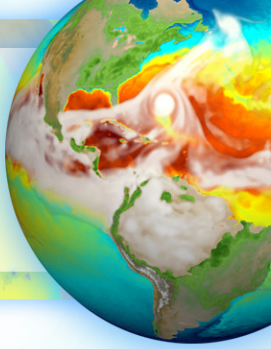
E3SMv2 Water Cycle



Model and Simulation Campaign

Part 2: v2 Low resolution ocean and sea ice results

Luke Van Roekel, Chris Golaz, and the **entire Water Cycle Group**

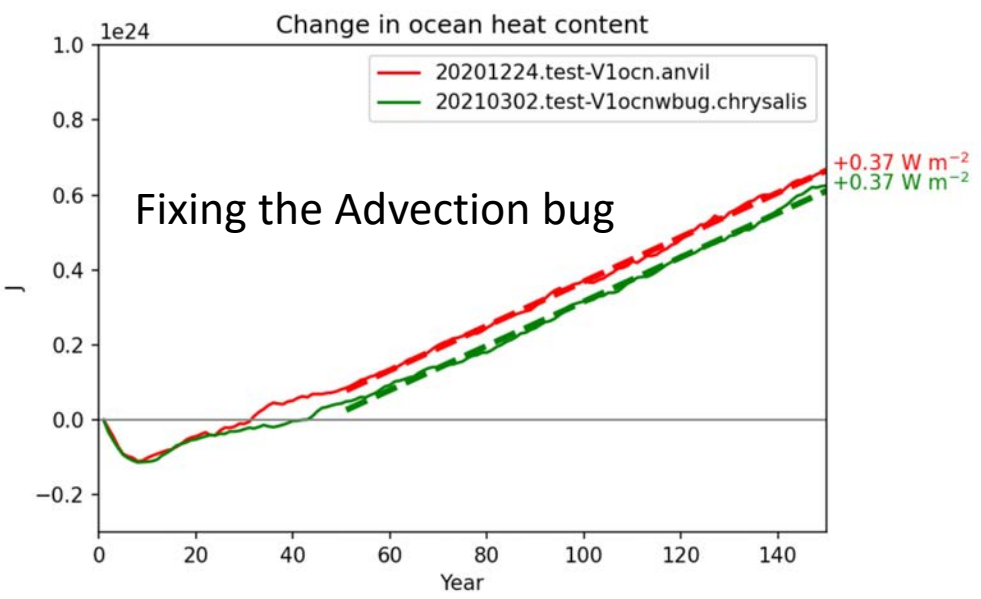
2022-01-20 E3SM All-hands Webinar

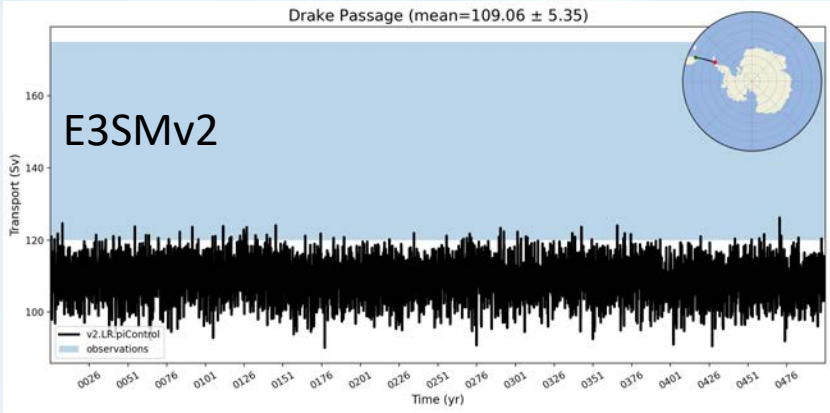
Special Thanks To: Andrew Roberts, LeAnn Conlon, Mat Maltrud, Karthik Balaguru

Outline

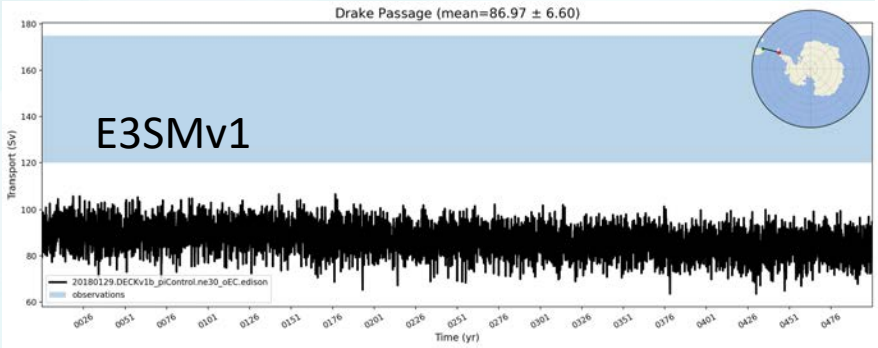
- Overview
  - Ocean
    - V2 code changes
    - Observational comparison
  - Sea ice
    - V2 code changes
    - Observational comparison
- Influence of Aerosol forcing on OHC
- AMOC update

E3SM-Ocean v2





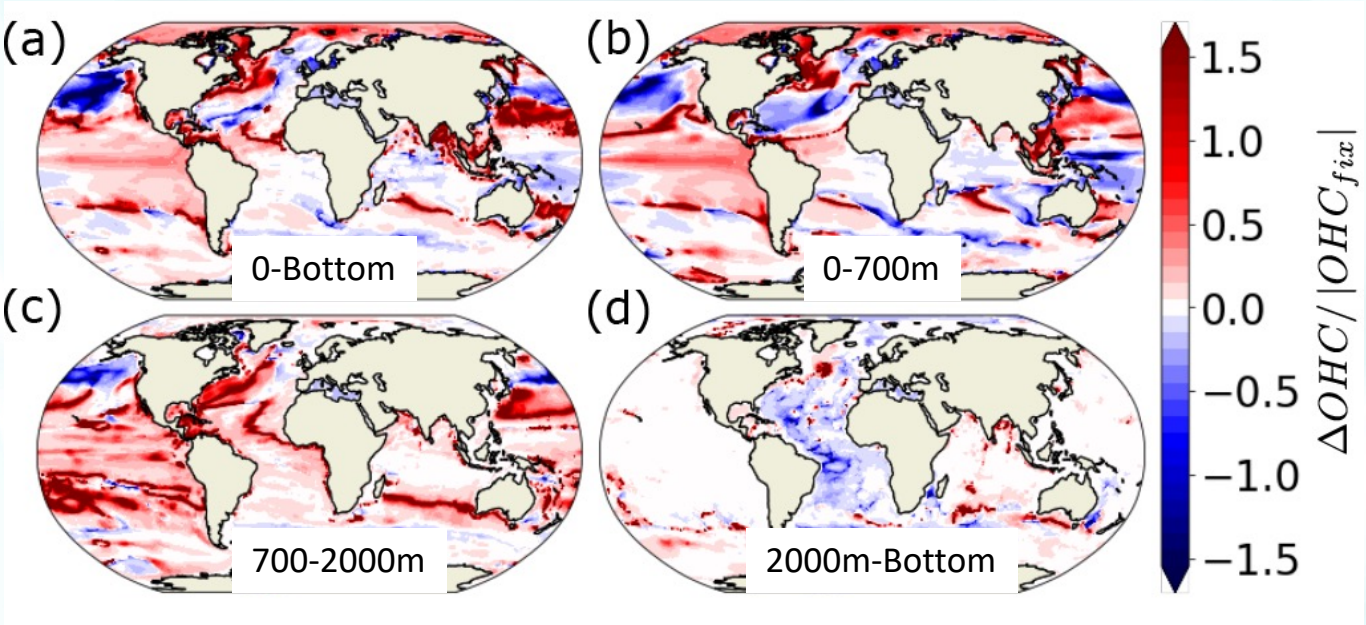
Reduced GM parameter



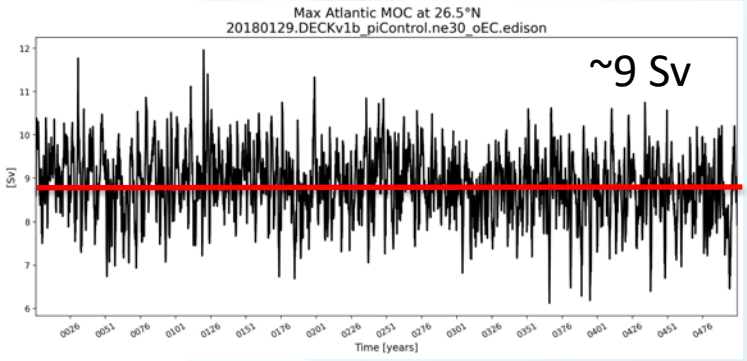
- Added Redi isopycnal mixing
- Spatially variable GM options
- Improved Energy Conservation

