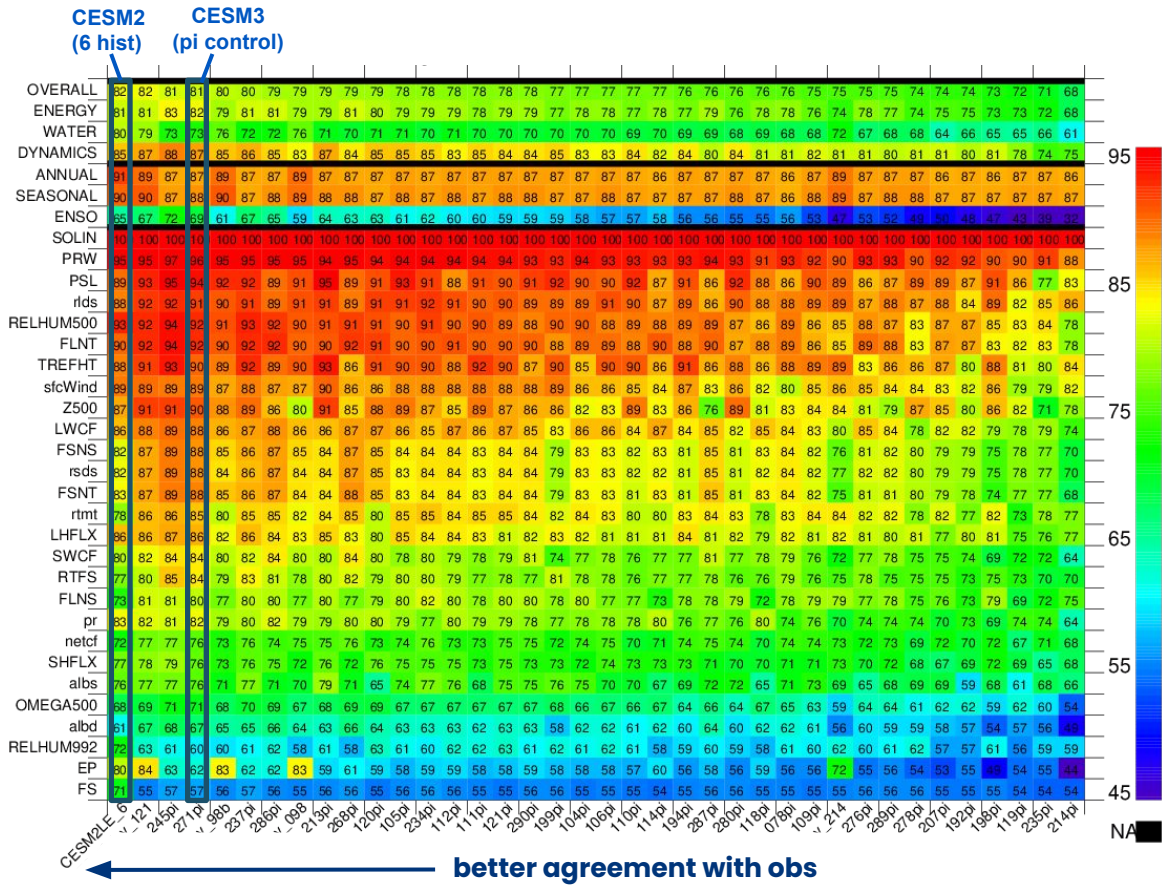
To estimate the aerosols effects

We ran **F cases** with **pre-industrial aerosols (pia)** versus **present-day aerosols (pda)**

- RESTOM(pda) - RESTOM(pia) -> **total aerosol effect** (aka “effective radiative forcing due to aerosols”)
- SWCF(pda) - SWCF(pia) -> **Cloud albedo effect** (1st indirect effect)
- LWP(pda) - LWP(pia) -> **Cloud lifetime effect** (2nd indirect effect)

	cesm3	cesm2	estimate
total aerosol effect	-0.7 W/m2	-1.6 W/m2	-1.01 ±0.23 W/m2 (CMIP6 estimate)
Cloud albedo effect (1st indirect effect)	-0.9 W/m2	-1.7 W/m2	-0.7 ± 0.5 W/m2 (CMIP6 estimate)
Cloud lifetime effect (2nd indirect effect)	0.6 g/m2	4.4 g/m2	

The Climate Model Assessment Tool (CMAT)



How is CESM3 scoring?

