Sea Level Rise, Ocean Heat Uptake, and Carbon Uptake Research at NOAA-GFDL

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Importance of SLR Modeling / Projections

Sea level rise is relevant to OAR's strategic plan and priorities:

Climate Adaptation and Mitigation

Informing society about sea level rise and providing an opportunities to address potential impacts

Resilient Coastal Communities and Economies

Population growth requires coastal communities remain a vital part of our economy

Healthy Oceans

Coastal ecosystems, vital to our economy and for recreation, are increasingly vulnerable to rising seas

Many Processes Contribute to SLR

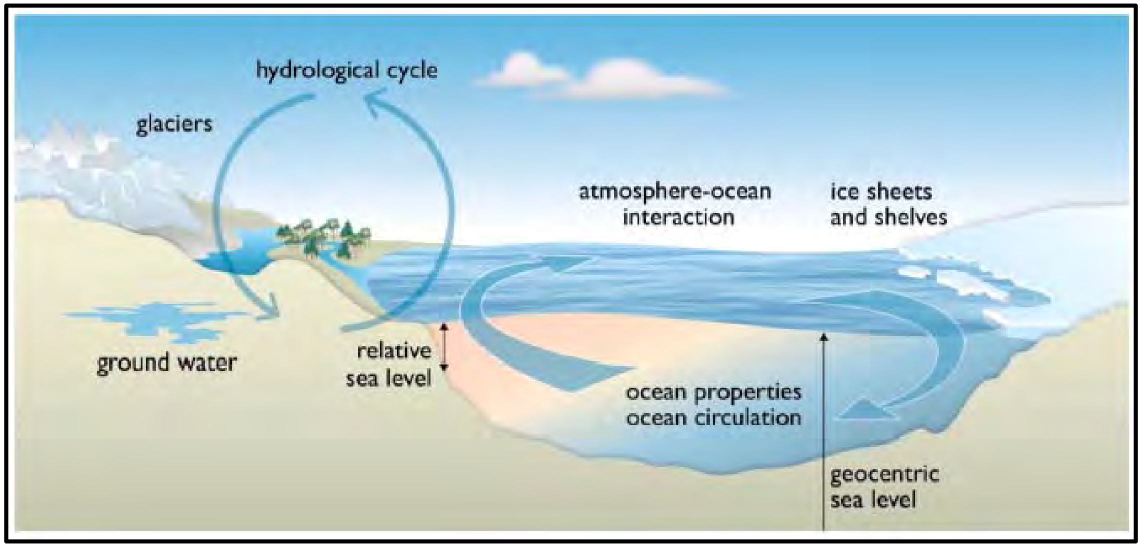


Image: IPCC AR5 WG-I Chapter 13

Sea level rise is an **integrated response** of many processes throughout the Earth system

Simulated in Current Generation Models	Not Simulated in Current Generation Models
Thermal expansion Dynamical circulation changes Hydrologic cycle changes	Glacier / ice sheet melt Local changes relative to the geoid

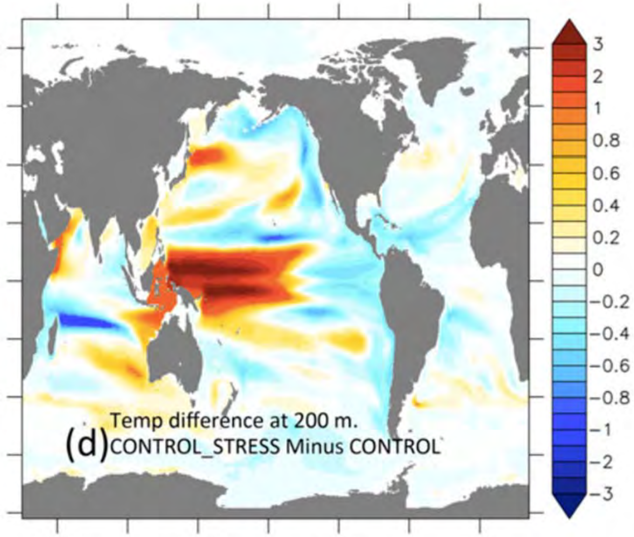
Major Accomplishments

- In the past 5 years, NOAA-GFDL has:
  - **Increased understanding** of ocean heat uptake
  - **Developed next-generation ocean models** with remarkably small temperature drift
  - Further explored links between AMOC response to forcing and **Northeast US sea level rise**
  - Projected long-term sea level rise, heat uptake, and carbon uptake through **carbon budgets and cumulative emissions**