Influence of the Advection Bug

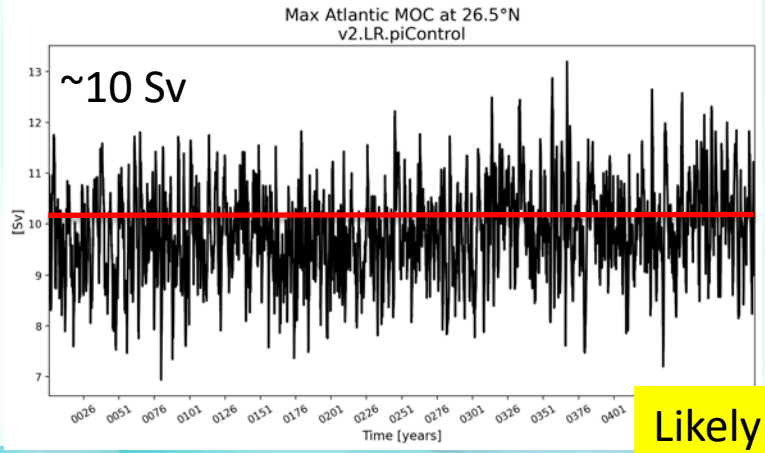
- Change in OHC between two companion runs (Bug fix – with bug)

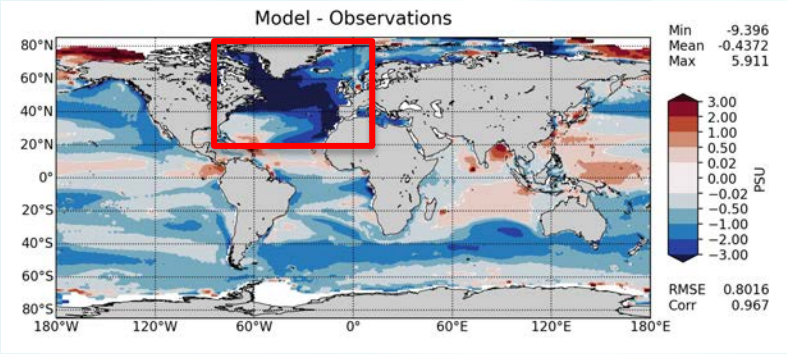


E3SMv2 (Bottom) vs E3SMv1 (Top)

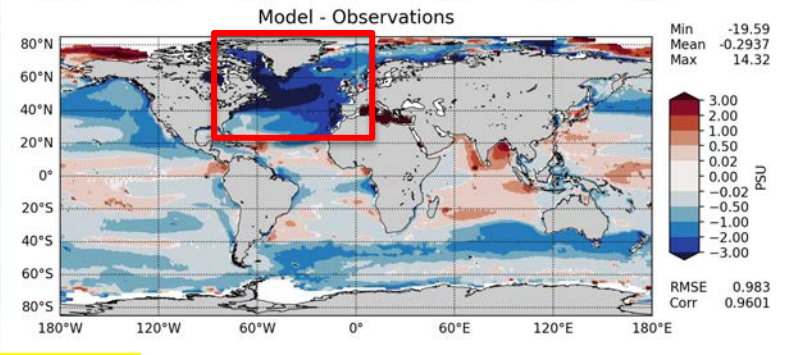


AMOC slightly improved



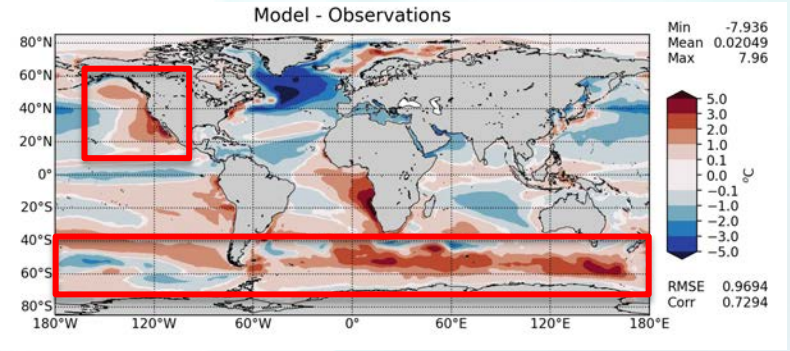


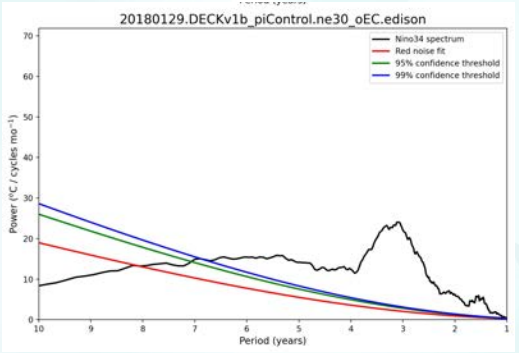
Sea surface salinity bias also improved



Likely due to GM tuning

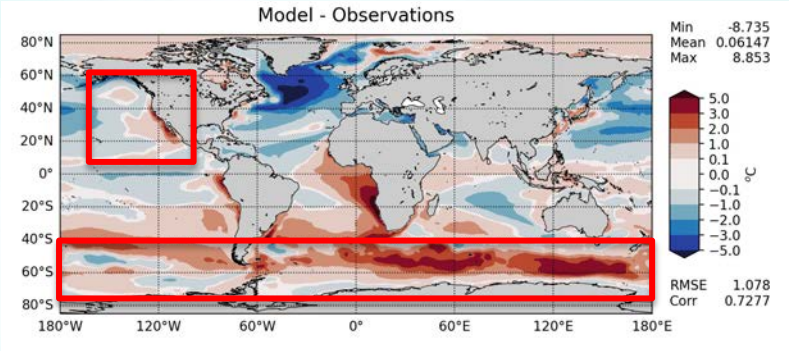
E3SMv2 (Bottom) vs E3SMv1 (Top)

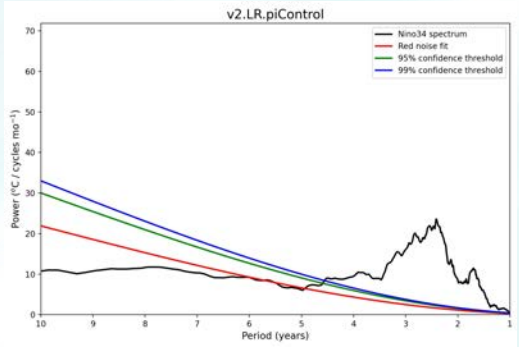




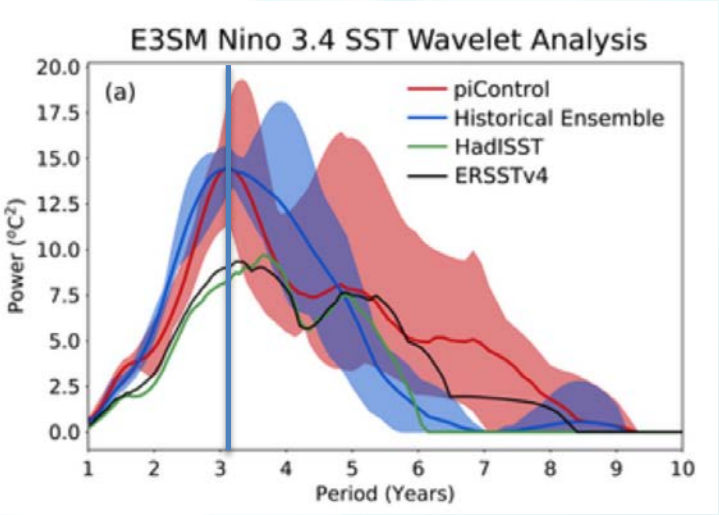
SST better in regions, but worse in global average