- Preliminary analysis (cesm3 pi ⇔ cesm2 hist)
- cesm3 (271) competitive with cesm2 (better radiative fluxes and dynamics but worse water cycle fields)
- Some development runs scores poorly because poor ENSO teleconnections (weaker Niño3.4 SST variance).

Plot courtesy of John Fasullo
CMAT reference: Fasullo et al,. 2020 GMD.

Taylor diagrams

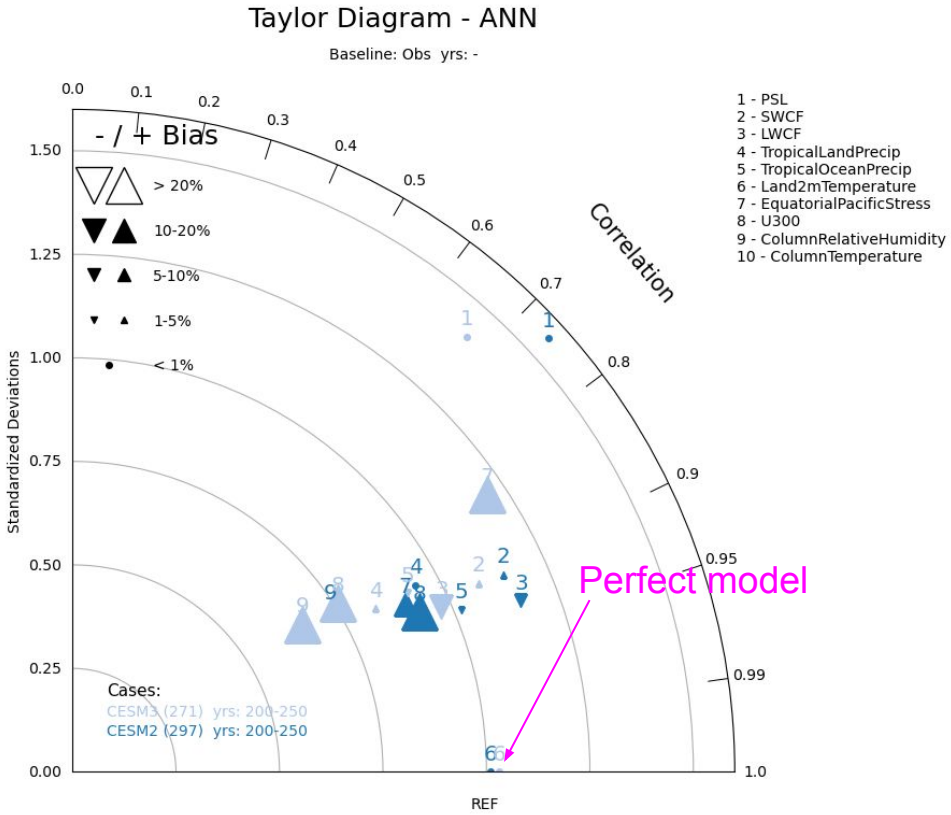
The return of Taylor Diagram (season 2)

Brian Medeiros is reviving the beloved Taylor diagram that was in the AMWG diagnostics.

How to read it:

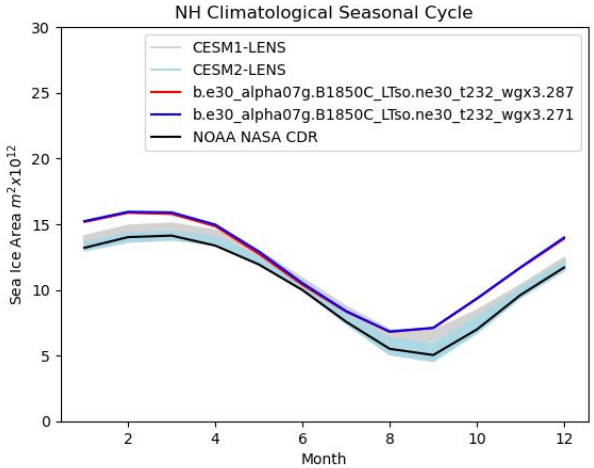
The Taylor diagram provides a compact **summary of model performance** (relative to observations).

- **Bias** -> size of symbol.
  (Larger symbol = larger mean bias)
- **Correlation** → represented by angle
  (closer to the x-axis = higher correlation)
- **Standardized deviation** -> radial distance
  Measure of model's annual cylce compared to observations. Value of 1 = correct annual cycle.