Understanding Regional Patterns of Heat Uptake

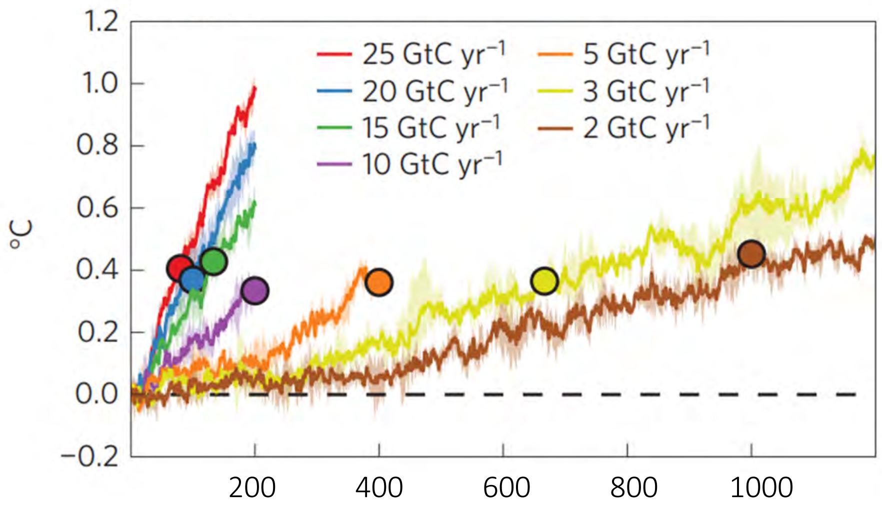
Inter-basin differences in heat uptake can arise from either decadal-scale ***internal variability*** or from ***climate forcing***

CM2.1 Temperature Response at 200 m



Enhanced Pacific subsurface warming when forced with observed wind stress – one mechanistic explanation for "hiatus" in SAT warming [Delworth et al., 2015, *J. Climate*]

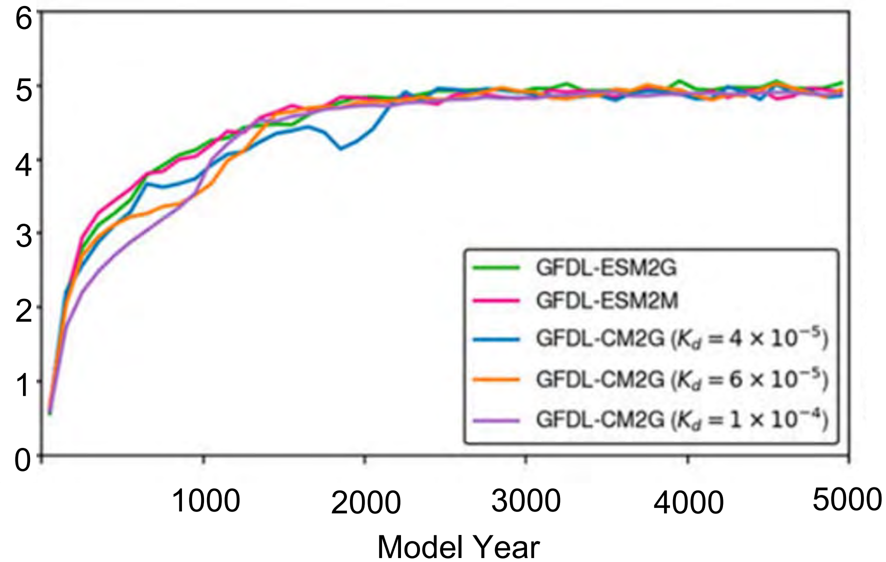
Atlantic minus Pacific 0-700 m Heat Uptake
GFDL-ESM2G Model