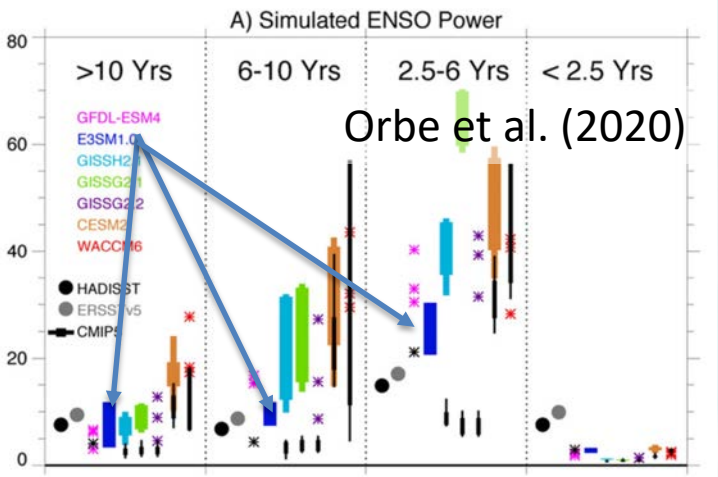
ENSO, more seasonally locked, less longer term variability



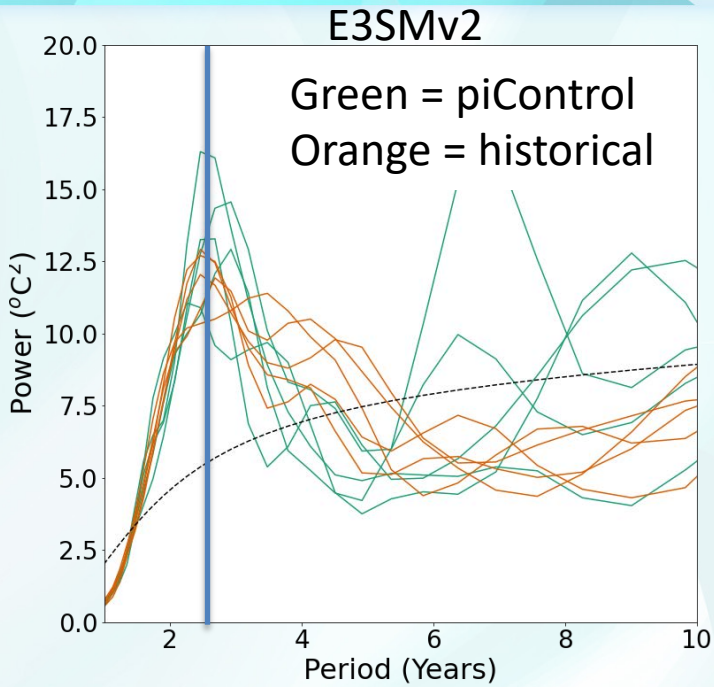


ENSO





Orbe et al. (2020)

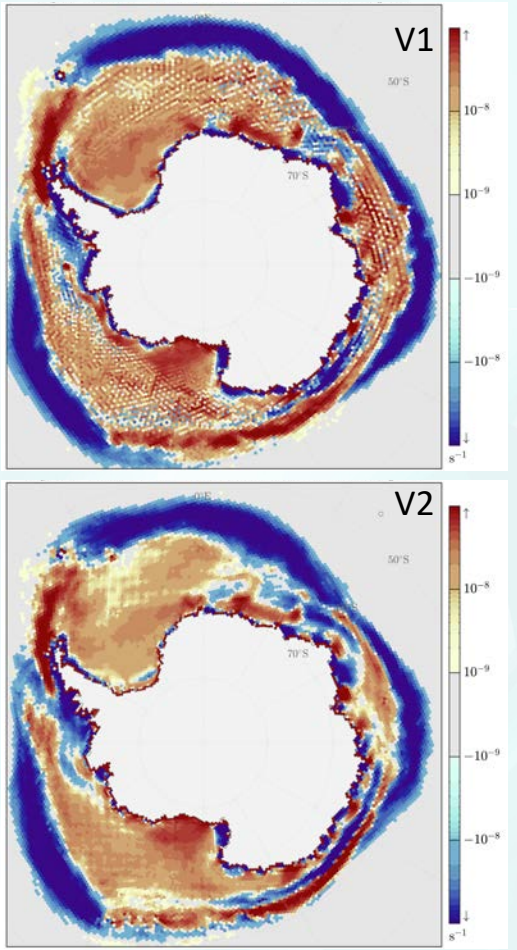


- The wavelet analysis here confirms the shift in peak power in v2
- Less long term period power except for a few chunks of the piControl
- ENSO still reasonable.

V2 Sea Ice Improvements

- Homogenization of snow radiative transfer over land and sea ice
  - SNICAR_AD
- Sophisticated snow morphology over sea ice
  - Including 5 snow layers instead of 1
- Ice basal temperature consistent with mushy-layer thermodynamics
  - Consistent with the equation of state of sea ice
- True high-frequency (30 minute) ice-ocean coupling
  - Removed a daily filter in sea surface height between ice and ocean
- Numerical noise removed in ice-ocean flux terms and ice deformation
  - See figure on right

- **Fixed frazil leak in ocean coupling with sea ice mushy-layer**
  - **V2 has net zero average PI ice-ocean mass and freshwater exchange budget**



200-year PI September average
Sea Ice Divergence

Courtesy of A. Roberts

Sea ice Climatology V1 to V2

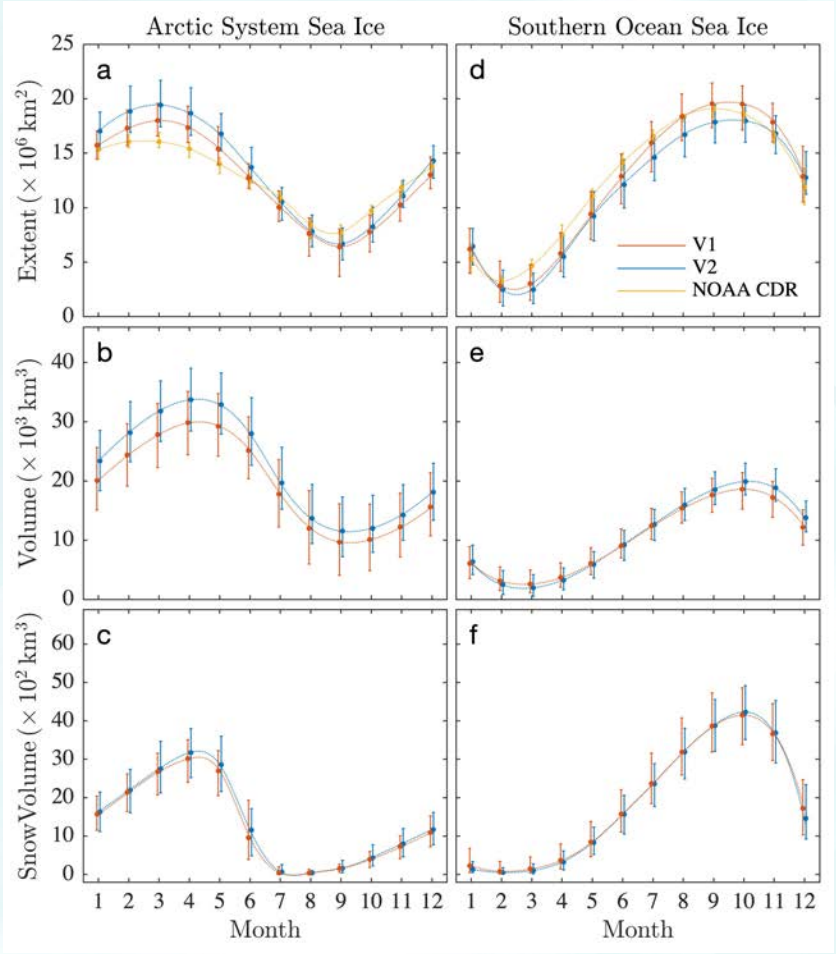
Did these V2 improvements have an impact?

