The state of GFDL's CM4

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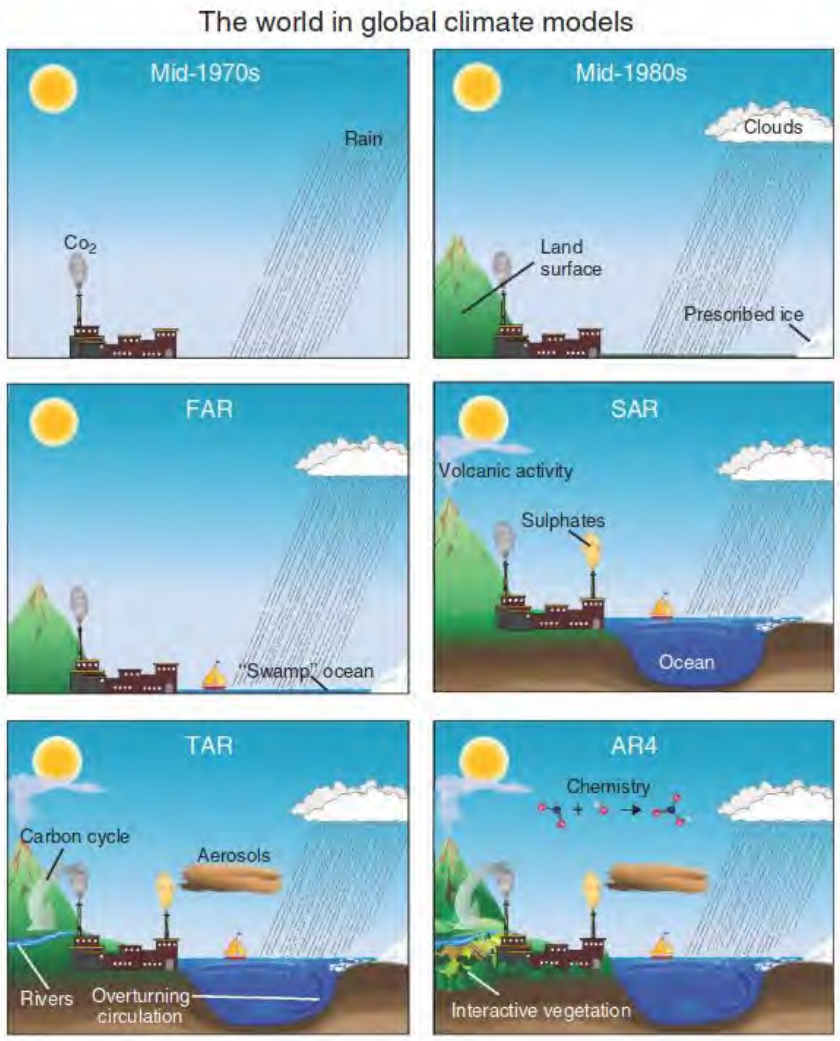
Material from this slide series: GFDL's Coupled Working Group, Atmosphere Workng Group, and Ocean Working Group, especially Mike Winton, John Dunne, and Andrew Wittenberg

An over of the Coupled Model Intercomparison Project

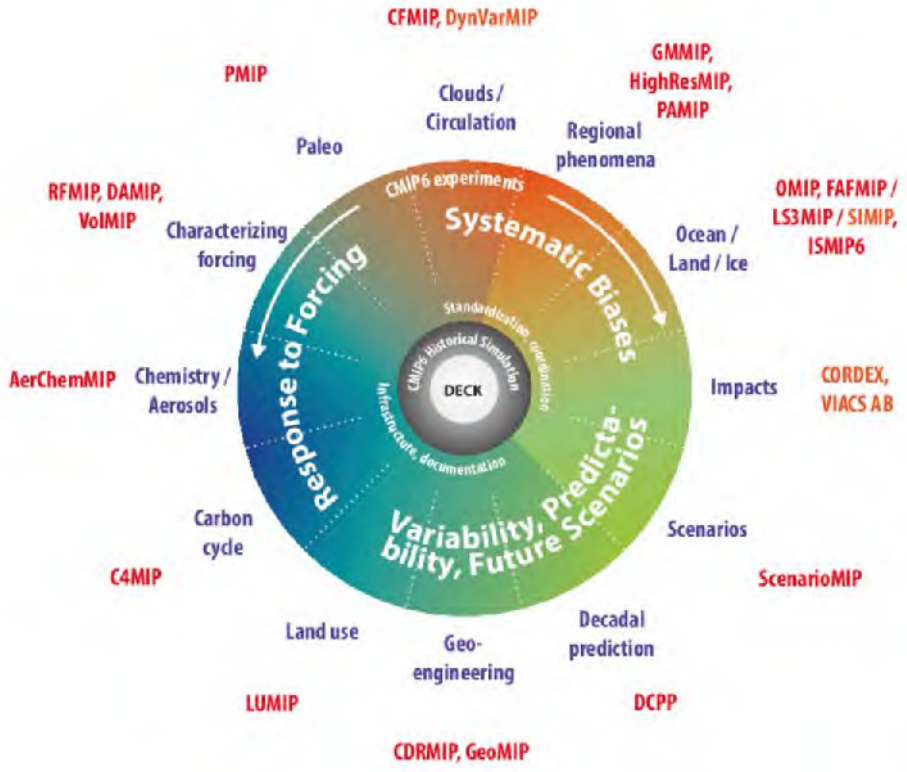
- Began in 1995 under the World Climate Research Programme
- Key component of the Intergovernmental Panel on Climate Change's assessment reports
- Each phase has seen significant improvements to each model component
  - Increasing complexity
  - Resolution
  - Physics
  - Biogeochemistry