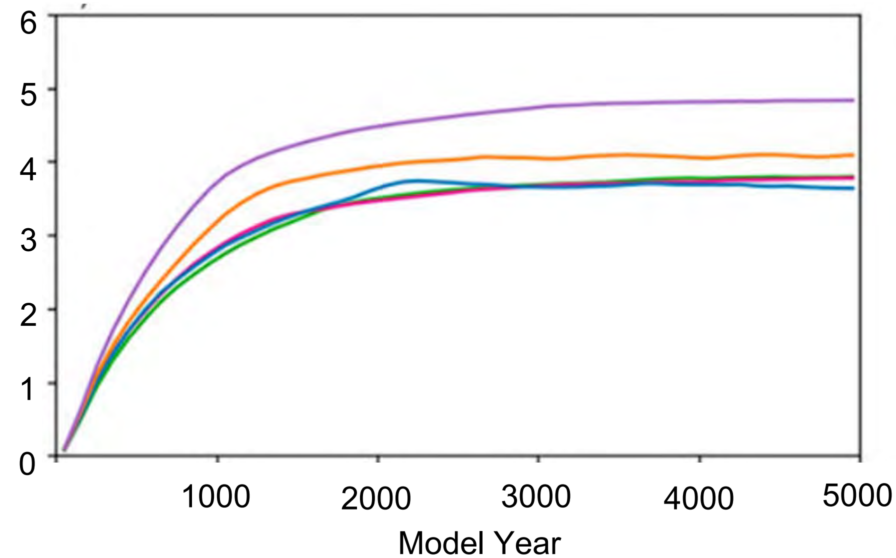
Atlantic-Pacific basin differential warming depends on the rate of carbon emissions [Krasting et al., 2106, *Nature Geosci.*]

Ocean Heat Uptake on Millennial Timescales

Sea Surface Temperature Response (°C)



Volume Mean Ocean Temperature (°C)



SST response depends on the atmospheric response,
ocean heat uptake varies more with **internal mixing**

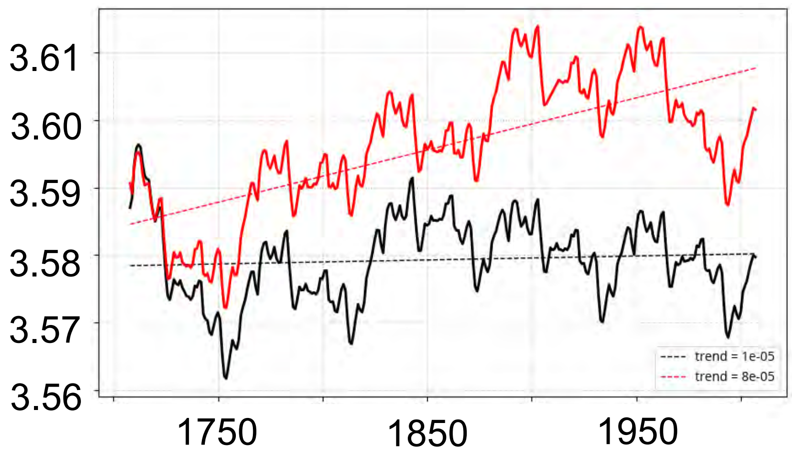
Despite similar equilibrium climate sensitivities, models with different amounts of internal mixing would produce different sea level responses

[Krasting et al., 2018, *J. Climate*]