Northern Hemisphere

- Deteriorated bias in annual extent amplitude, significant and unrealistic increase in March sea ice extent.
- Significant increase and improvement in sea ice volume from fixed frazil ice coupling, spanning all seasons.
- No significant change in snow volume

Southern Ocean

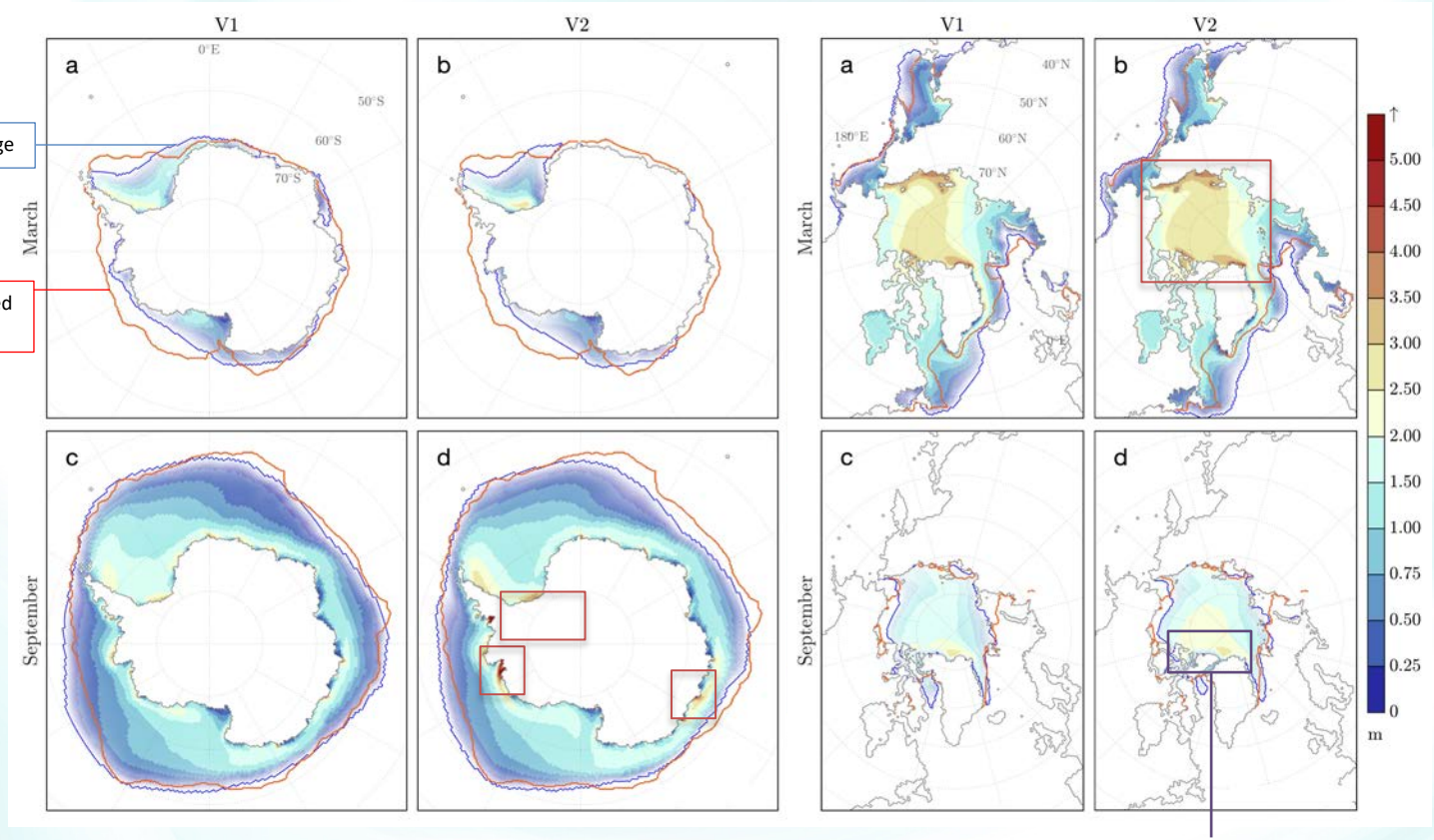
- Diminished annual extent amplitude, now consistently less than observations.
- No significant changes in sea ice volume
- No significant change in snow volume



200 year PI Climatology [CDR is 1979 to 1999 Climate Data Record Reference]

Sea ice Climatology V1 to V2

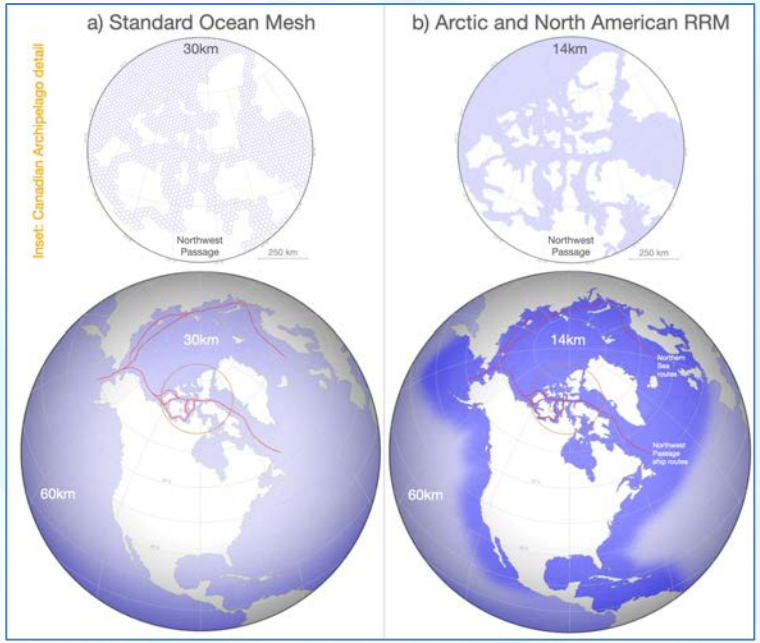
Frazil bug correction offered the largest improvement



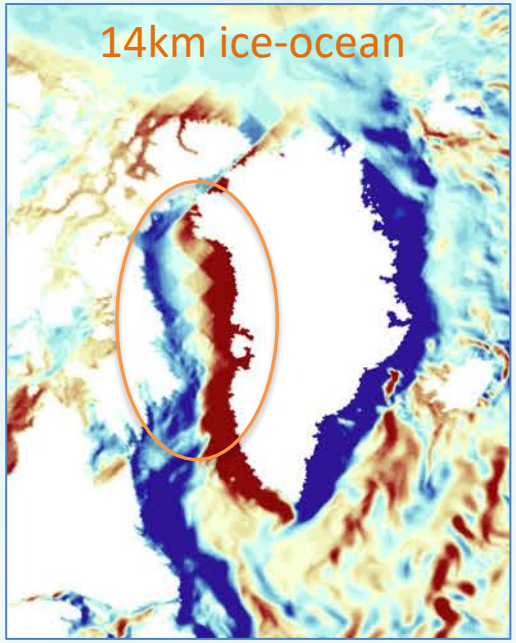
Courtesy of A. Roberts

Lack of build-up against archipelago related to atmospheric resolution

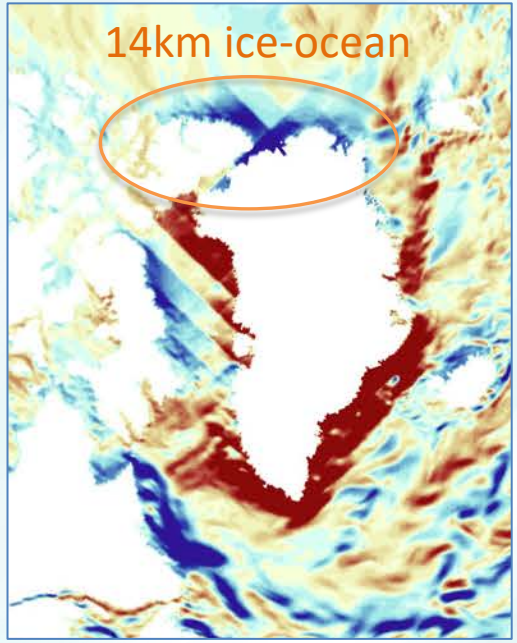
Impact of standard atmospheric resolution in polar regions