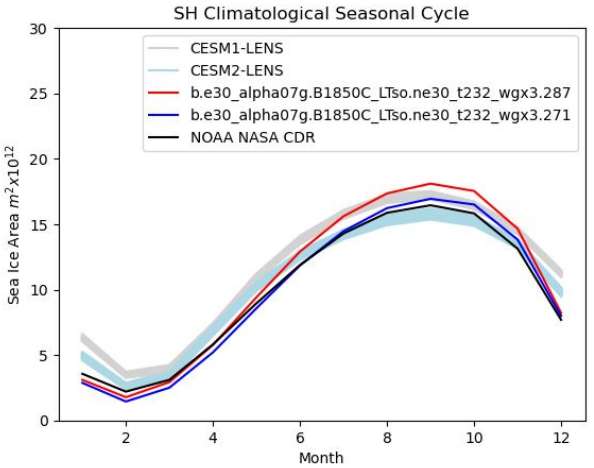


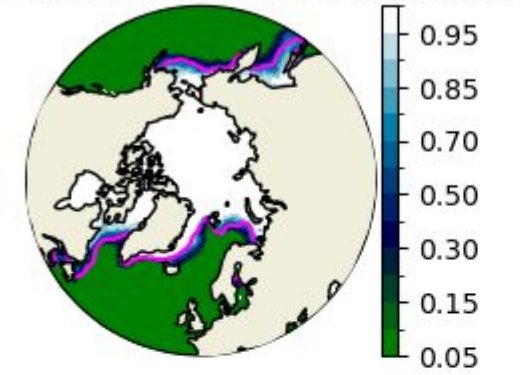
Plot courtesy of Brian Medeiros

Sea-ice climos and seasonal cycle



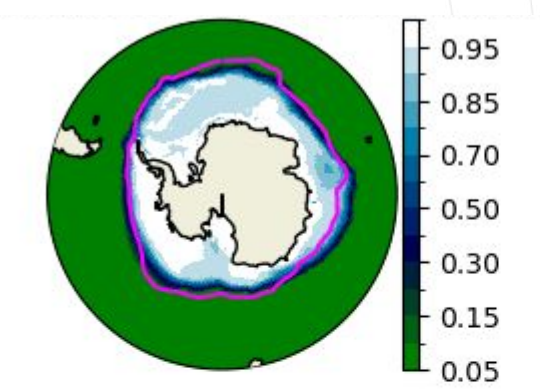
Focus on
287





Annual Mean
Sea Ice
Concentration

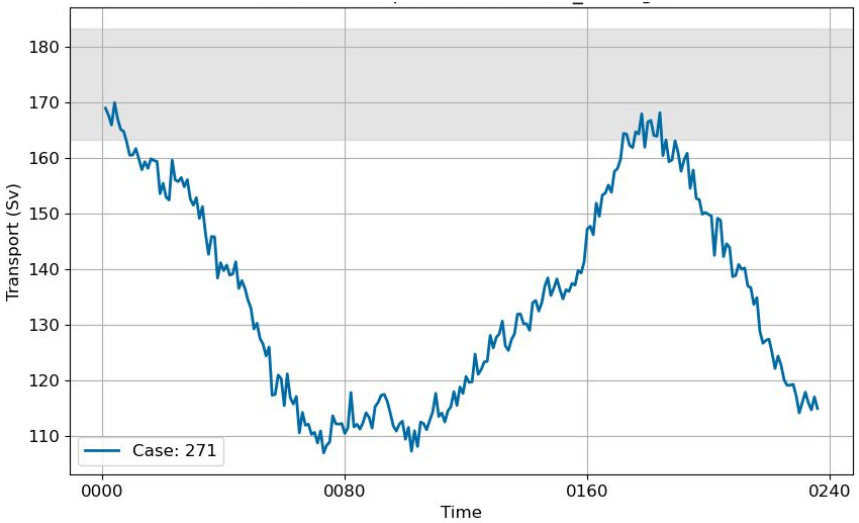
287



Courtesy of Alice DuVivier and Dave Bailey

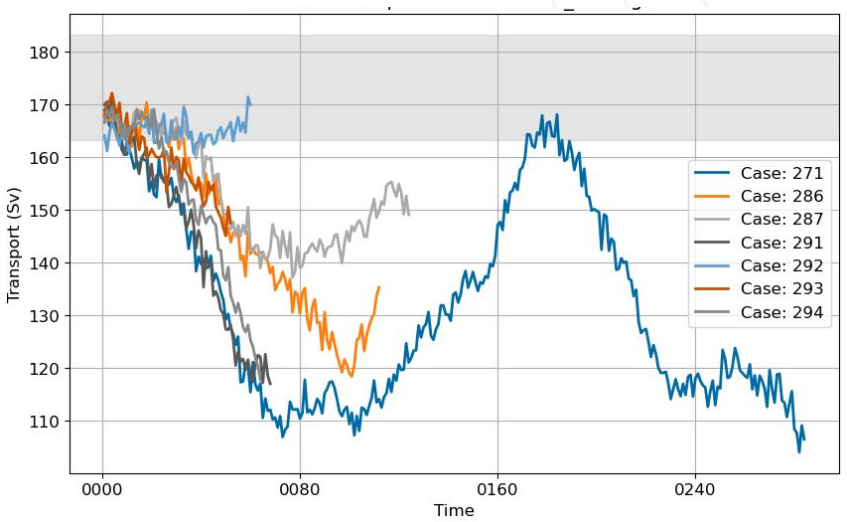
Antarctic Circumpolar Current (ACC) transport

ACC transport