Ocean Model Temperature Drift

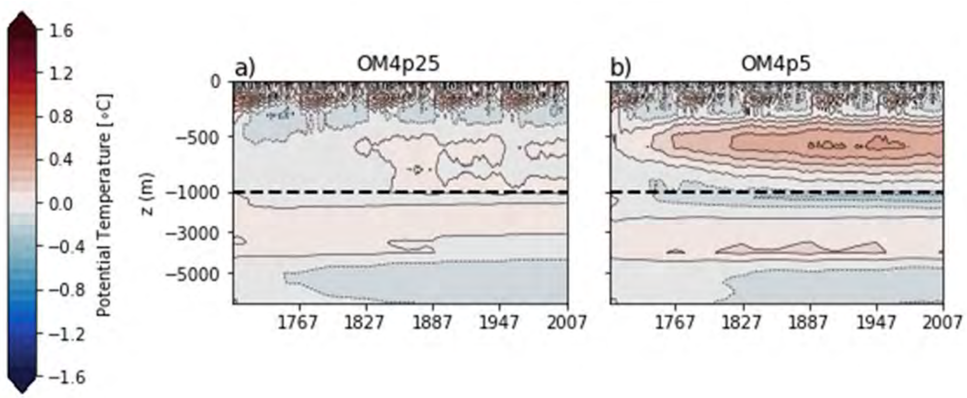
GFDL's latest generation ocean models have **small temperature drifts**, making them **well-suited** for studies of heat uptake and SLR

Volume Mean Ocean Potential Temperature (°C)



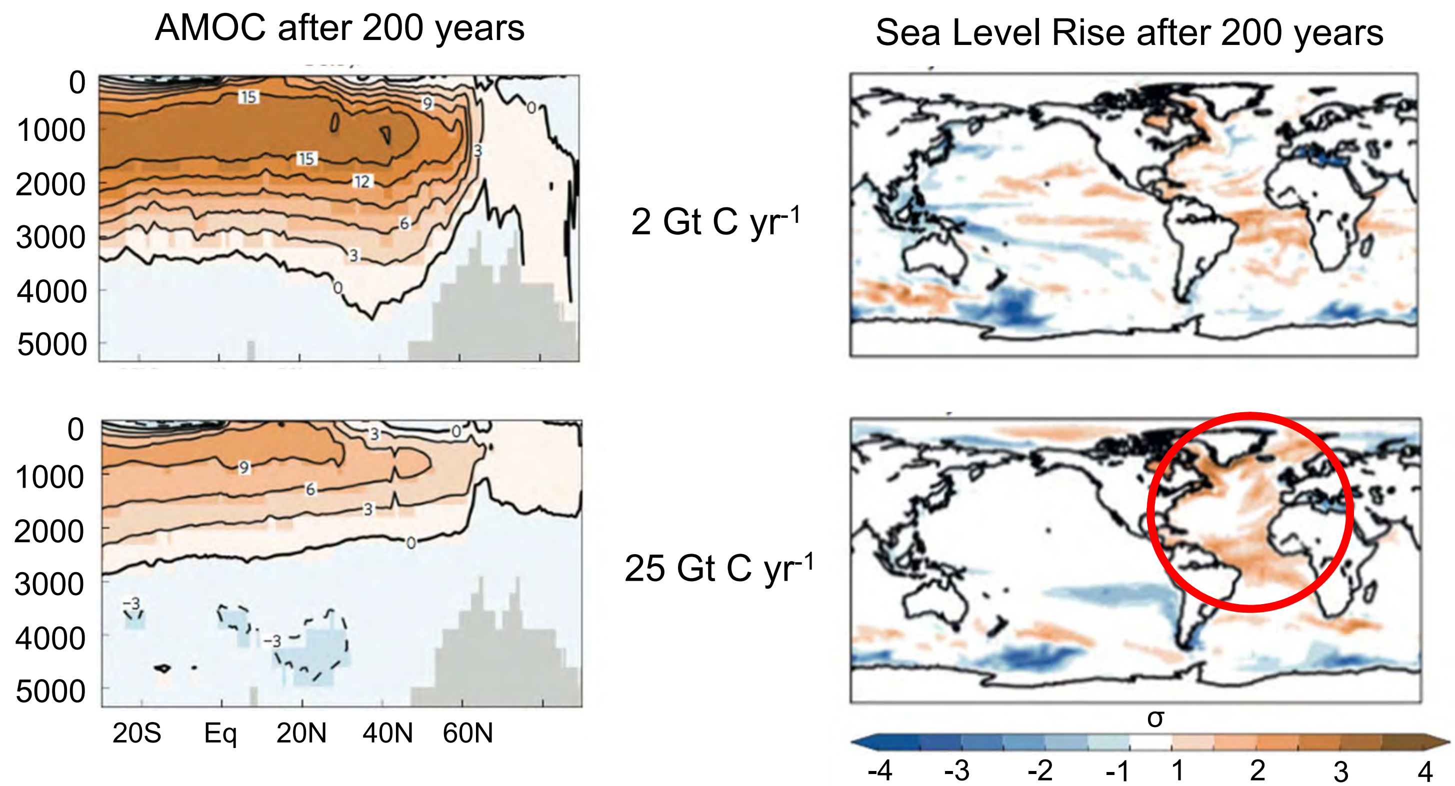
Drift:
OM4p25: 0.001 °C / century
OM4p5: 0.008 °C / century

