Sea Level Rise and Coupled Carbon-Climate Projections

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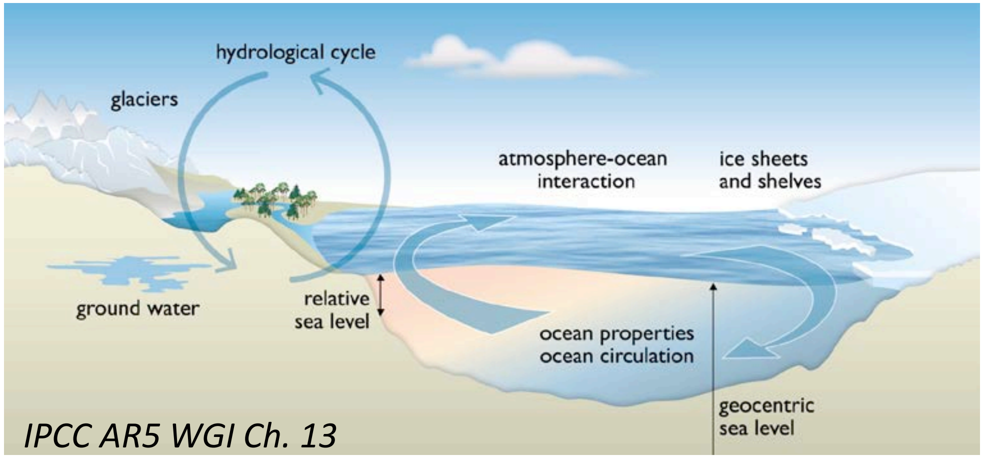
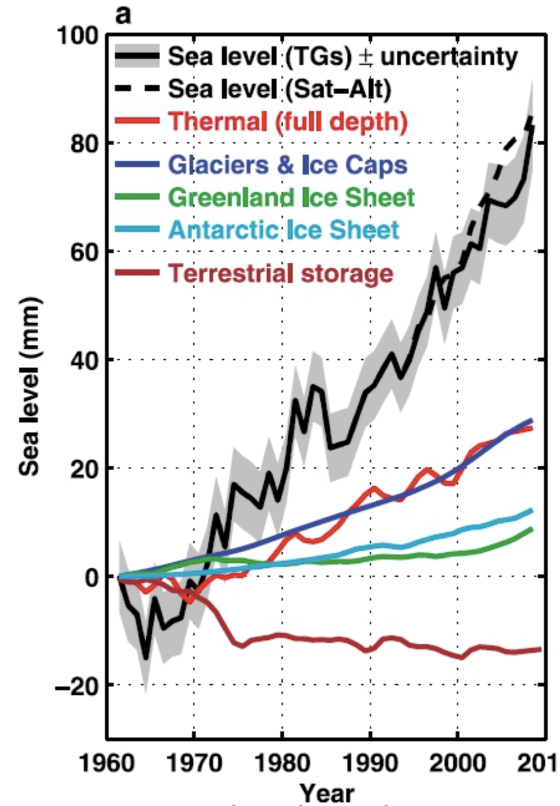
Earth System Processes related to Sea Level Rise