IPCC AR4

CMIP6 design and accompanying MIPs

- For CMIP, models must run the DECK experiments (Diagnosis, Evaluation, and Characterization of Klima)
  - AMIP (1979-2014
  - Pre-industrial control
  - 1%/yr CO2 increase
  - Abrupt 4x CO2
- If participating in a CMIP6-endorsed MIP
  - Must also do historical run with prescribed forcings (1850-2014)
- At least 33 models (13 new participants)



GFDL model components

Atmospheric Model 4.0
Documented Zhao et al. [2018ab]

- Finite volume, cubed sphere dynamical core
- Lagrangian vertical coordinate
- New convection parameterization
- Orographic wave drag

Land Model version 4.0

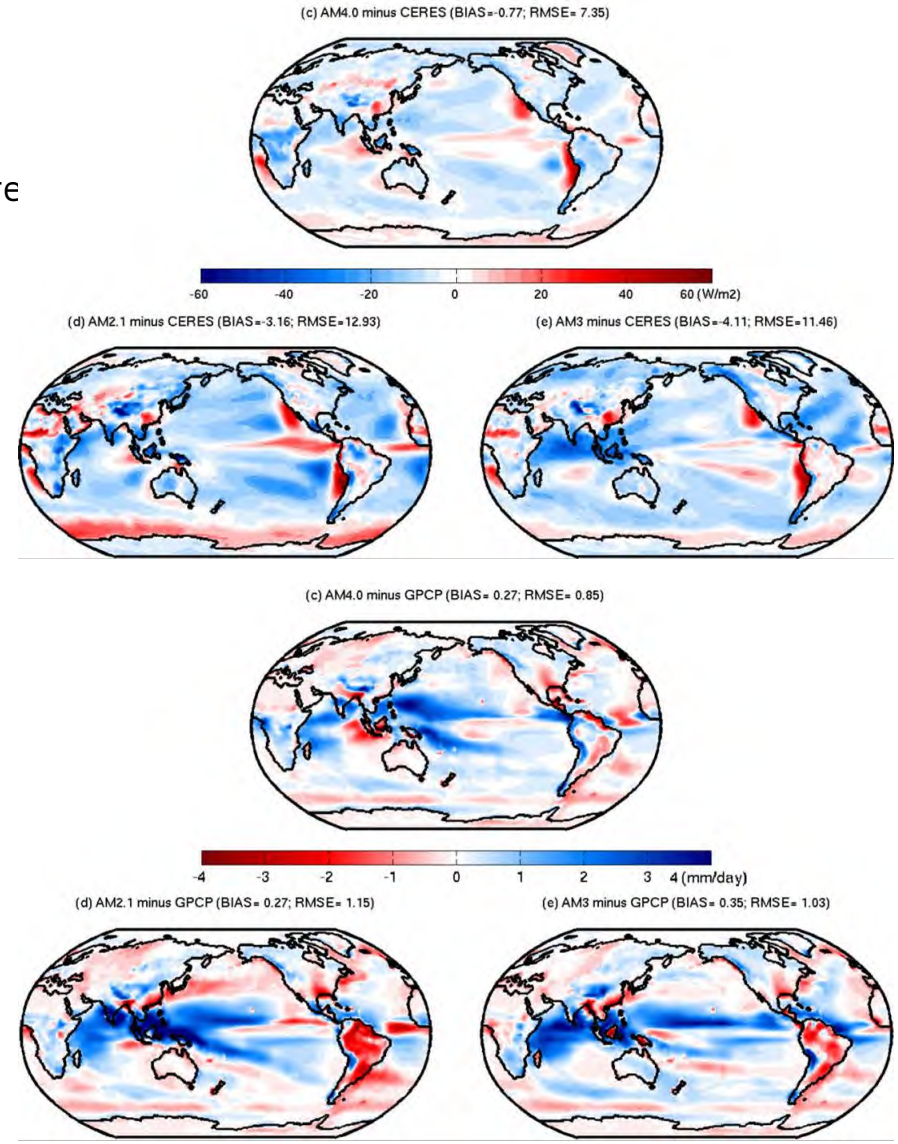
- Prescribed land use
- Seasonal vegetation

Sea-ice Simulator version 2

- Enthalpy conserving
- C-grid formulation

Modular Ocean Model version 6

- Arbitrary Lagrangian-Eulerian
- Depth-isopycnal hybrid coordinate
- 75 vertical levels



GFDL's two contributions

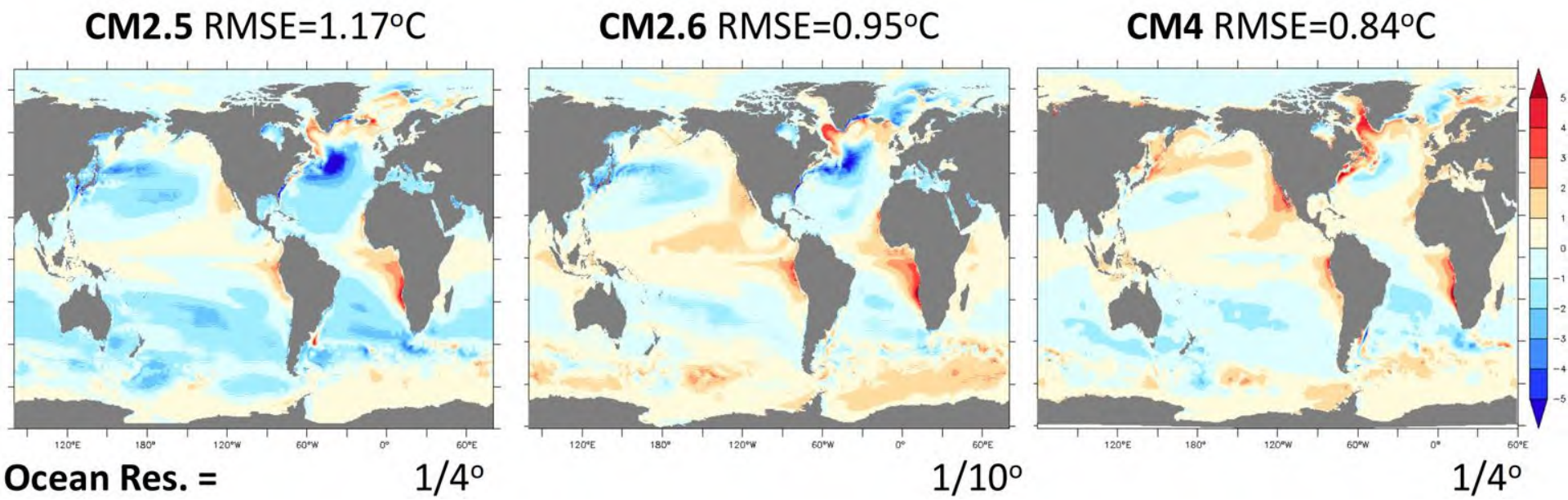
Coupled Model 4.0
Frozen in spinup phase