Drifts in OCMIP2 models 2 - 3 orders of magnitude larger (Griffies et al. 2009)



Models with low drift increase confidence in projections of SLR and allow for better assessment as to whether or not the ocean is in equilibrium with forcing.

Regional Changes in SLR



Mechanism identified by Yin et al., 2009, Nat. Geosci. - Seen in obs [Goodard et al., 2015, Nature]

High carbon emissions -> reduced AMOC -> warmer Atlantic vs.Pacific -> more Atlantic SLR

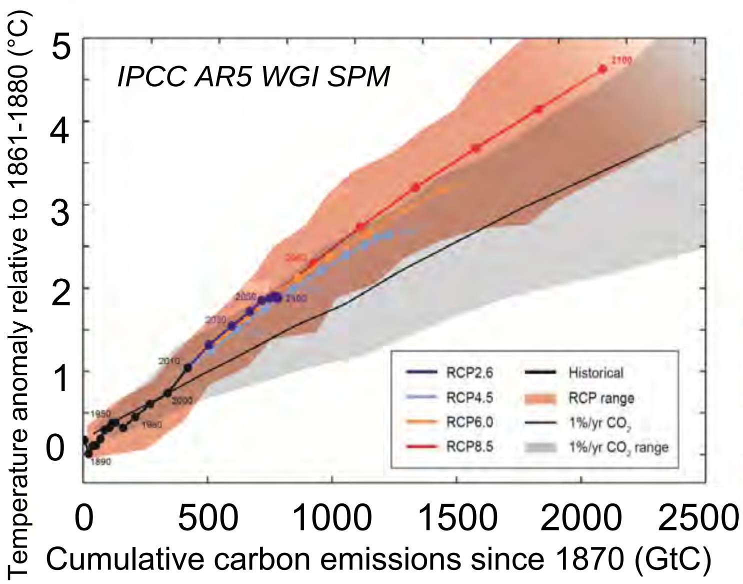
Results highlight that the ***Northeast US Coast*** *is particularly vulnerable to sea level rise*

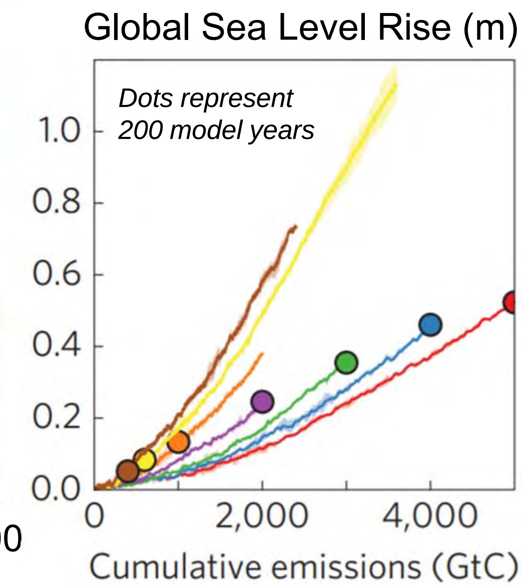
[Krasting et al., 2016, *Nature Geosci.*]