IPCC AR5 WGI Ch. 13

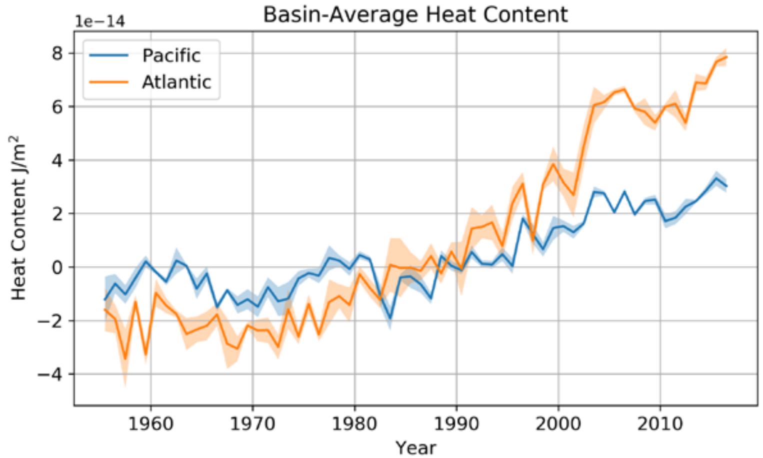


Church et al. 2011

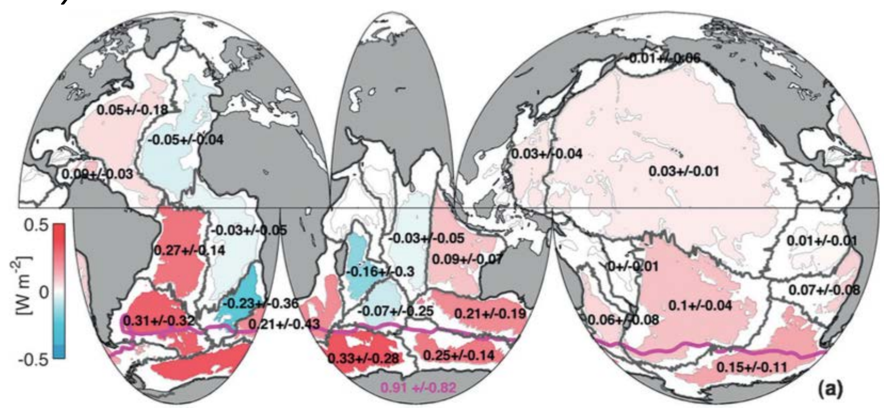
- One major IPCC AR5 accomplishment was to close the sea level budget using XBT, GRACE, and altimetry measurements
- Thermosteric and glacial melt contributions dominate historical SLR
- The GFDL-ESM2G model has had major contributions with both realistic forcing and idealized carbon emissions

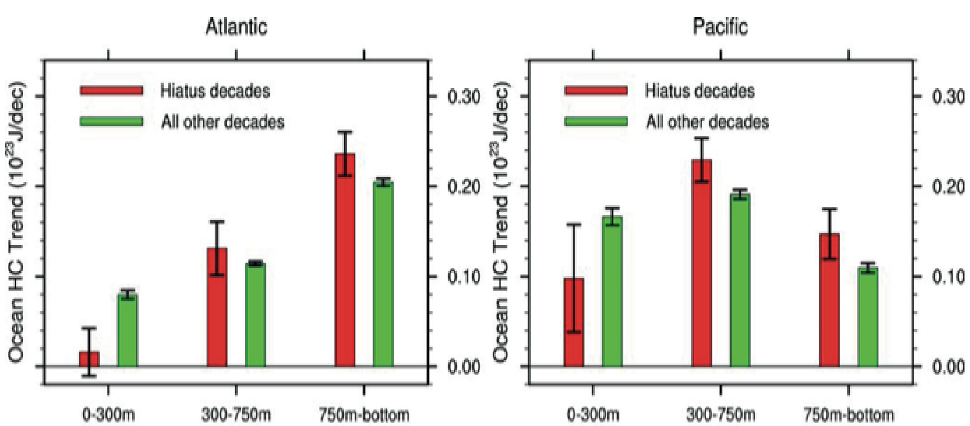
Simulated in GFDL-ESM2M/G	Not Simulated in GFDL-ESM2M/G
Thermal expansion Dynamical circulation changes Hydrologic cycle changes	Glacier / ice sheet melt Changes relative to the geoid