Excessive multi-decadal variability in Southern Ocean

GM coefficient impact on ACC

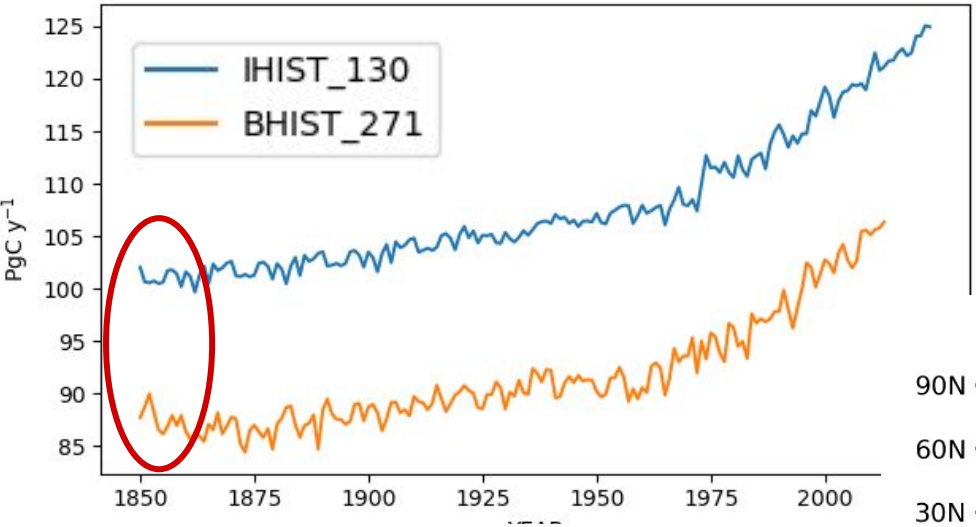


Reducing GM reduces the strength of the ACC

Plot courtesy of Gustavo Marques, Ian Grooms & Mike Levy

Land carbon cycle in CESM3 climate

Global plant productivity

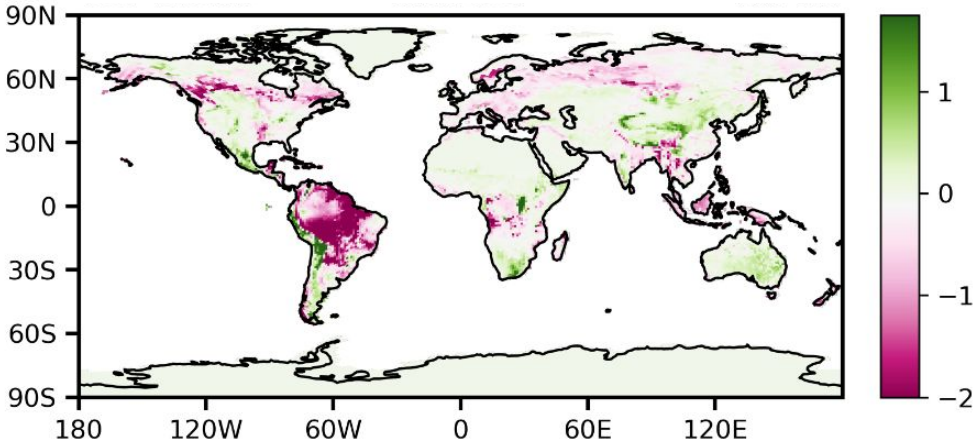


Warm Temperatures
+ Low humidity
Low Leaf Area in Amazon
Low plant growth, globally

Working on tuning land parameters to simulate reasonable carbon cycle.