Zonal ∇SSH



Meridional ∇SSH



Indirect impact of 110km atmospheric resolution on sea surface height gradient state variable passed between sea ice and ocean at 14km resolution

Courtesy of A. Roberts

Composite configurations

- Treating single-forcing simulations as linear perturbations from the piControl, we can recompose them with alternate strengths:

$$\psi_{\text{all}} = \psi_{\text{piControl}} + \alpha_{\text{GHG}} \left(\psi_{\text{GHG}} - \psi_{\text{piControl}}\right) + \alpha_{\text{aer}} \left(\psi_{\text{aer}} - \psi_{\text{piControl}}\right) + \left(\psi_{\text{other}} - \psi_{\text{piControl}}\right)$$

Baseline | Modulate GHG response | Modulate aerosol response | Keep the rest unchanged

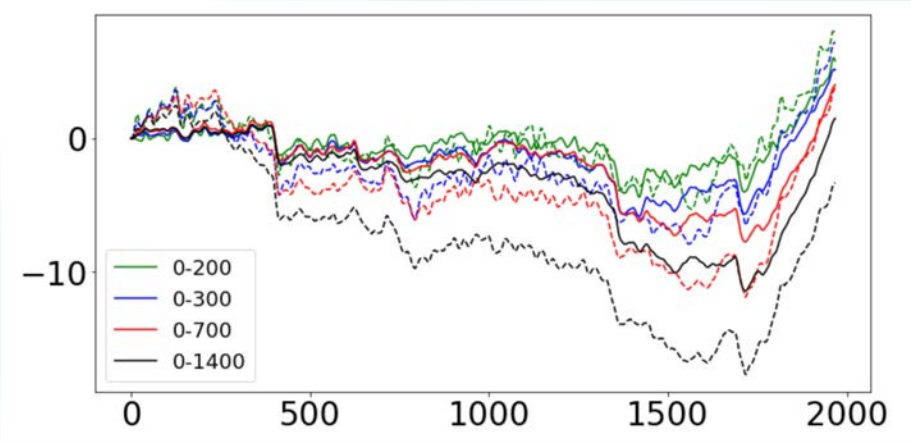
- Modulate strength of GHG response (proxy for TCR/ECS) and aerosol related to create alternate **composite configurations**.

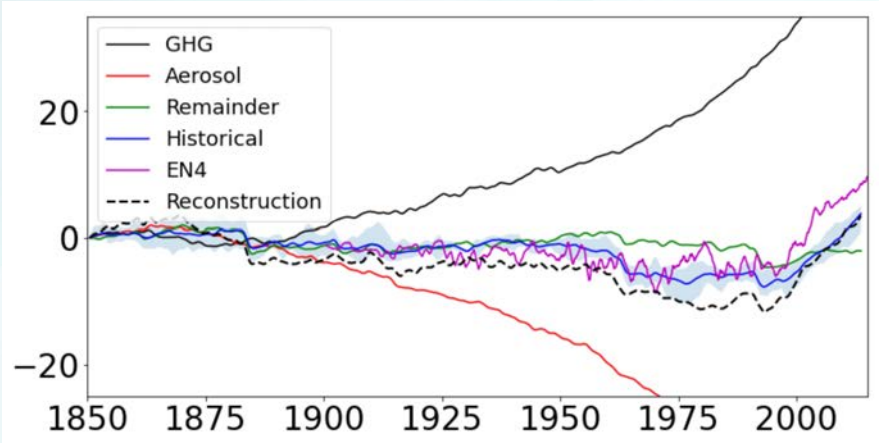
- Applicable to any field; linear approximation holds well.

From Chris Golaz all hands webinar. November 2021

Ocean Heat Content

- Following the analysis shown by Chris Golaz in November.

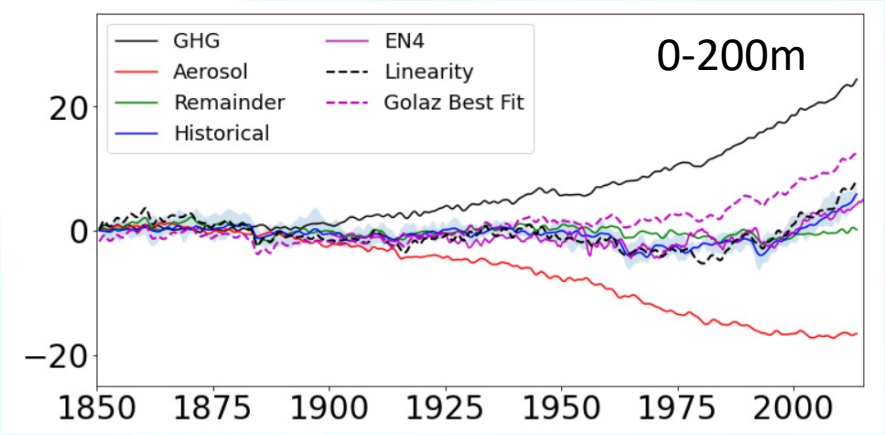


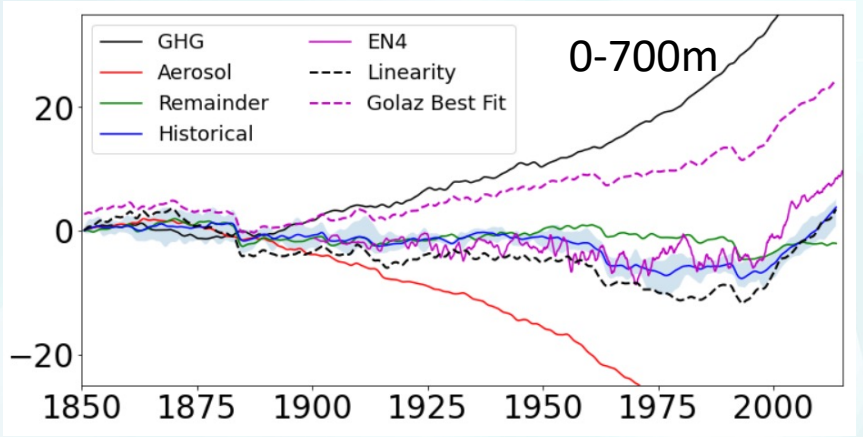


- Linearity (dashed) works well in upper 300m
- Interesting 0-700 matches well in late 20th century

- Reanalysis (EN4; magenta) match pretty well in 0-700 until late 20th century.
- Ocean warming slows relative to data