- 'High' resolution
- AM4
  - 100km horizontal (compared to 250km)
  - 33 vertical levels
  - "Light" atmospheric aerosols
    - 21 tracers
- MOM6
  - 0.25 degree ocean
- Ocean biogeochemistry
  - BLING version 2
    - 6 tracers

Earth System Model 4.0
In development

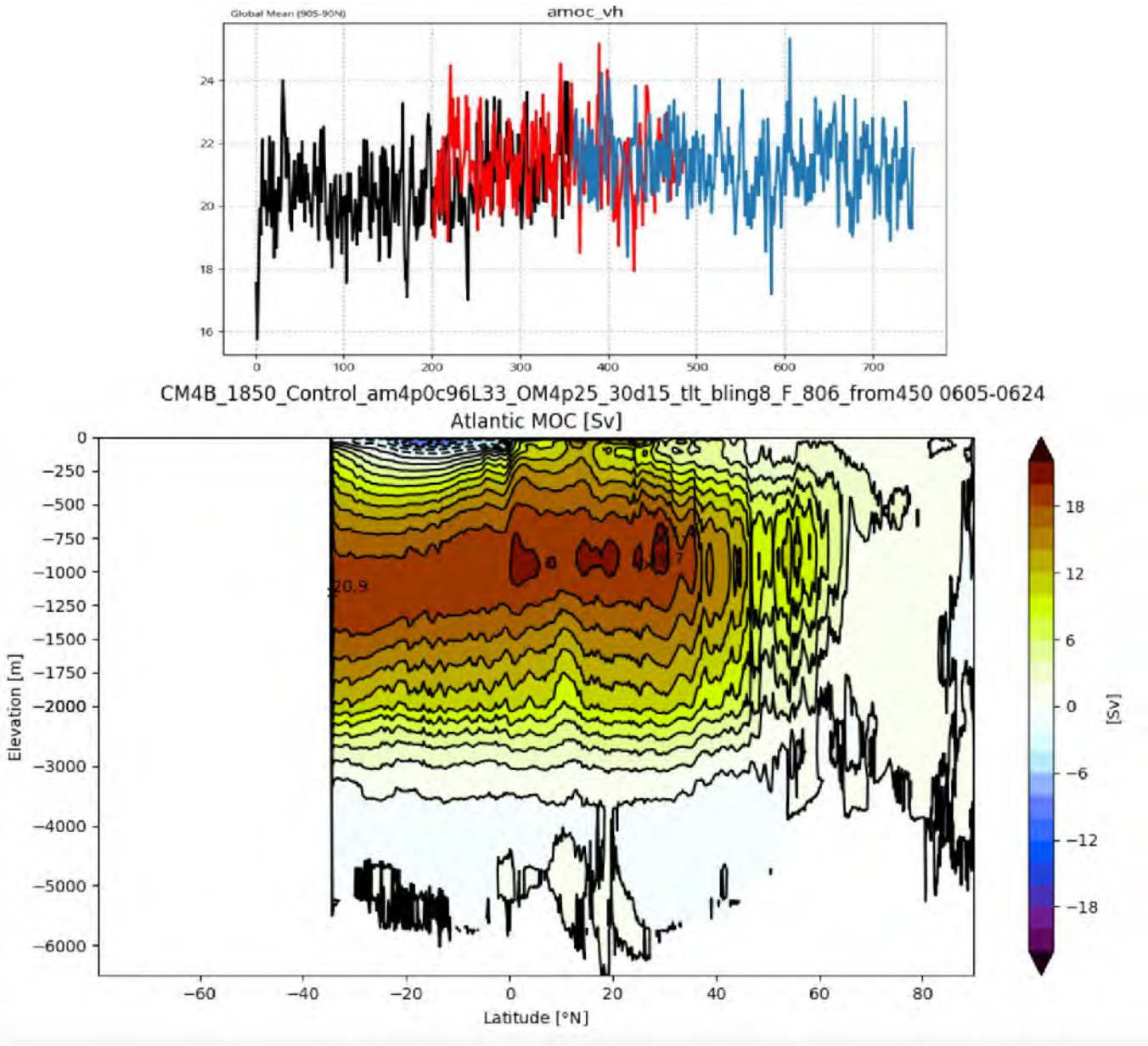
- 'Lower resolution' physics
- 'Better resolution chemistry/biology
- AM4
  - 49 levels
  - Aerosols and Ozone Chemistry
  - 103 tracers
- MOM6
  - 0.5 degree ocean
- COBALT v2
  - 30 tracers

CM4 is now GFDL's best model (for SST)

