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

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

Simulated in Current Generation Models
- Thermal expansion
- Dynamical circulation changes
- Hydrologic cycle changes

Not Simulated in Current Generation Models
- 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.

**Atlantic-Pacific basin differential warming**

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

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.]
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

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

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

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**