Regional Changes in Ocean Heat Content

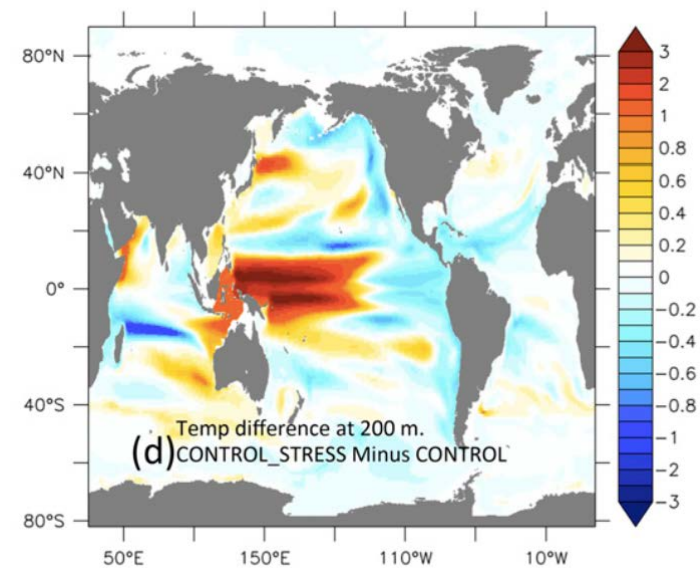


Purkey and Johnson 2010



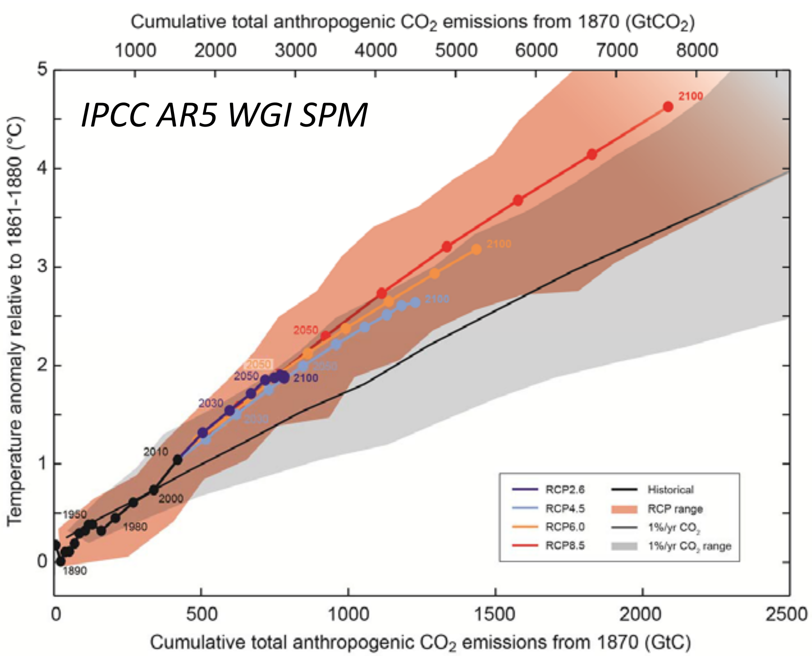


Meehl et al. 2011

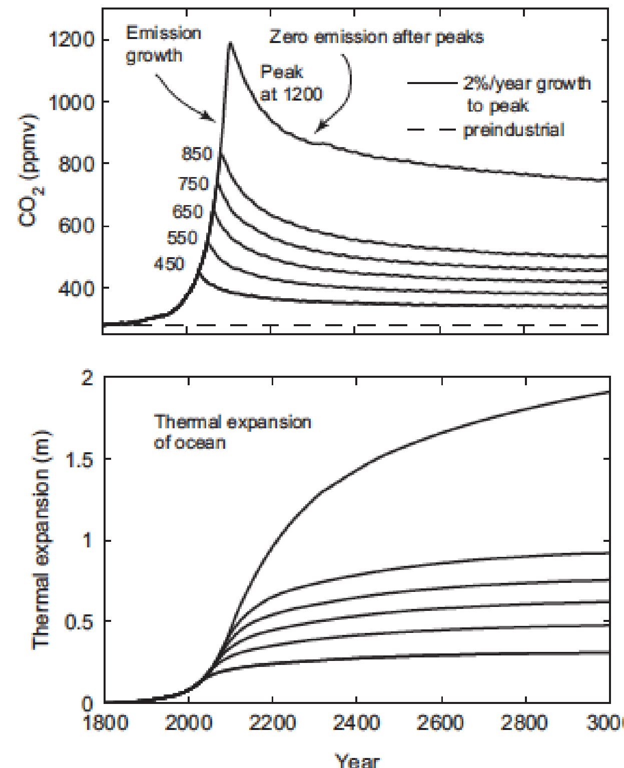


Delworth et al. 2015

Transient Climate Response to Cumulative Carbon Emissions (TCRE)

