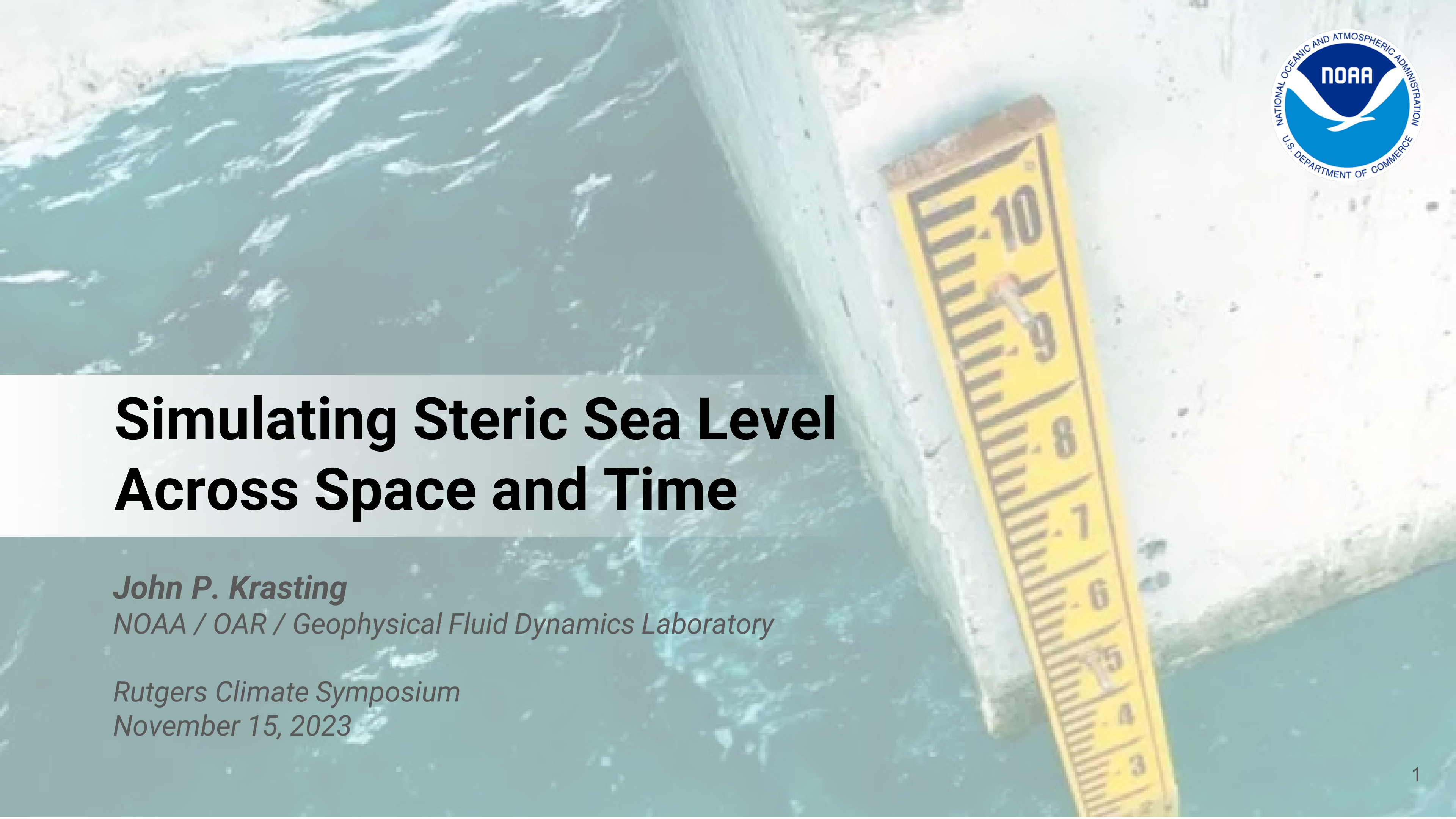


Simulating Steric Sea Level Across Space and Time

John P. Krasting
NOAA / OAR / Geophysical Fluid Dynamics Laboratory

Rutgers Climate Symposium
November 15, 2023

Ocean City, New Jersey

One example of many nationwide …

Amid rising seas, 'dry' resort is wetter than it likes

By WAYNE PARRY   February 17, 2021

OCEAN CITY, N.J. (AP) — Ocean City, New Jersey is officially a "dry" town.