Plot courtesy of Will Wieder

ELAI differences (BHIST-IHIST)



cesm3 workflow

What to expect for cesm3?

```
./create_newcase --case $case --compset $compset --res $res --workflow
```

workflow

- run cesm
- short-term archive: move files from run to archive directory
- timeseries: create single variable timeseries from history file
- cupid diagnostics: run diagnostics package
- cmorization: translate to cmor variables

Jim Edwards (workflow)

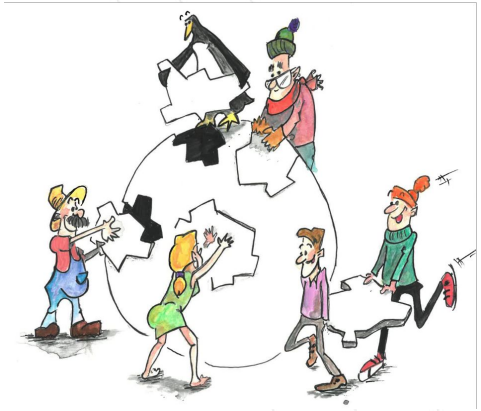
CESM project meeting and development team

Project Meeting: Tuesday at 10am in the director conference room and online.

(*) Smaller group than usual since this was not our regular Tueday 10 a.m. time slot.

Conclusions

- It takes tons of **time and work** to build a coupled model.
- The **CESM development team** is working very hard on that.
- The **CESM3 physics configuration** is set but we are ironing out last details & tuning for reasonable cloud forcing and top of the model radiative balance.
- Once this is compled, we will start the long **CESM3 spinup procedure**.
    - Create ICs (from separate offline simulations ocean/ice/waves and land)
    - Produce chemistry & surface forcings (MTt4s run)
    - Long ocean spimup (to reach minimal drift)
    - BGC spinups (using coupled output)
    - MTt4s adjustment run
    - pi control + 20th century
    - emissions driven runs
- **Target date for release**: June 2026 but in model development world, deadlines are never fully guaranteed.



Questions ?

Image credit:
Kolya Dols

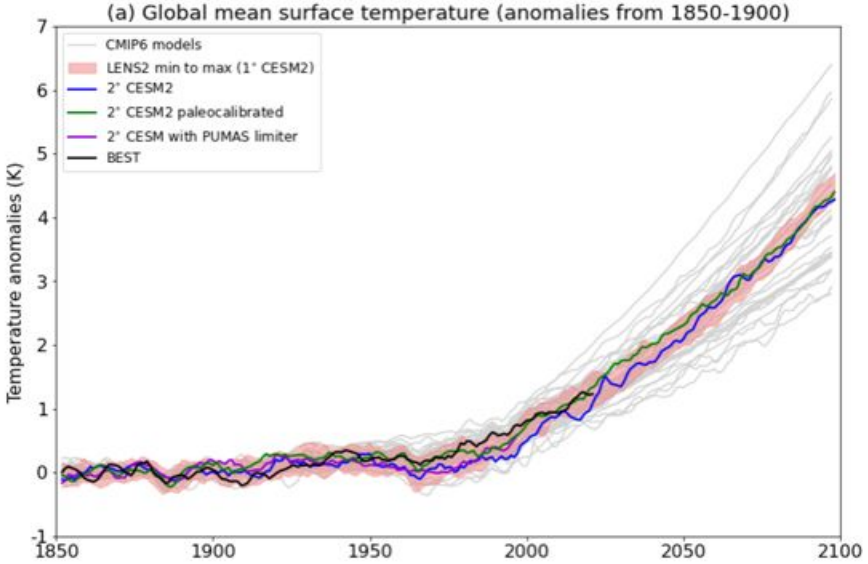
ECS / microphysics commentary manuscript

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



Accepted to JAMES

Aerosols effects (Discussion: #768)

To estimate the aerosols effects, we ran FHIST_LTso simulations with pre-industrial aerosols (pia) versus present-day aerosols (pda)

- 271_pda -> f.e30_cam6_4_142.FHISTC_LTso.ne30.271_pda.001 #764
- 271_pia -> f.e30_cam6_4_142.FHISTC_LTso.ne30.271_pia.001 #765

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