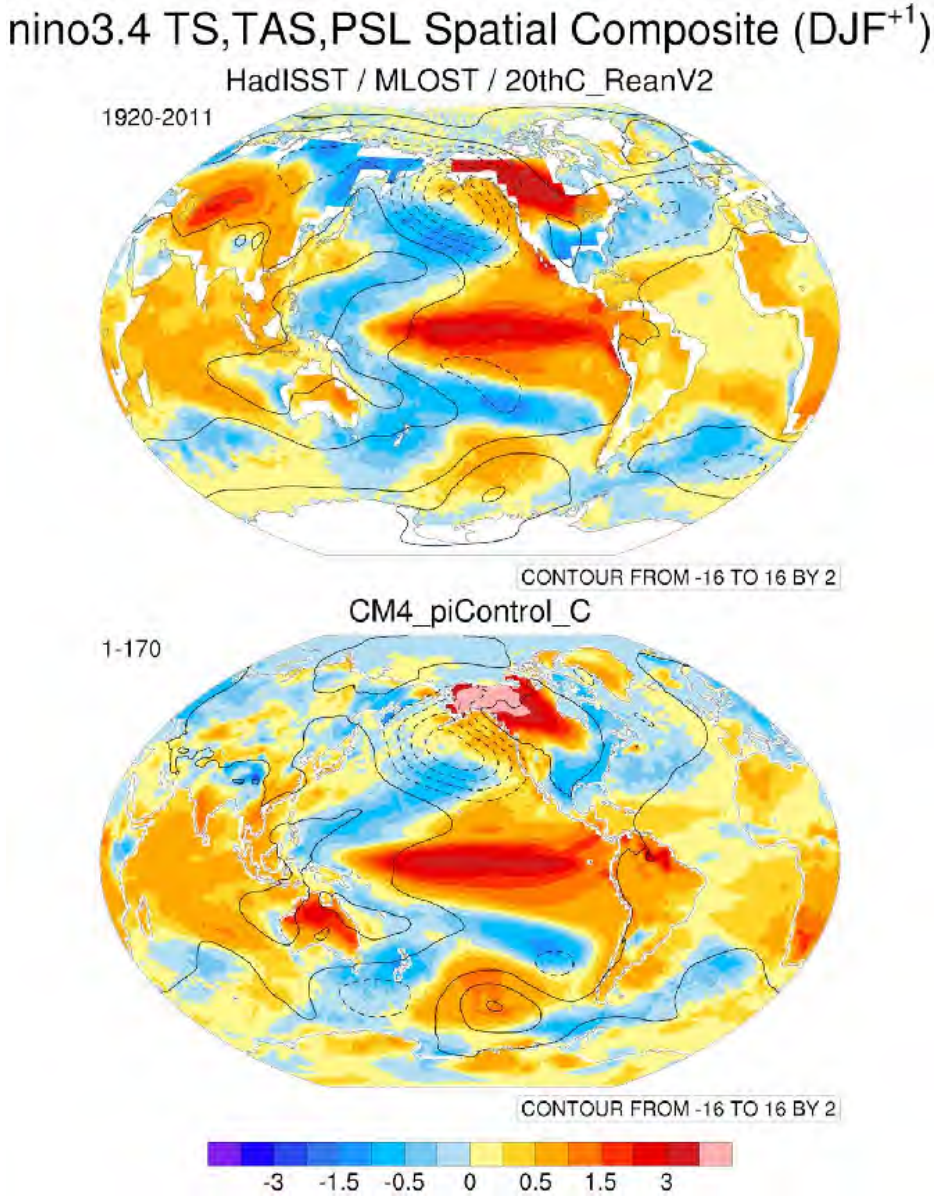


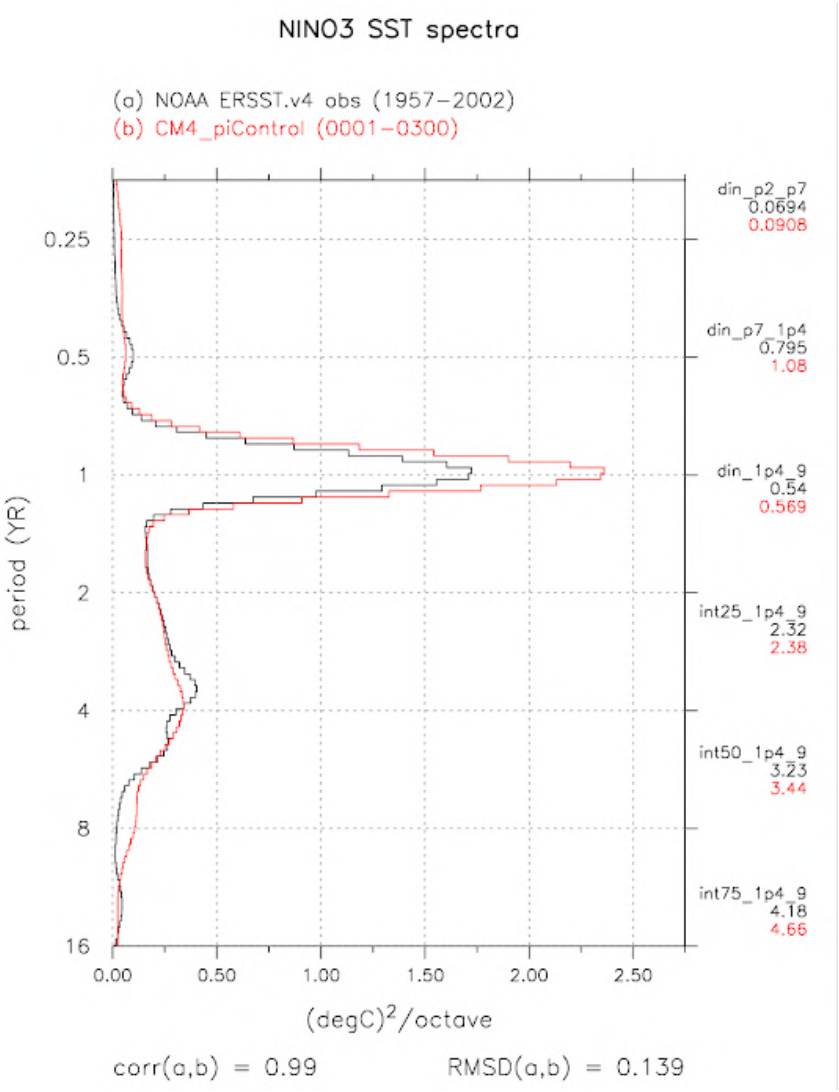
- CM2.6 was an eddy-resolving model, previous best
- CM4, despite being lower resolution outperforms CM2.6
  - On the oceanside perhaps due to
    - Boundary layer model
    - Better parameterizations
- Expect to see even better improvements with higher resolution