14th Street, Ocean City NJ, October 2021 (Credit: The Patch)

- NYC + Philadelphia population is ~26 million
- Median home price in Ocean City, NJ is $1M

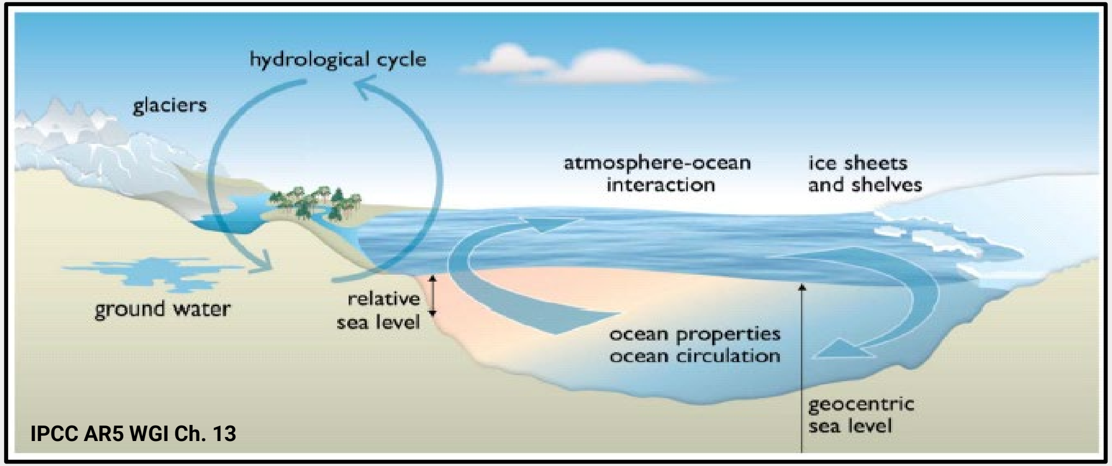
- Sunny day floods in 2050 will exceed current 10-year flood event (~3.3 ft)
- Under moderate warming scenario, floods like Sandy (~5 ft) could occur on a yearly basis

2019 New Jersey Science and Technical Advisory Panel Report

Motivation

- Sea level rise is and will continue to be one the ***primary impacts*** of a changing climate
- ***Steric sea water expansion*** is a leading cause of historical sea level rise
- Climate model simulations of ocean heat uptake and redistribution can be used to understand the ***patterns, projections, and mechanisms*** of steric SLR

Sea Level Rise Linked to Earth System Processes



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

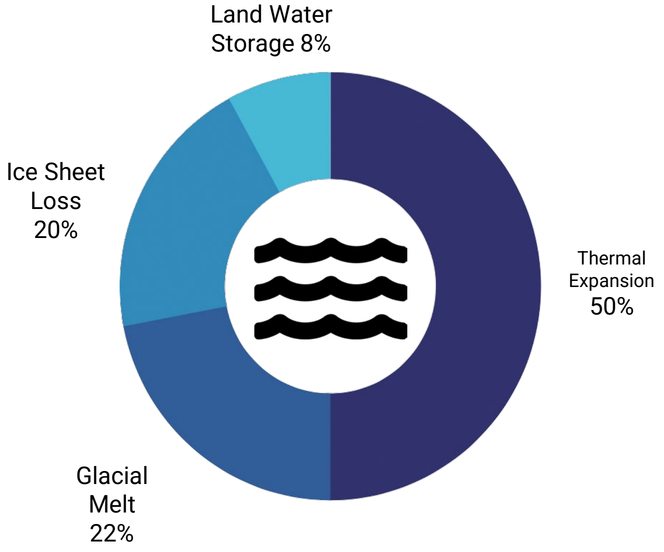
Thermal expansion, ocean circulation*, hydrologic process*, land cryosphere interactions, and geoid changes*