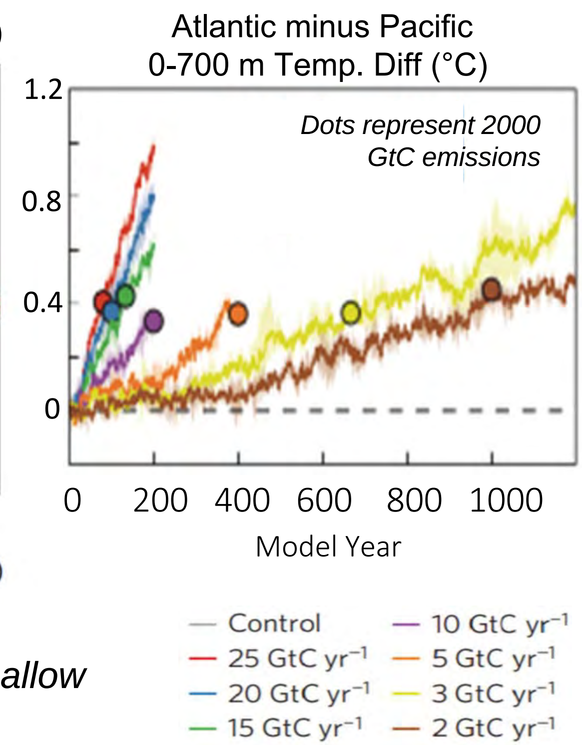
SLR is not Proportional to Cumulative Emissions

Unlike processes correlated with surface air temperature,
sea level rise is **not proportional to cumulative carbon emissions**.

Building on *Solomon et al., 2009, PNAS* and *Zickfeld et al., 2012, GRL* …





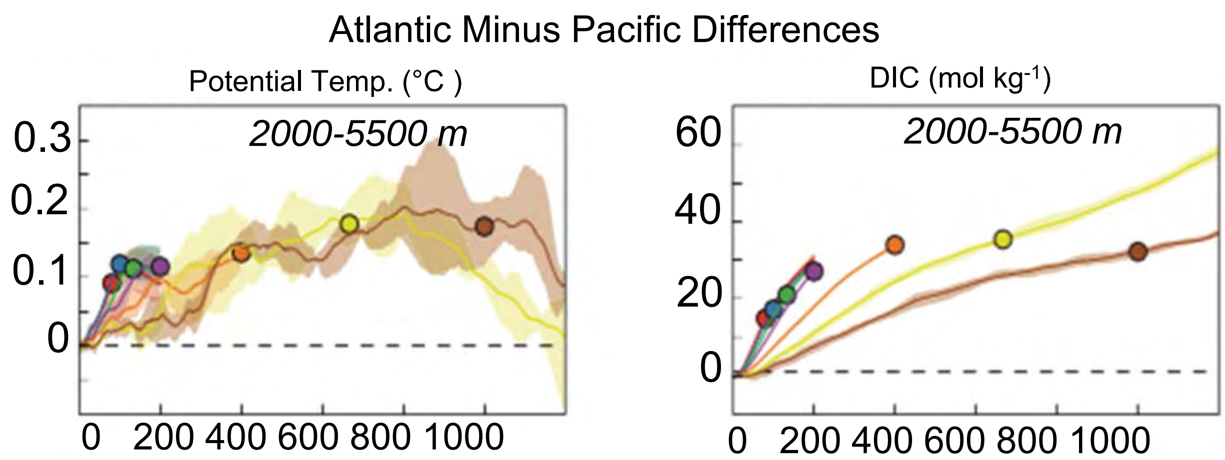


- *Longer timescales associates with slower rates of carbon emissions allow more ocean heat uptake and more SLR per unit of emitted carbon*
- *Upper ocean Atlantic minus Pacific differential heat uptake is proportional to cumulative emissions*

[Krasting et al., 2016, *Nature Geosci.*; Krasting et al., 2014, *Geophys. Res. Lett.*]