Strong, stable AMOC

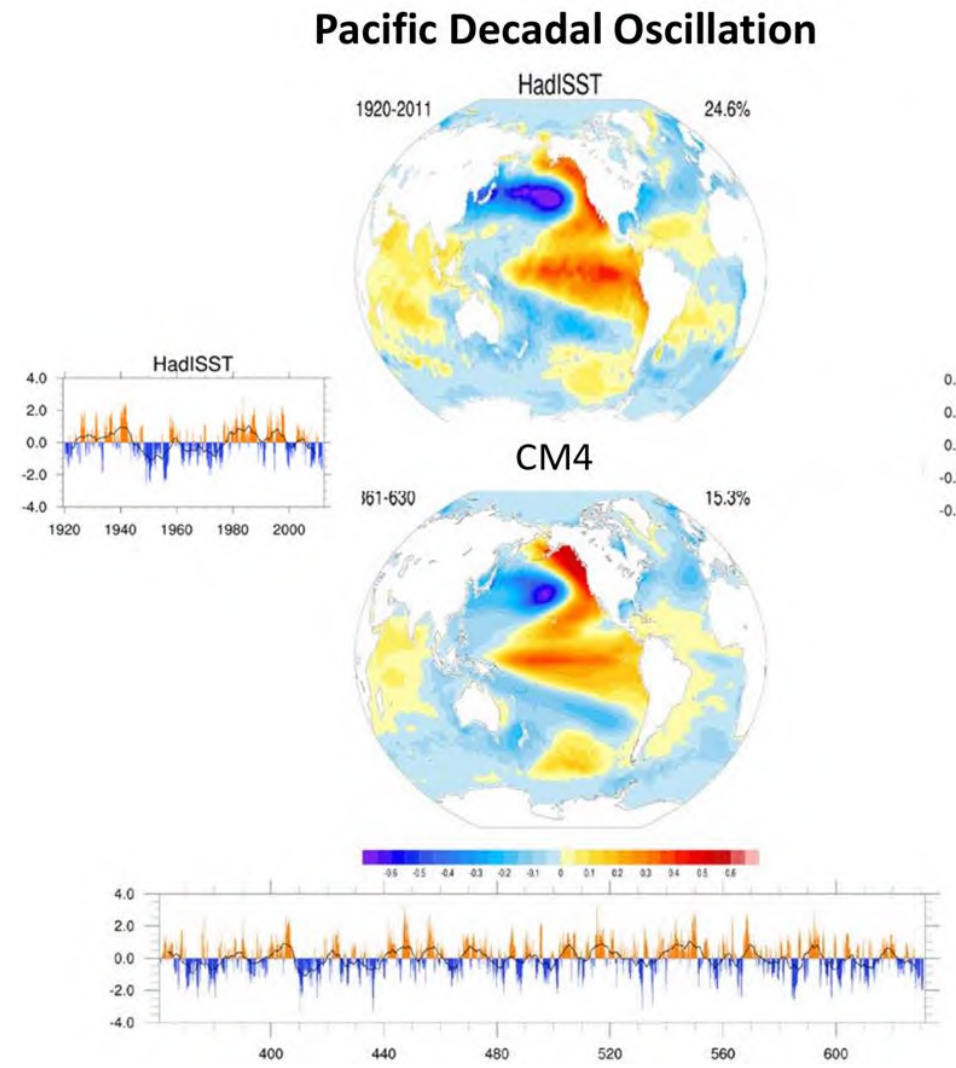


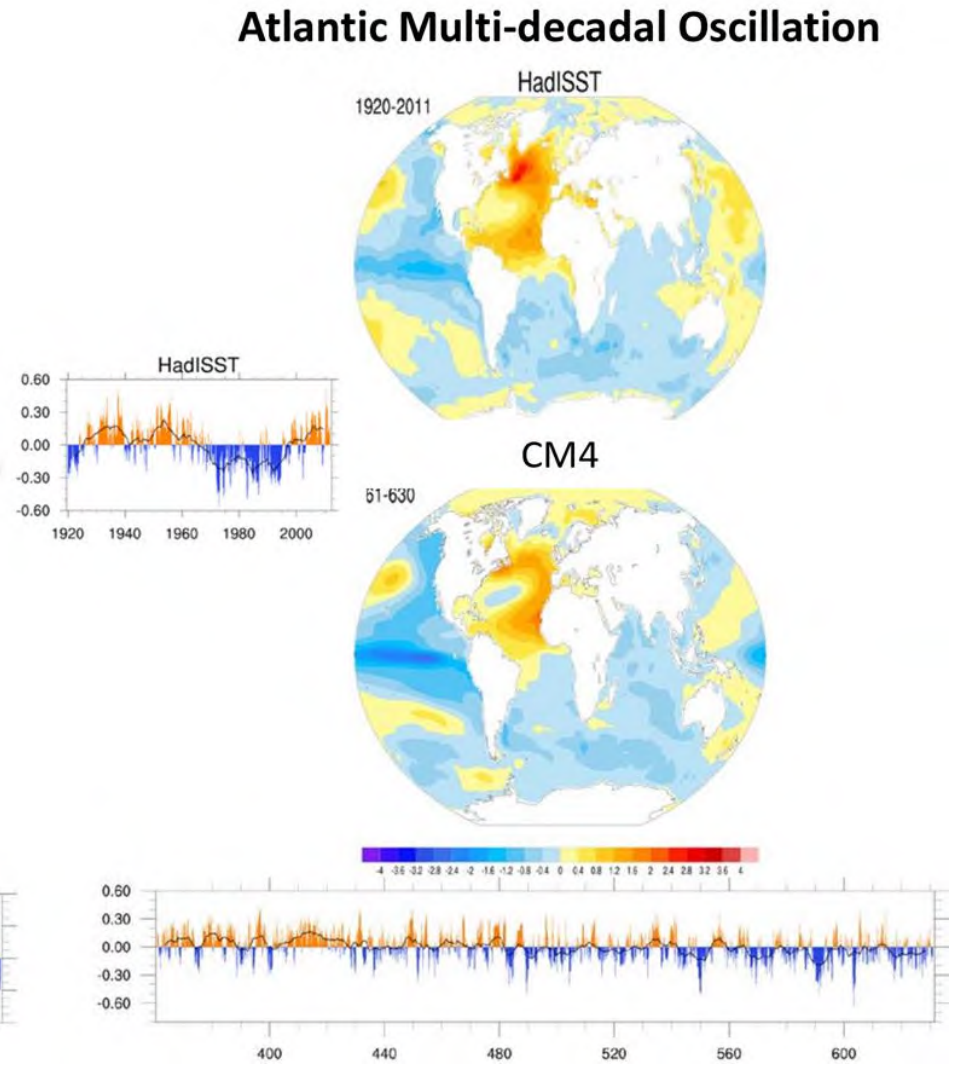
Representation of ENSO