*(* denotes processes represented in GFDL coupled models)*

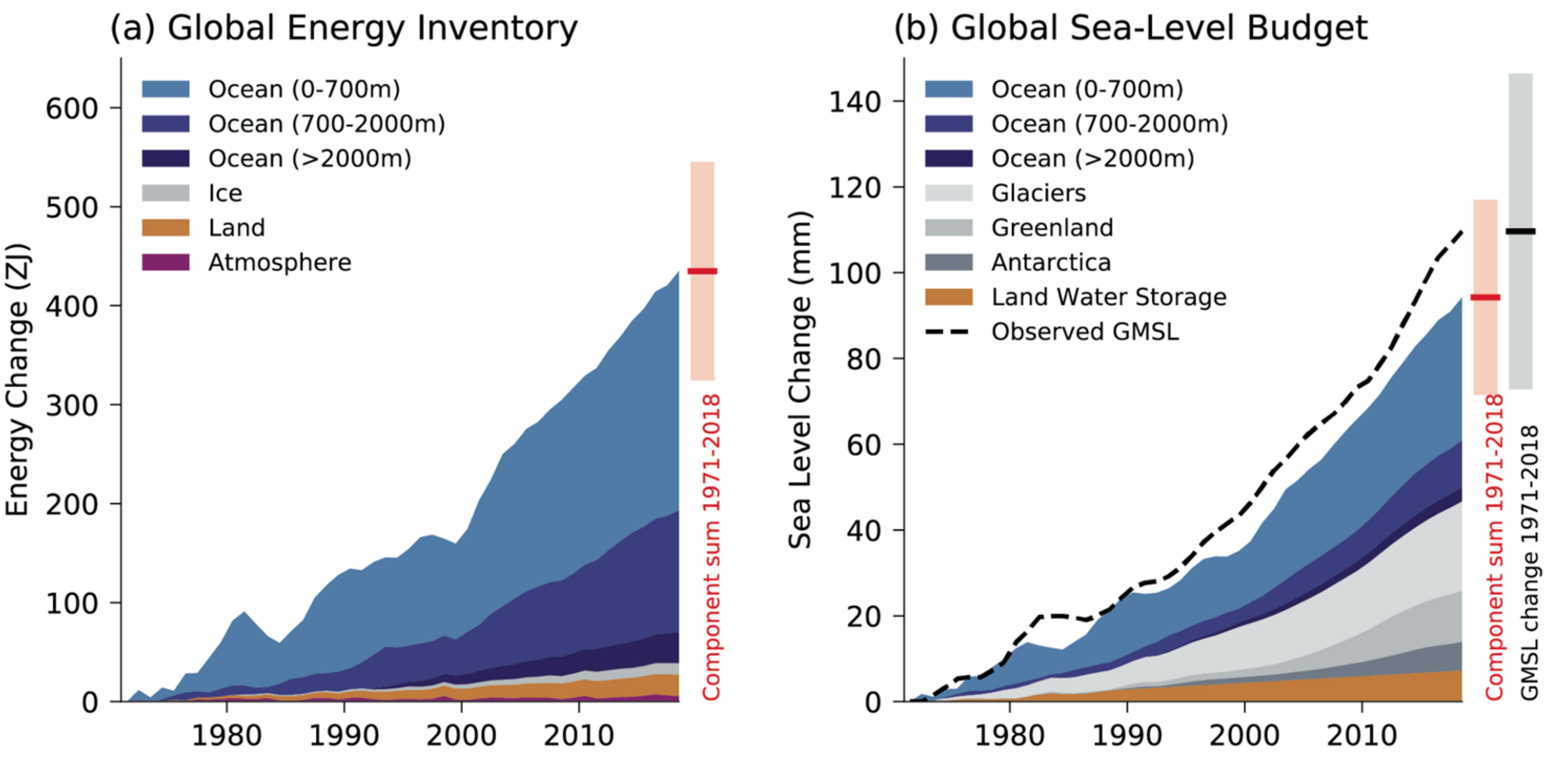
Global Mean Sea Level Rise in IPCC AR6

- ***Thermal expansion*** accounts for 50% of sea level rise from 1971-2018
- Considerable uncertainty remains in projections of global mean sea level rise by 2100
  - Uncertainty stems from forcing pathway
  - "*Likely*" global SL projections ***0.28 to 1.01 m*** by 2100 relative to 1995-2014 levels
  - Ranges do not include models that simulate marine ice cliff instability
- AR6 projections are "*modestly higher*" than AR5
  - Most contributing factors are consistent from AR5 to AR6 except for Antarctic ice melt

Contributions to Global Sea Level Rise 1971 to 2018



From IPCC AR6 Summary for Policymakers



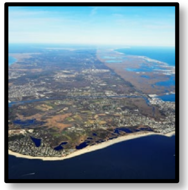
IPCC AR6 - Chapter 9

Importance of SLR Modeling / Projections

Sea level rise is relevant to OAR's strategic plan and maps into aspects of:

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

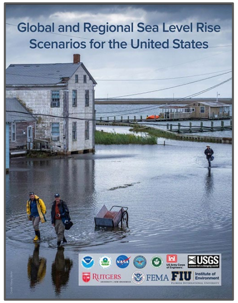
Healthy Oceans

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

2022 Interagency Sea Level Rise Report

Sweet et al., 2022

https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report.html



Next 30 Years

US sea level projected to rise ***10-12 inches*** *– same as the previous 100 years*

More Flooding

Today's "moderate" flooding events will occur ***10x more*** *frequently*

Emissions Matter

Curbing GHG emissions could ***prevent up to 5 feet*** *of additional SLR by 2100*

Continual Tracking

Sustaining and expanding sea level monitoring crucial for ***adaptation planning***

Timescales of Steric Change

- **Steric changes that occur on medium to long time scales**
  - Multi-decadal to centennial ventilation timescales
  - Climate change forcing

- **Steric changes on shorter timescales**
  - Decadal variability: e.g. AMOC
  - Annual to seasonal

Using GFDL ocean and climate models, we are examining simulations of steric sea level that span these timescales.

Sea Level Science using GFDL's Modeling Hierarchy

GFDL-CM4
Held et al. 2020, JAMES

Atmosphere:
100-km, 33 level AM4.0 with simplified chemistry
Ocean:
0.25° eddy permitting MOM6 with non-interactive BGC (BLING)
Sea Ice:
Sea Ice Simulator v2
Land:
Land Model v4.0

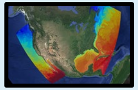
GFDL-ESM4
Dunne et al. 2020, JAMES

Atmosphere:
100-km, 49 level AM4.1 with full chem.
Ocean:
0.5° MOM6 with complex interactive BGC (COBALT)
Sea Ice:
Sea Ice Simulator v2
Land:
Land Model v4.1 with ecology