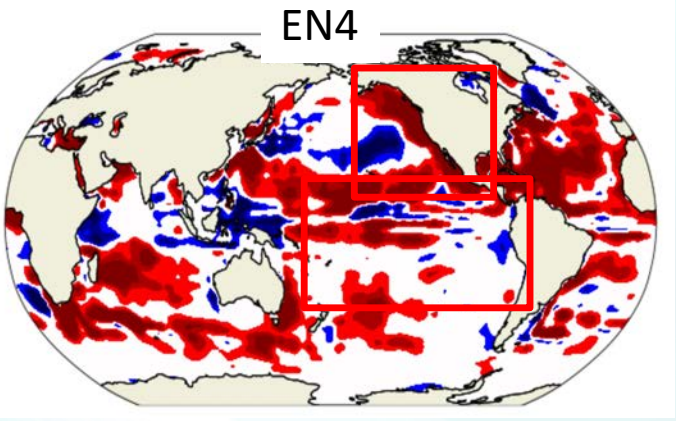
OHC composite analysis

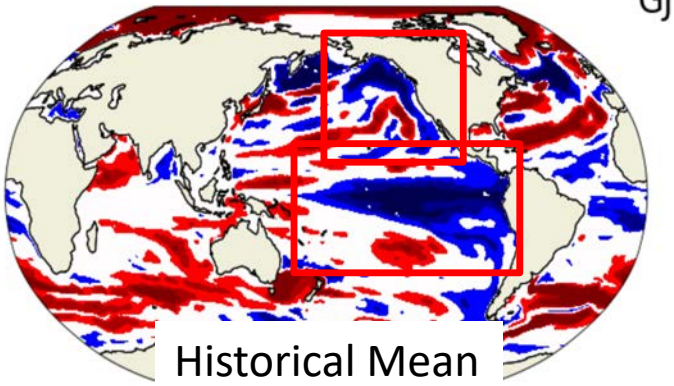


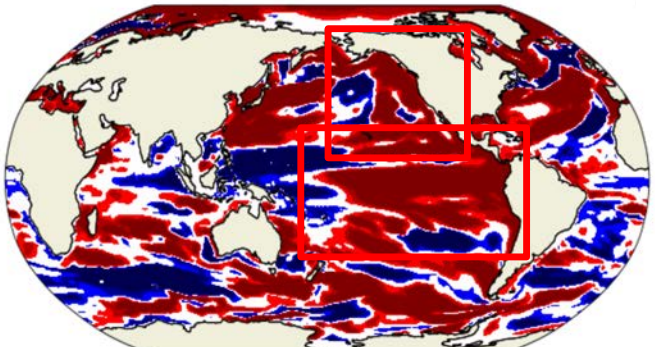


- The reduction in aerosol forcing and GHG worsens comparison to observations (dashed pink)
- Also examined: sea surface salinity biases and AMOC for reduced aerosol forcing
  - SSS had limited change, AMOC virtually no change

Composite analysis 2D maps (0-200m)

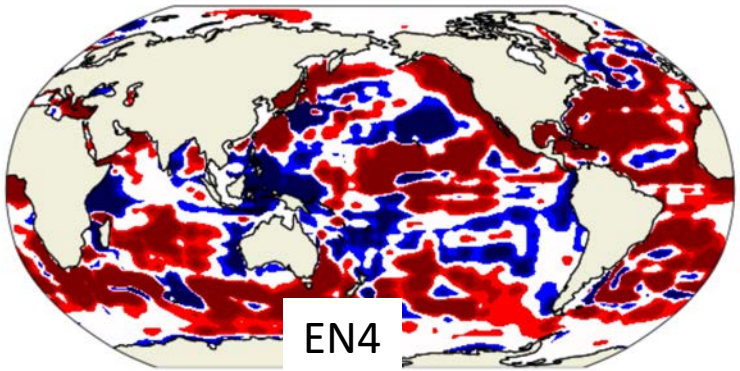


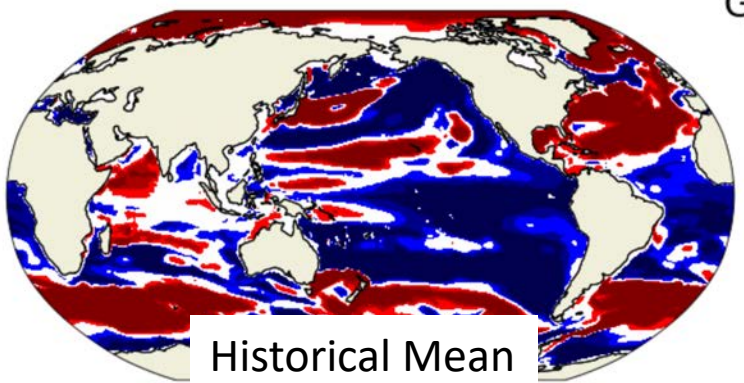


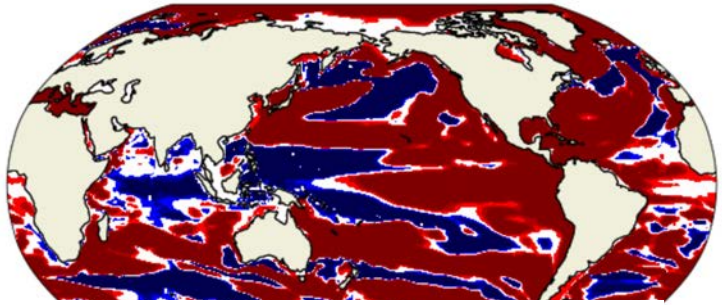


- Good timeseries agreement with data is due to compensating biases
- Reducing aerosol forcing improves OHC in some regions
  - But certainly not the only factor in biases

Composite analysis 2D maps (0-700m)







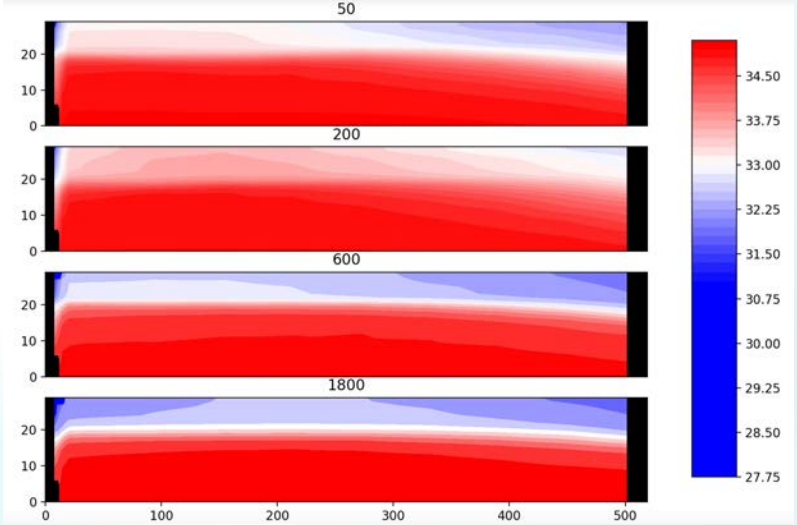
Composite – reduced Aerosol

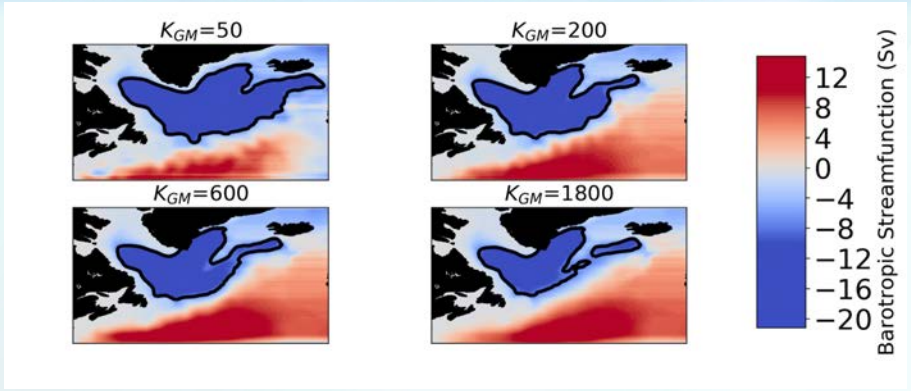
- Similar regional impacts through these depths
- The OHC average is taken over the period linearity holds well