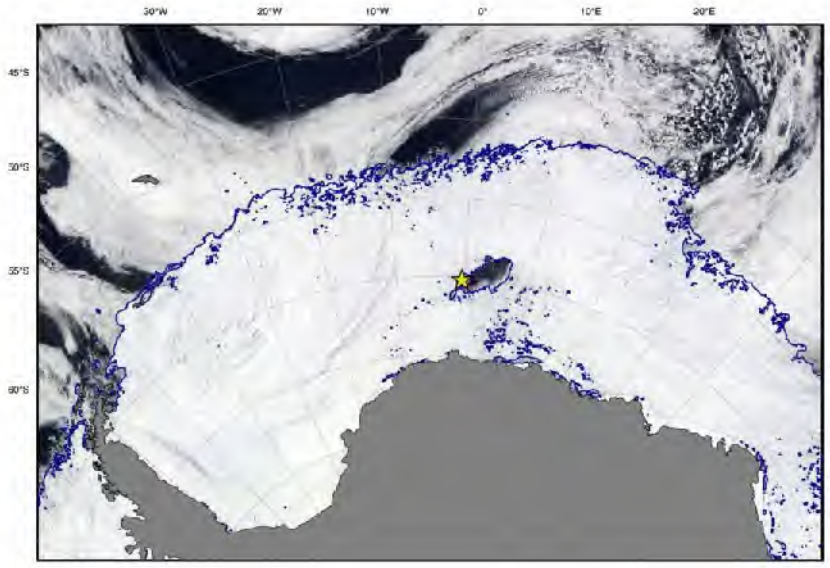


Other modes of climate variability





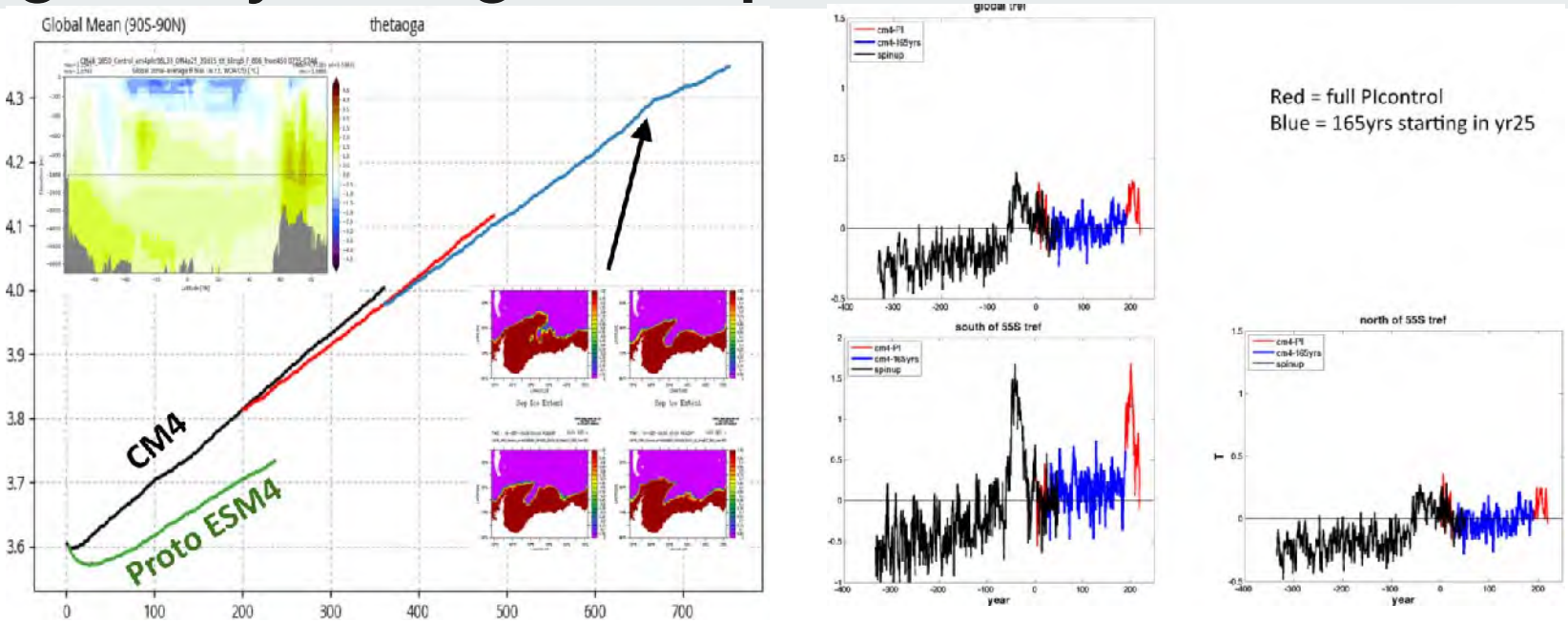
CM4's Original main problem: Super-polynyas