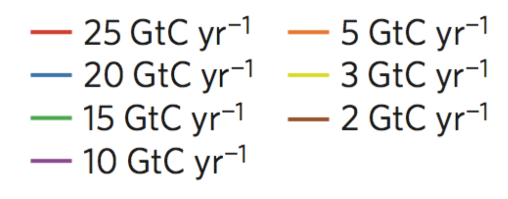


Solomon et al. 2009

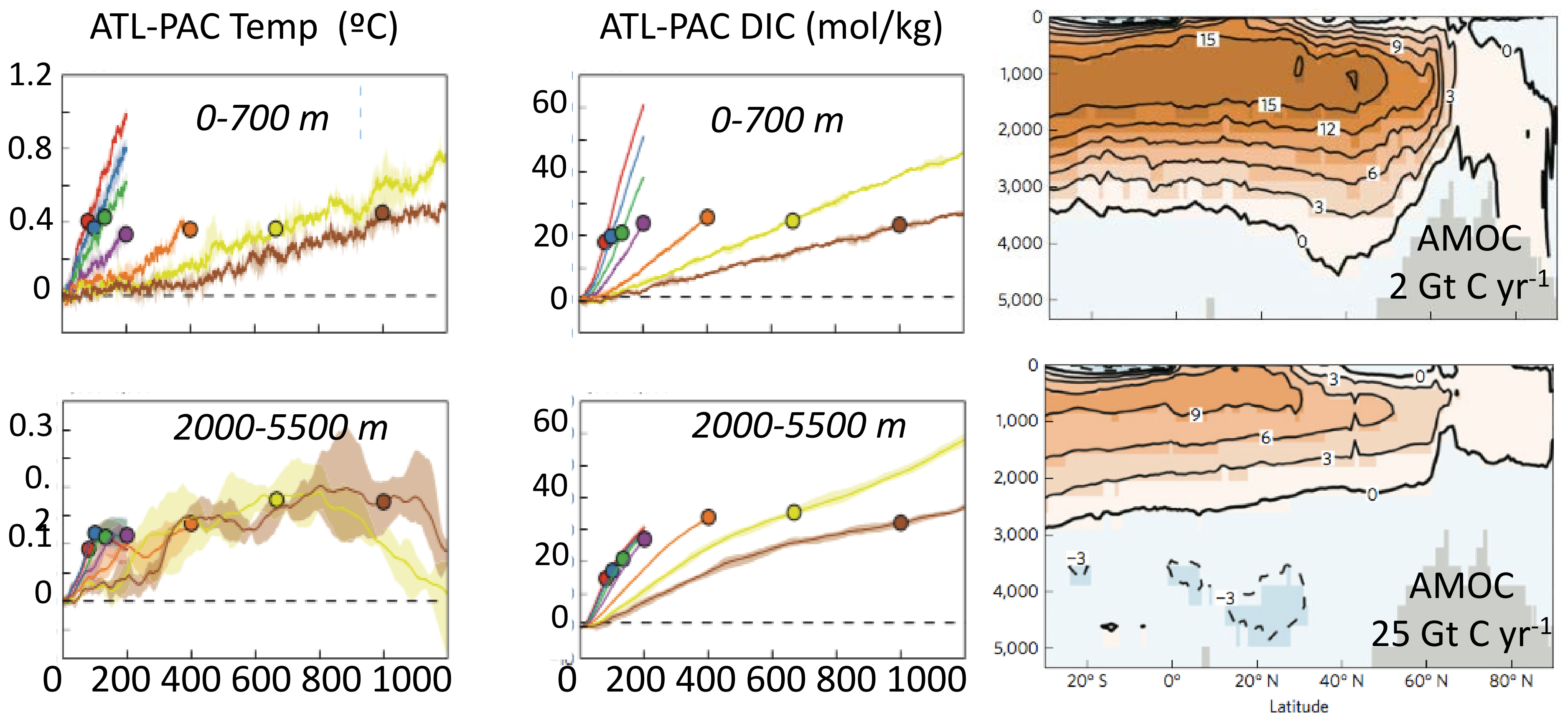


- TCRE highlighted in IPCC AR5 WGI Report (2014) *(e.g. Allen et al. 2009, Matthews et al. 2009)*
- Many aspects of climate change are related to cumulative carbon emissions *(e.g. Zickfeld et al. 2012)*
- Global SLR is not proportional to cumulative carbon emissions *(e.g. Solomon et al. 2009)*

Are there aspects of basin-scale SLR and heat / carbon uptake that can be related to cumulative emissions?



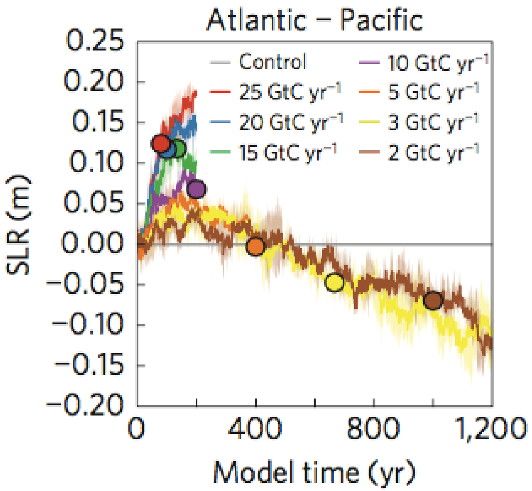
Dynamical Ocean Changes Lead To Atlantic-Pacific Differences in Heat & Carbon