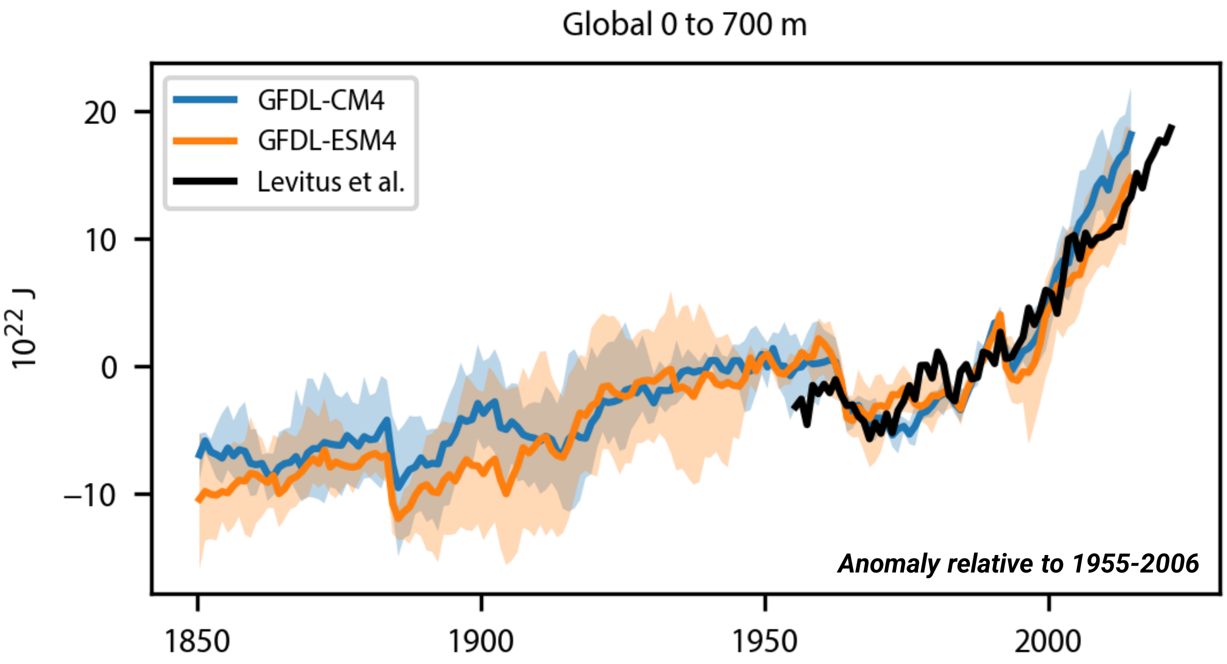
GFDL-SPEAR
Delworth et al. 2020, JAMES

Atmosphere:
LO - 100 km, 33 level AM4.0
MED - 50 km, 33 level AM4.0
Ocean:
1° MOM6 physical-only (no BGC)
Sea Ice:
Sea Ice Simulator v2
Land:
Land Model v4.0