Last year a polynya observed in the Weddell Sea

- Polynyas are a natural climate phenomenon
  - Two observed in the past century
- Characteristics
  - Katabatic winds off Antarctica open a hole in the sea ice
  - Buoyancy loss to the atmosphere
  - Breaks through weak halocline
  - Deep convection releases stored heat in the ocean

Effect of super-polynyas can be seen in globally averaged temperature

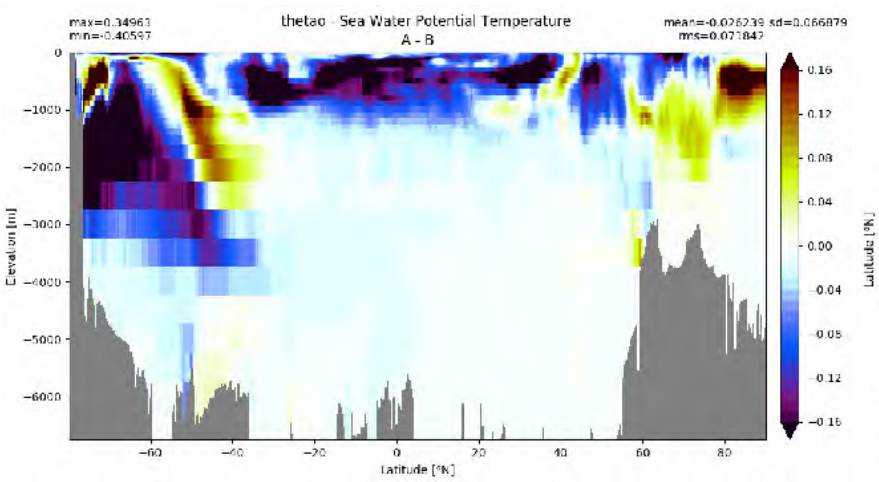


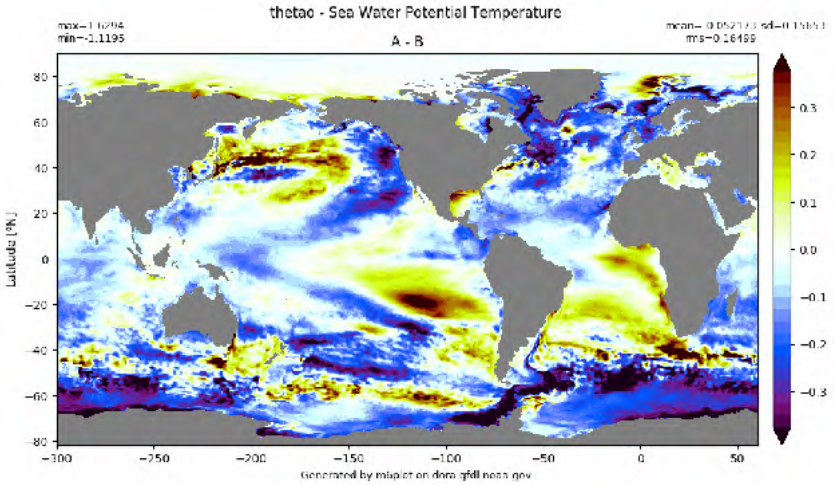
- Original thought: 1st super-polynya was a one time event (adjustment)
- Later two more showed up, one even bigger than the first
- From a climate perspective, physically unjustifiable
  - Risky to do historical and climate change scenarios
- Pre-polynya, oceanic heat uptake much lower than CM2.5
- Remaining biases due to model not representing deep water formation
- Super-polynya solution came from Seasonal-to-Decadal Prediction Team
  - Change one parameter: Increase snow-on-ice albedo

Salinity and temperature with the albedo change

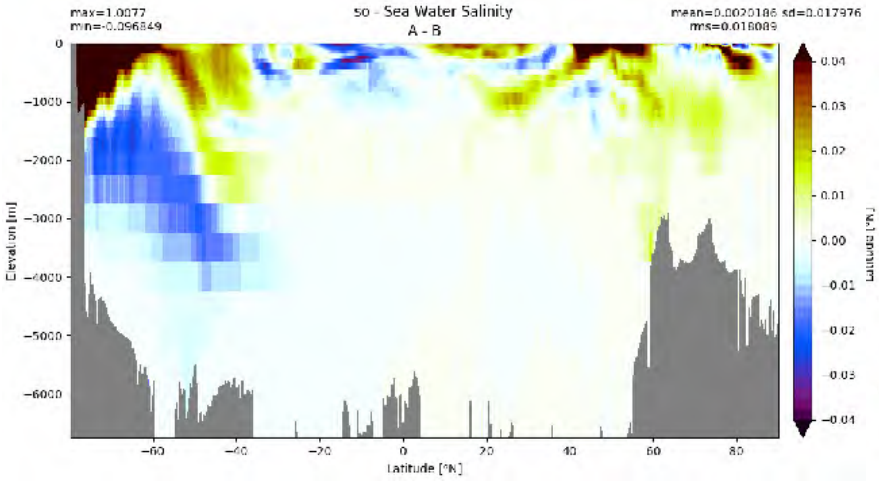
Difference between Run C (albedo change) - Run A (prototype)