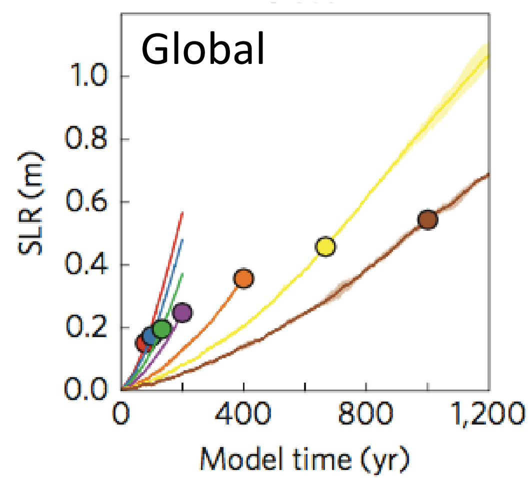


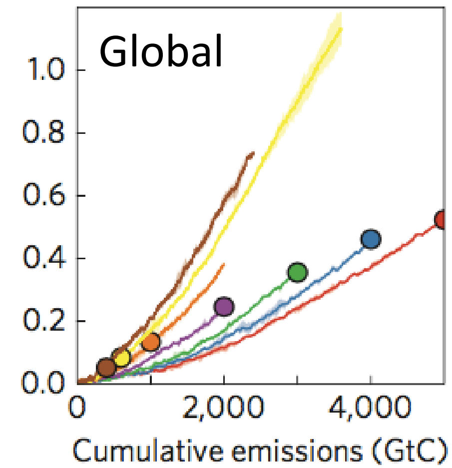
- Higher emissions rates → bigger differences between the Atlantic and Pacific.
- Deep Pacific heating eventually overtakes the Atlantic in the low emissions cases (2-3 Gt C yr^{-1}).
- Inter-basin temperature differences between 0-700 m are proportional to cumulative emissions.
- Deep oceanic heat and carbon uptake behave differently on millennial timescales.
- Reduction in AMOC and less deep water formation makes the Atlantic warmer, and less-ventilated. Similar to Yin et al. 2009.