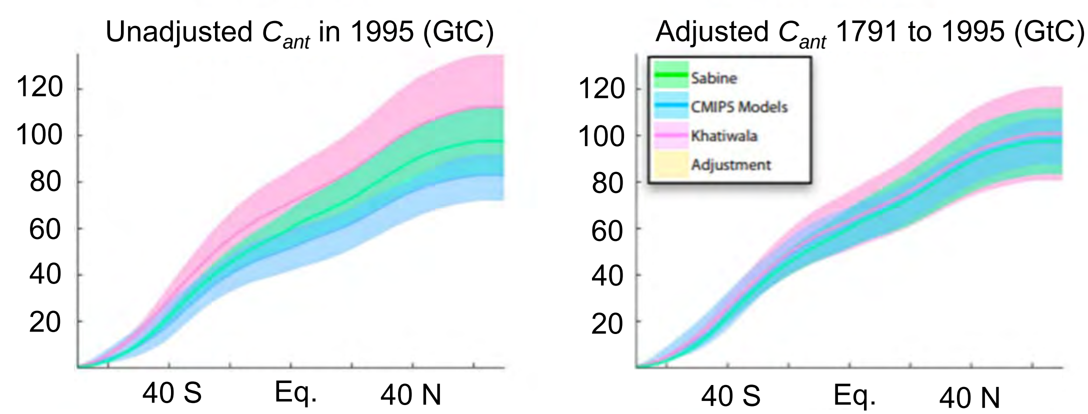
Ocean Carbon Uptake

Deep ocean carbon evolves differently than temperature, implying mechanisms for TCRE may not persist on long timescales



[Krasting et al., 2016, *Nature Geosci.*]

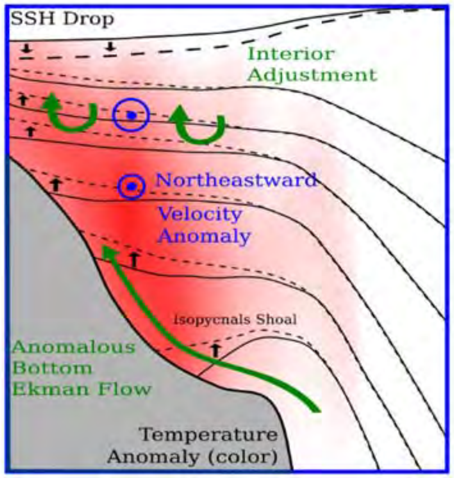
Adjusting for emissions prior to 1850 reconciles biases between models and obs. estimates of ocean carbon uptake



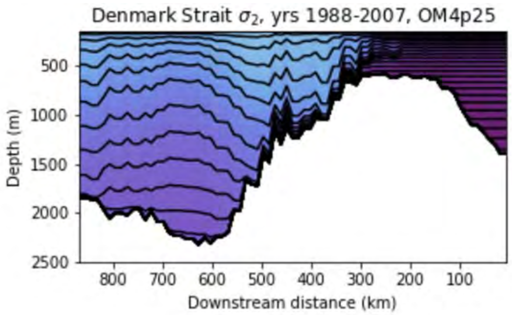
[Bronselaer et al. 2017, *Geophys. Res. Lett.*]

Future Plans & Challenges

- Engage in research on **ocean-cryosphere interactions** that have implications for SLR:
  - High-resolution & regional ocean modeling
  - Process-based studies (e.g. Spence et al. 2017)
  - Coupled ice shelf - ocean modeling



- Continue to **reduce ocean interior biases**
  - Further explore use of hybrid vertical coordinates
  - Improve ocean model numerics
  - Work on representations of ocean mixing
  - Improve representations of
    - deep water formation
    - ventilation pathways
    - water mass transformation processes



[Spence, Holmes, Hogg, **Griffies**, Stewart, and England, 2017, *Nature Clim. Change*]

Summary

- Sea level rise an **integrated response** among many different Earth system processes

- GFDL contributed to improvements in SLR modeling and projections through:
  - Forced vs unforced **regional patterns** of heat uptake
  - Developing ocean models with **very little drift**
  - Highlighting and modeling relationships between **SLR and ocean/cryosphere dynamics**
  - Projecting SLR, heat uptake, and carbon uptake **through cumulative carbon emissions**