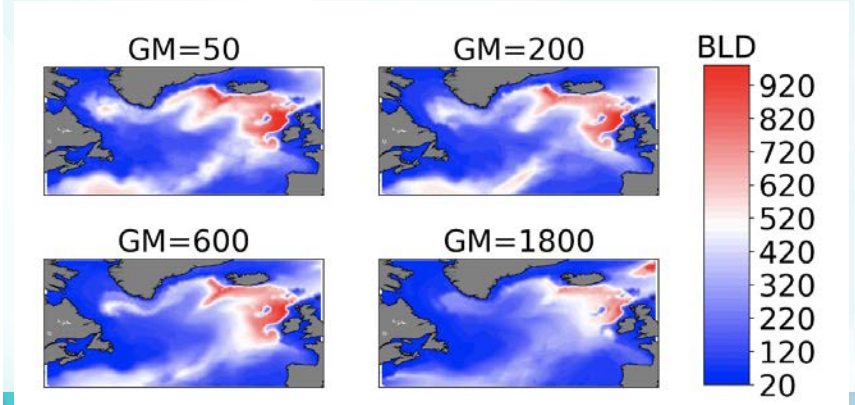
AMOC update

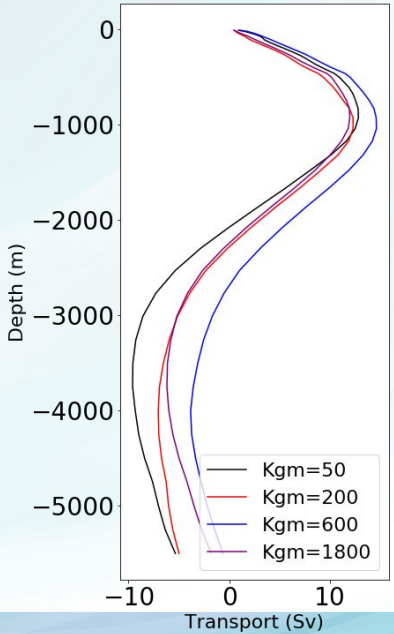
- New Format: smaller focused team, meeting frequently.
- Known Knowns
  - AMOC at high resolution is robust
    - Missing or poorly represented physics?
  - Variable resolution has not helped more than a Sv
    - Various SORRM iterations, WC meshes
  - Tuning rudimentary GM has given 1-2 Sv
  - Changing Redi parameters
    - Helps in some ways but yields other, much larger biases
- Known Unknowns
  - Why is MPAS so sensitive to surface freshwater forcing at low resolution?
    - Likely a combination of factors

GM Analysis





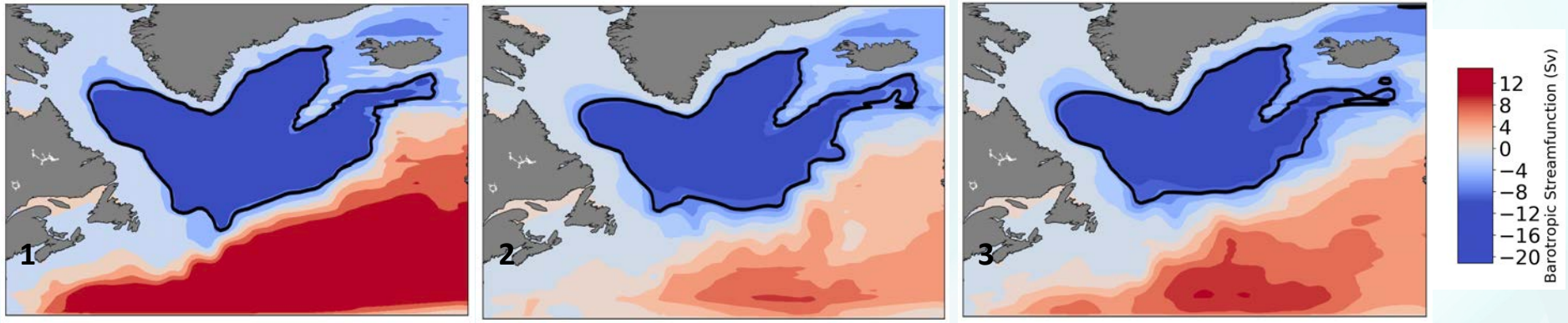


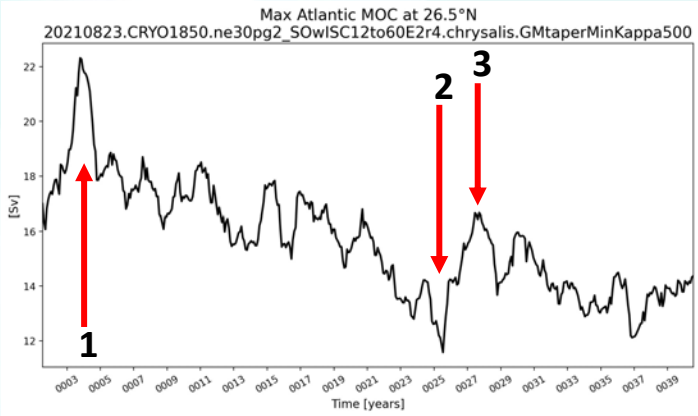


- Subpolar gyre improves with lower Kappa
- BLD improves but response saturates
- AMOC does not respond as expected

Analysis from L. Conlon

GM (Visbeck)





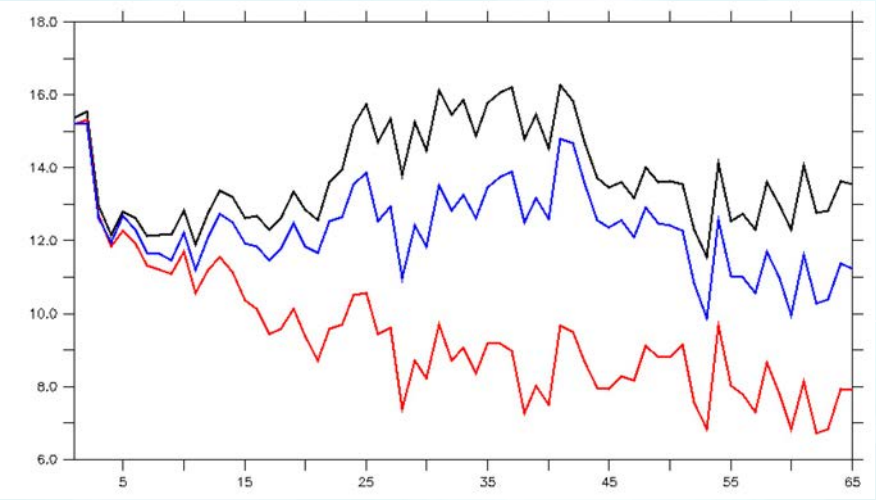
GM is spatially variable.

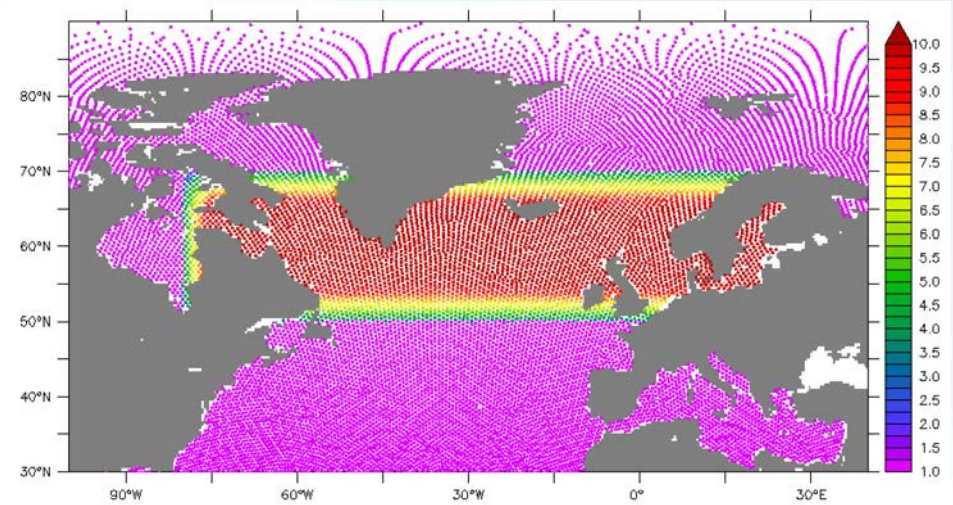
- Subpolar gyre looks good (above)
- AMOC still declines (left)
- Likely a combination of northward salinity transport and subpolar gyre