Regional Ocean Modeling
3-km domains around US Coastline



Globally Integrated Heat Content Change since 1850

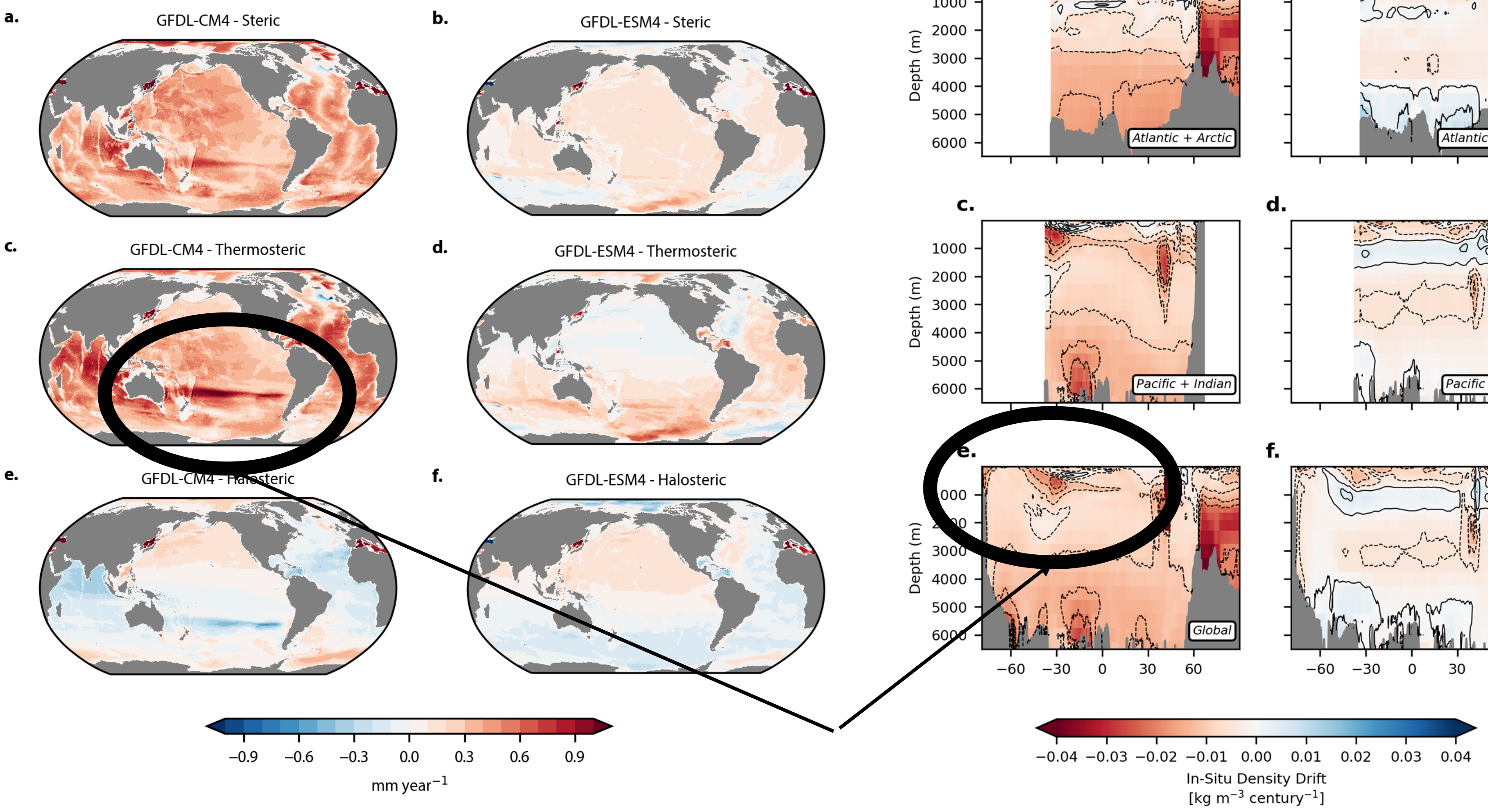


Much of the anthropogenic-driven ocean heat content change is within the upper 700 m

Result is consistent with previous studies and compares well with observations (Levitus et al.)

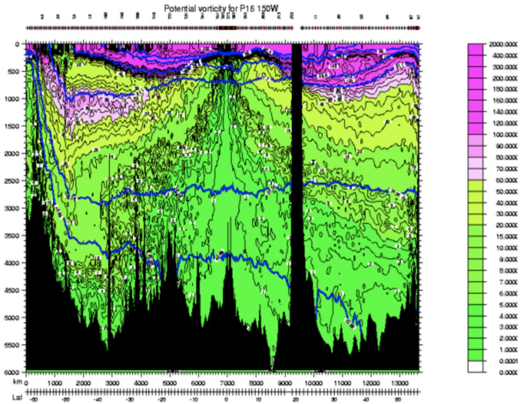
Krasting et al., in review.