Krasting et al. 2016

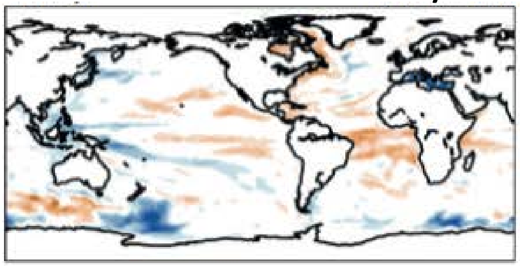
Atlantic vs. Pacific Sea Level Rise Under Different Carbon Emission Rates



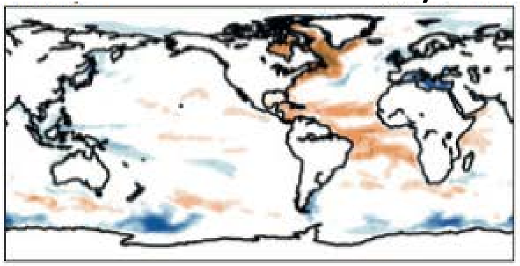




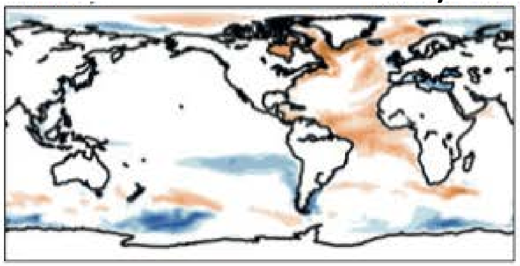
Normalized 2 Gt C yr^{-1}



Normalized 5 Gt C yr^{-1}



Normalized 25 Gt C yr^{-1}



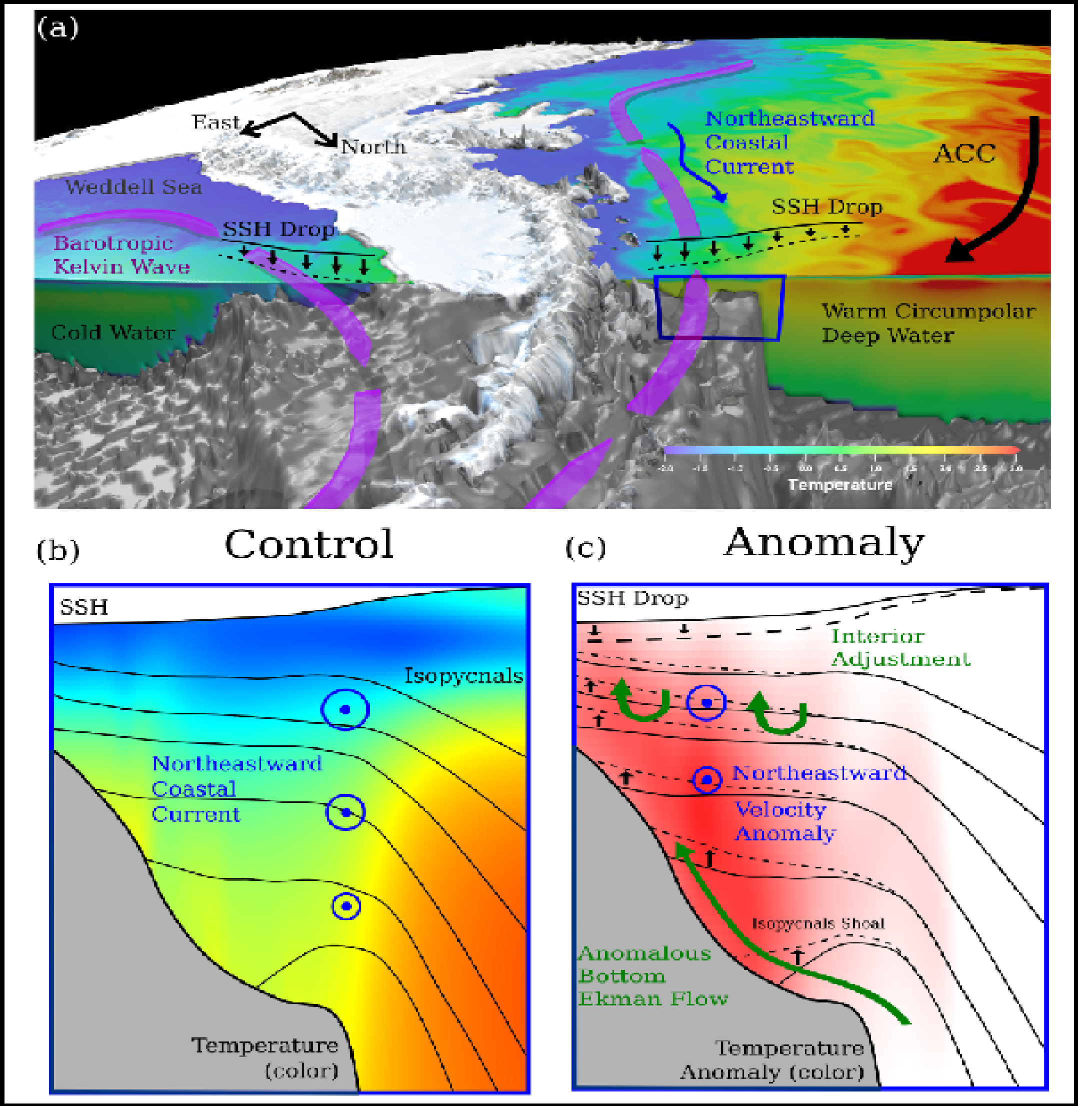
**Normalization based on interannual σ from preindustrial control run*