Analysis from L. Conlon

Influence of SSS restoring

- Three cases
  - Standard 1 year restoring everywhere (red)
  - Increase to 36.5 days everywhere (blue)
  - 1 year everywhere except 36.5 days in North Atlantic (black)



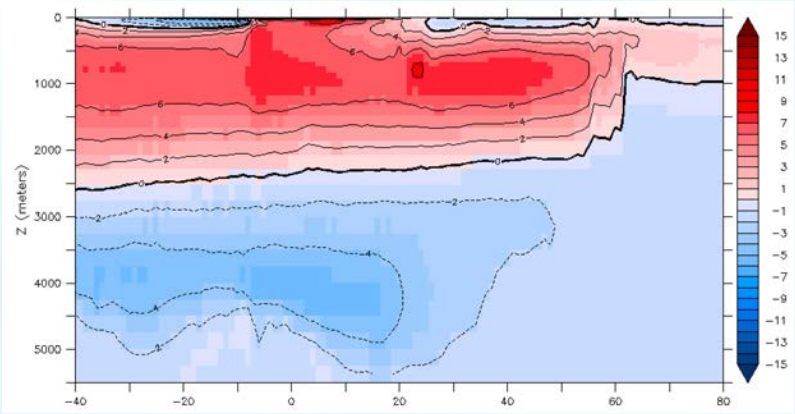


- Strong restoring in the N. Atlantic greatly improves AMOC
- Global strong restoring slightly less effective
  - Compensating bias eliminated?

Analysis from M. Maltrud

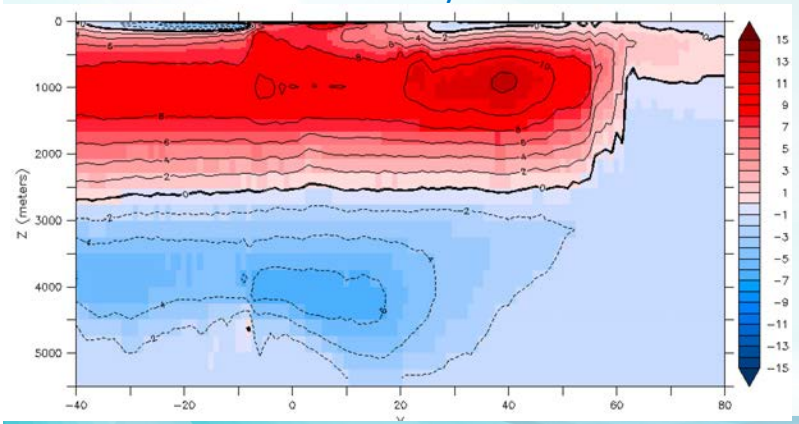
Analysis from M. Maltrud

Years 61-65 average Atlantic Meridional Stream Function

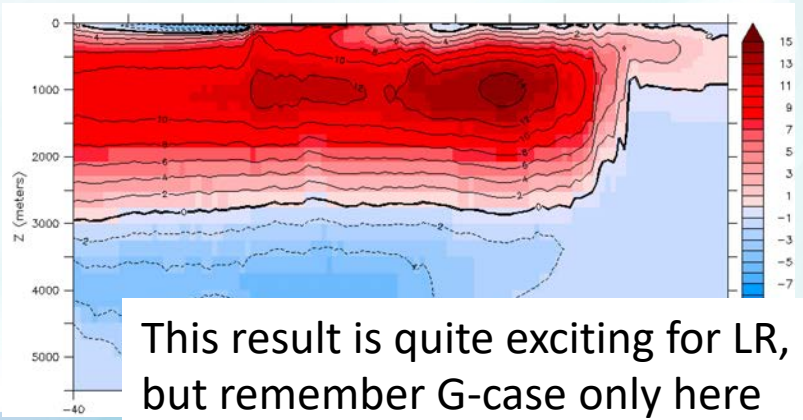


Standard

Enhanced everywhere



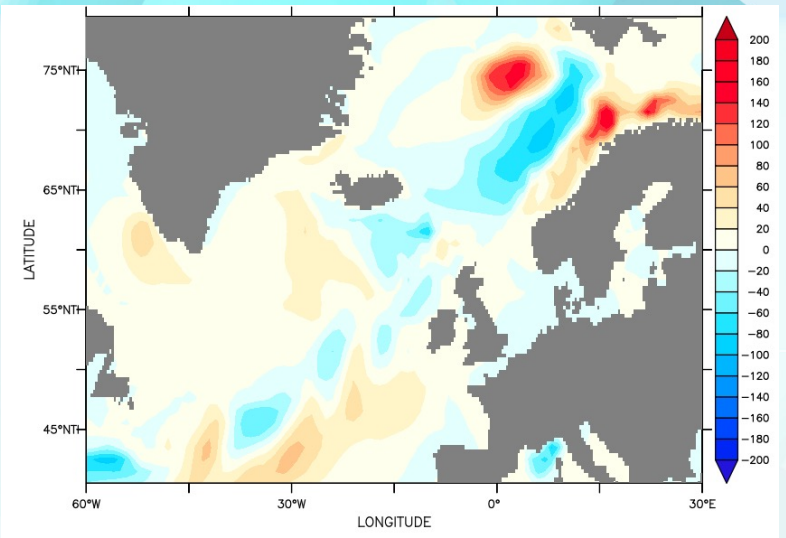
Enhanced NAtl

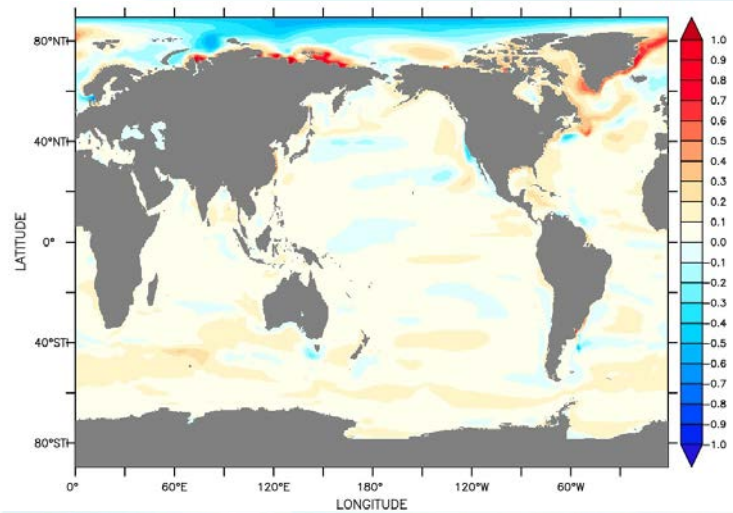


This result is quite exciting for LR, but remember G-case only here

Ocean Freshwater

- The likely candidates
  - Vertical Mixing
  - Redi Mixing
- Given high resolution has robust AMOC, Redi seems more likely.





- Left – change in salinity from increasing Redi
- Above – change in MLD from increasing Redi
- Some hints that improving Redi could improve AMOC

Analysis from K. Balaguru

Summary and Next Steps

- v2 Ocean looks quite similar to v1
  - Some regional improvements, some slight degradations
- V2 Seaice
  - Numerous fixes and improvements. Improved sea ice volume with some degradations in extent
- OHC
  - Global timeseries matches reanalysis well in upper ocean
    - Due to compensating biases
  - Reducing aerosol impact improves some regional OHC biases but exacerbate others.
- AMOC
  - Good progress being made
  - **Critical question** – why is the ocean model so sensitive to high latitude freshwater forcing?