Spatial Patterns of Drift in piControl Simulation

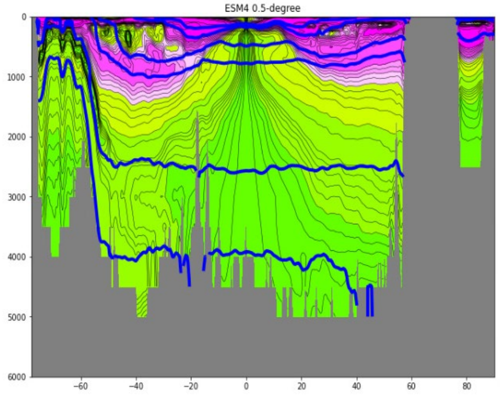


Reduced AAIW Representation in CM4

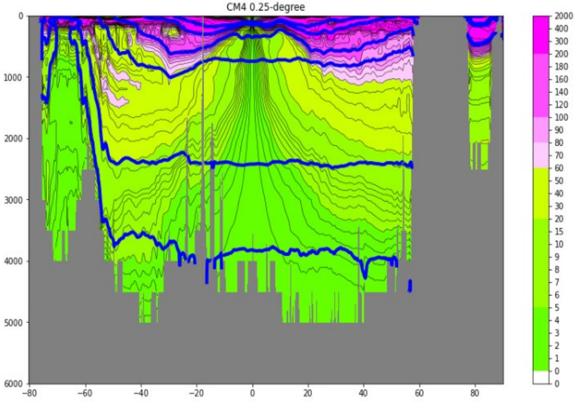
Talley et al. 1998



GFDL-ESM4



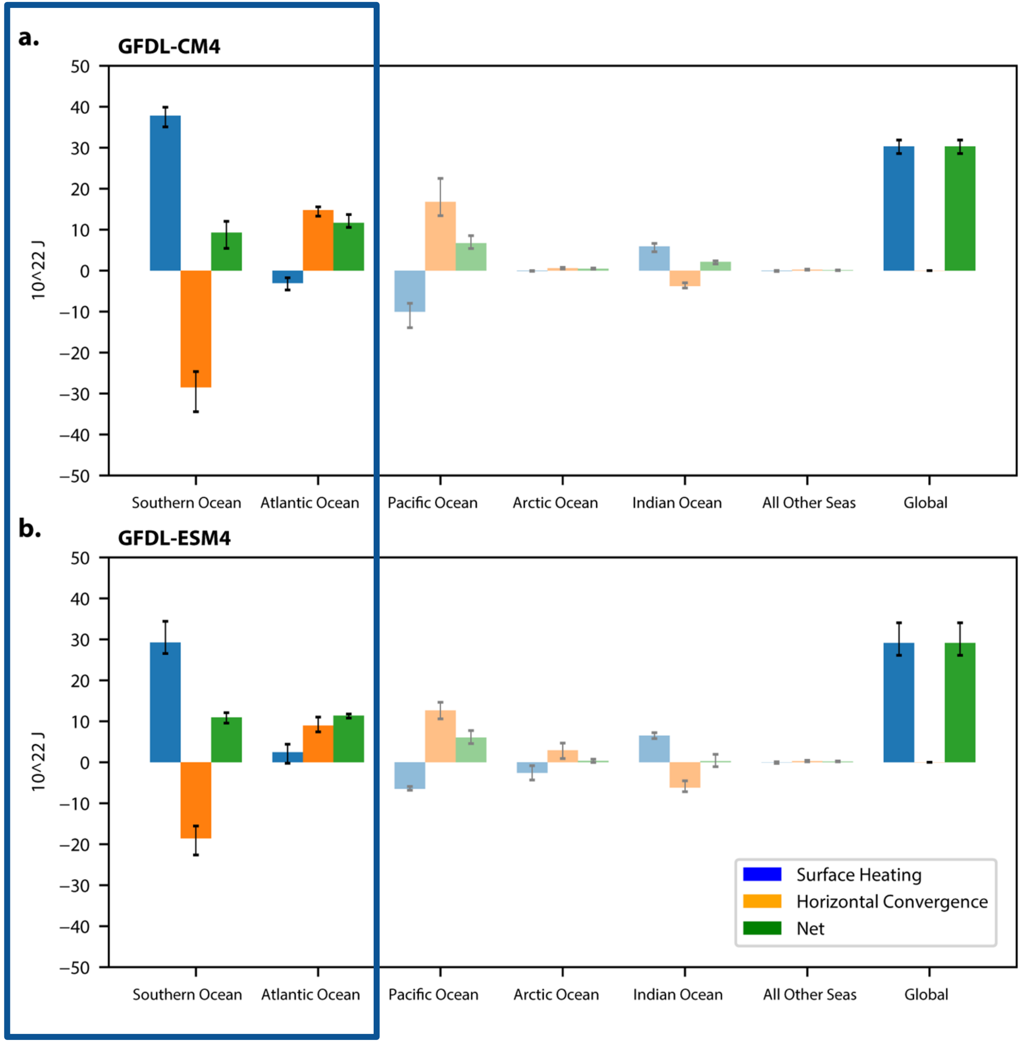
GFDL-CM4



- Plots above represent the stratification contributions to PV
- AAIW is the tongue of higher PV between 500-1000 m
- Lack of AAIW ventilation in CM4 leads to localized thermal expansion

From: J.E. Tesdal

Vertically Integrated Heat Budget in MOM6

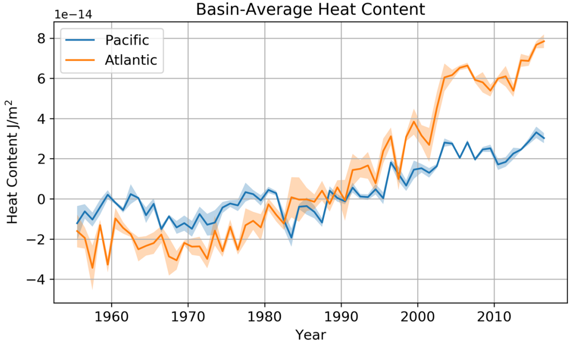


$$\frac{dQ}{dt} = F + \rho_0 C_p \int_{-H}^{\eta} -(\nabla \cdot \mathbf{u}\theta)\, \mathrm{d}z + \text{residual}$$

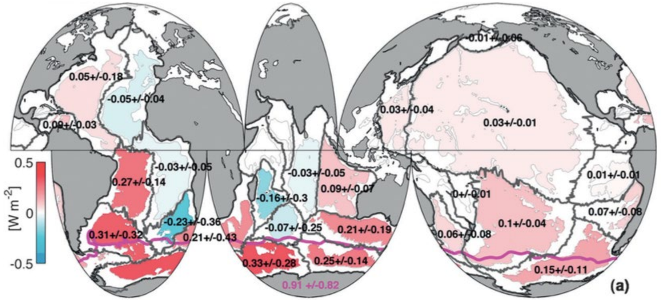
- Most of the excess anthropogenic heat enters through the Southern Ocean
- 10 x 10^{22} J net storage change in the SO in both models
- CM4 takes up ~30% more heat from the atmosphere than ESM4 in the SO

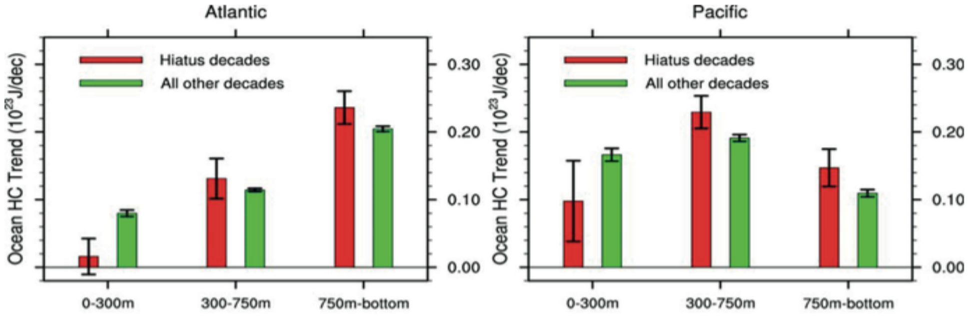
Krasting et al., in review.