Krasting et al. 2016

- Atlantic SLR greater than Pacific under higher carbon emission rates
- SLR is more uniform under low emissions before Pacific overtakes Atlantic after 600 years
- Lower emission rates take longer to achieve a given cumulative emission amount allowing a larger fraction of the ocean to experience warming and produce more global SLR
- Largest SLR signal along the US and Canadian East Coasts in the 25 Gt C yr^{-1} scenario

A nonlocal wave mechanism for heat to reach Antarctic shelves

Spence, Holmes, Hogg, Griffies, Stewart, England, Nature Climate Change (2017)



- Winds depress sea level off East Antarctica.
- Kelvin wave sends sea level depression around coast (non-dispersive waves).
- Shoreward anomalous barotropic pressure gradient.
- Arrested Ekman and interior B/C adjustment causes upslope flow, shoaling warm CDW along shelf.
- Western Peninsula is particularly prone to warming due to steep bottom (strong f/h flow and strong B/C and Ekman adjustment) and proximity to warmer CDW in ACC.

Spence et al (2017)

Summary and Future Work

- Sea level rise reflects changes in processes throughout the Earth system
- Regional changes in ocean heat content may be either internal variability or a forced response
- Varying the rate of carbon emissions leads to
  - Different dynamical ocean responses (AMOC)
  - Basin-scale differences in warming and sea level rise
  - Different interpretation of sea level rise for a given carbon budget
- *High carbon emissions -> reduced AMOC -> warmer Atlantic relative to Pacific -> more Atlantic sea level rise*

- Future directions:
  - Further understand the coupled climate-carbon cycle system, sensitivity, and feedbacks through efforts such as C4MIP, emission-driven simulations, and reversibility experiments
  - Continue efforts to incorporate more processes related to sea level rise, such as dynamically and thermodynamically-interactive ice sheets in GFDL coupled models
  - Leverage new models (MOM6 + COBALT) to better understand the sensitivity of heat and carbon uptake to ocean diapycnal mixing