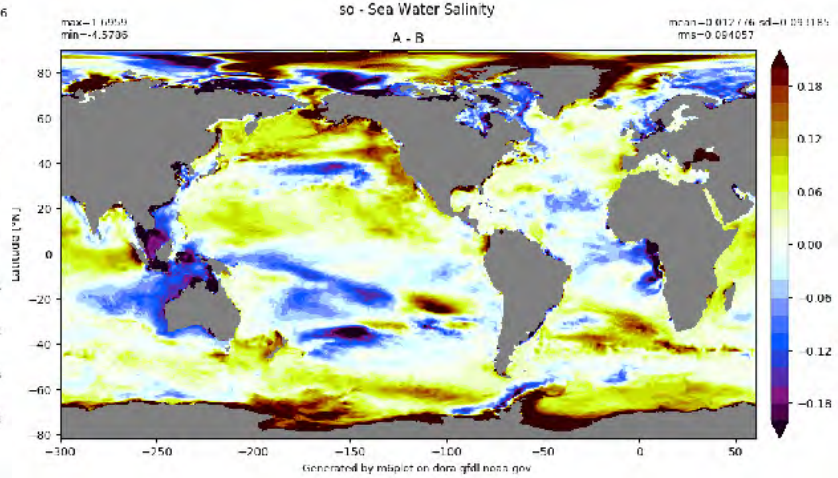
Temp.



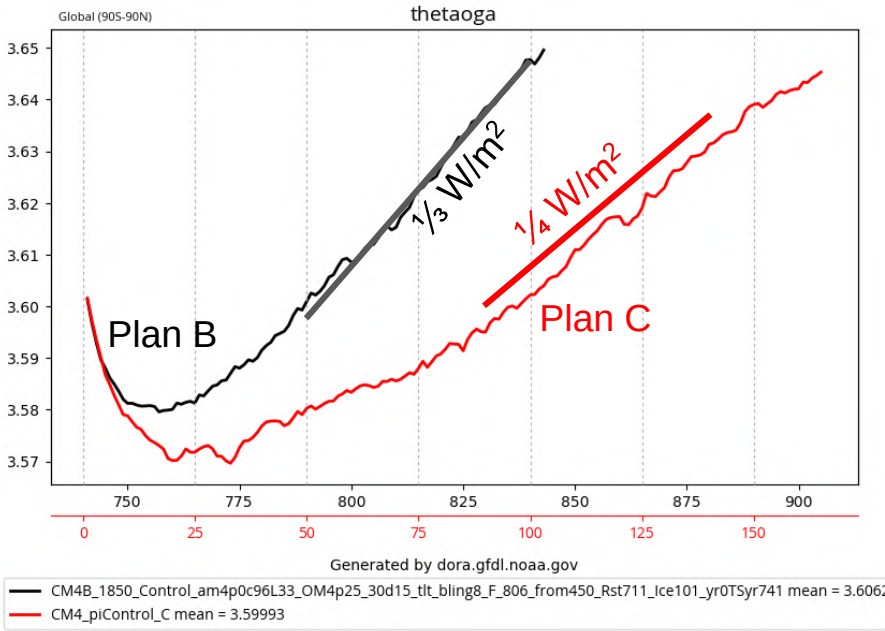


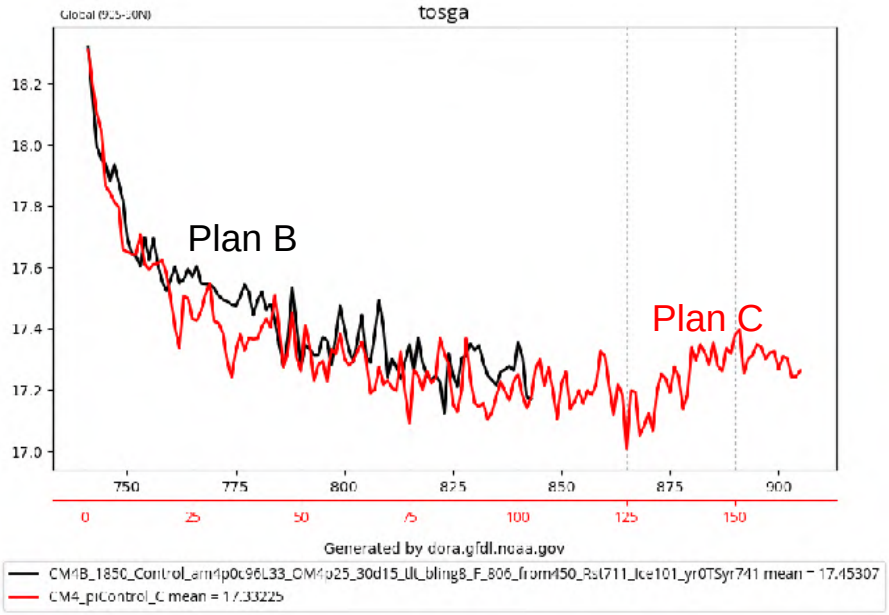
Salinity





Heat uptake is reduced even further





- Plan C (Albedo increase) has a stable climate (accepted for production)
  - Polynyas form in Ross and Weddell but are reasonable (and actually a good thing!)
  - Heat uptake even further reduced
  - Other large-scale climate features unaffected
- All DECK experiments have been completed for CM4

Summary of the GFDL's CMIP6 effort

- All DECK experiments with CM4 have been completed
  - Other MIPs are underway
- CM4 captures many large-scale features of the climate
  - Significant improvement over GFDL CMIP5
- ESM4 is currently under development
  - Full atmospheric and oceanic biogeochemistry
- Anticipate finishing all runs by end of 2018