Observed Regional Changes in Ocean Heat Content

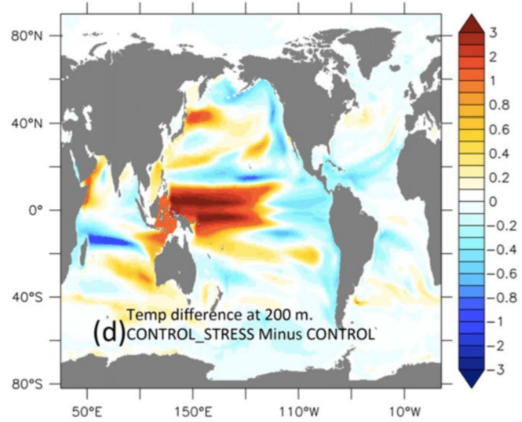


Purkey and Johnson, 2010



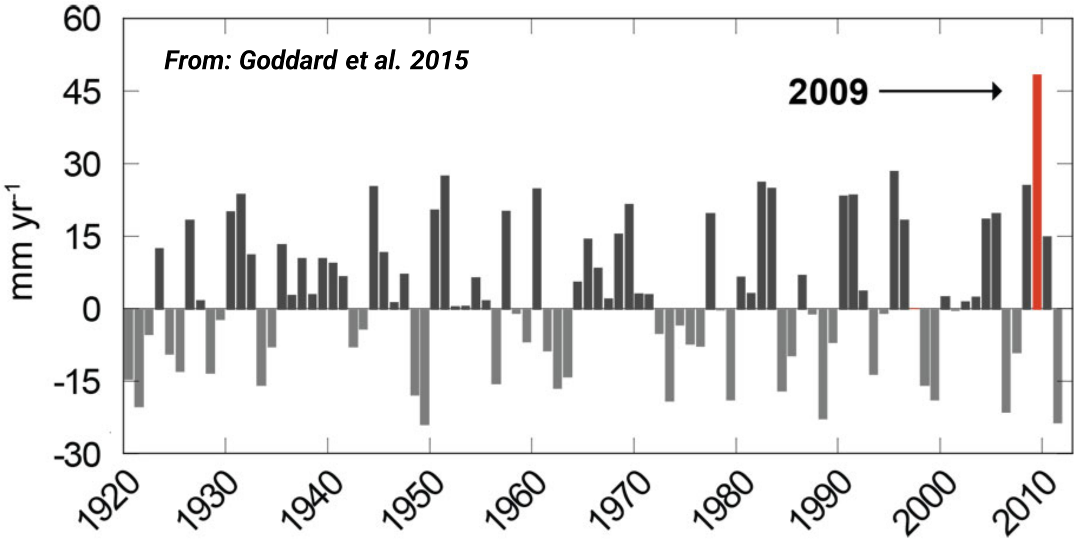


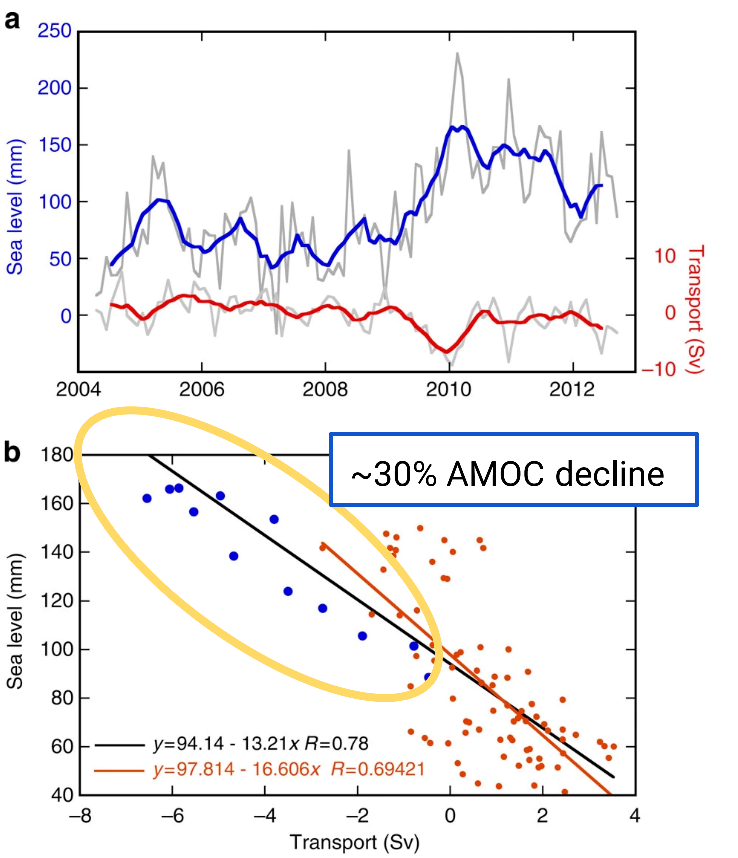
Meehl et al. 2011



Delworth et al. 2015

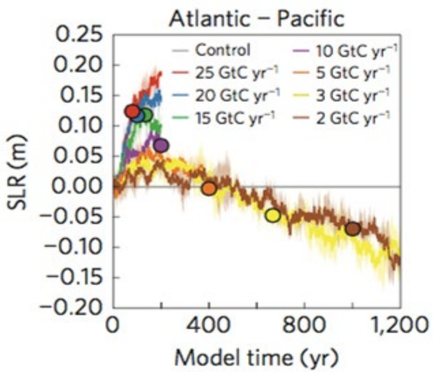
2009-2010 East Coast Sea Level

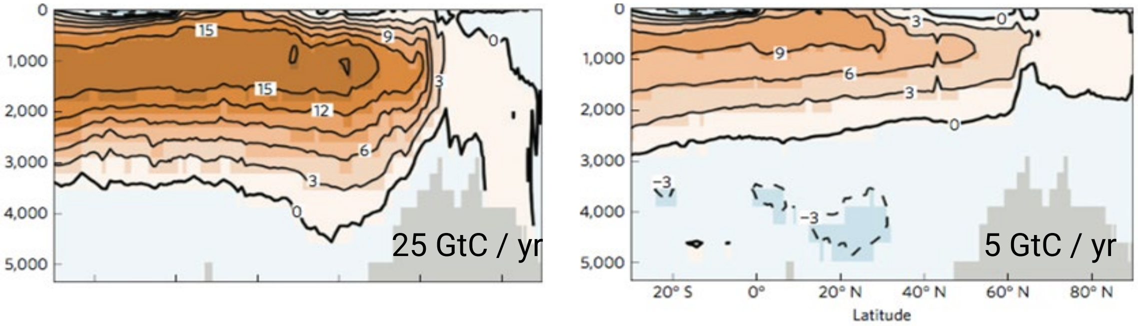


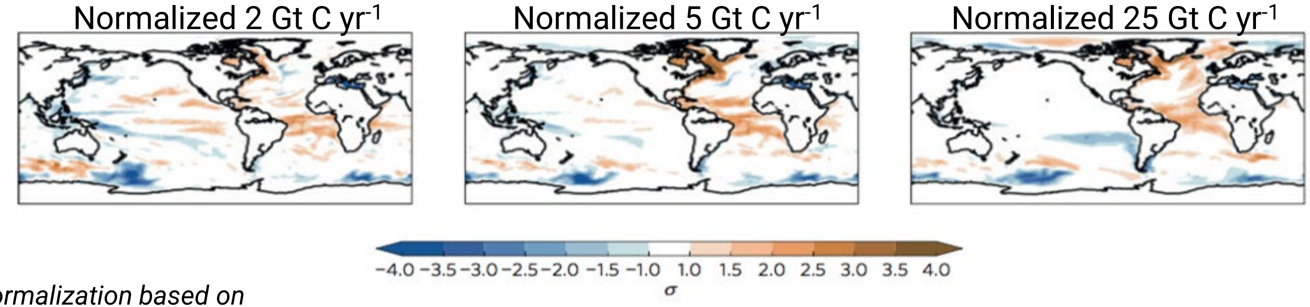


Observed increase in the rate of sea level rise linked to a weaker AMOC state in 2009-2010

Weaker AMOC Leads to Enhanced Atlantic SLR



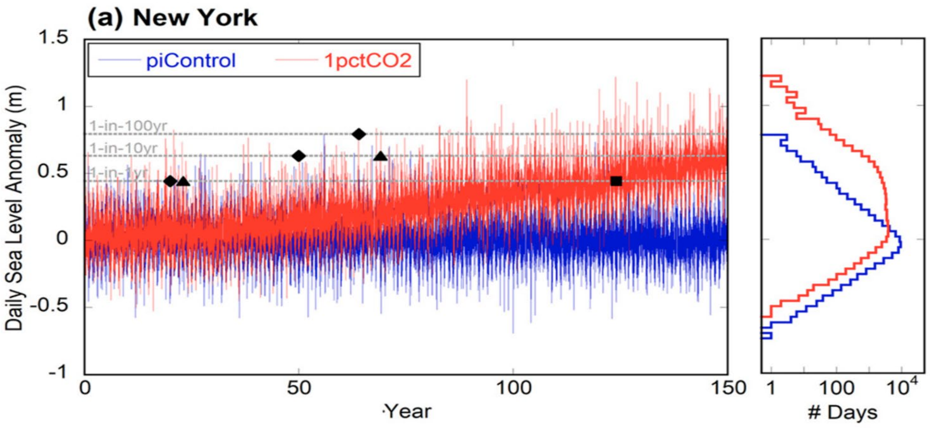


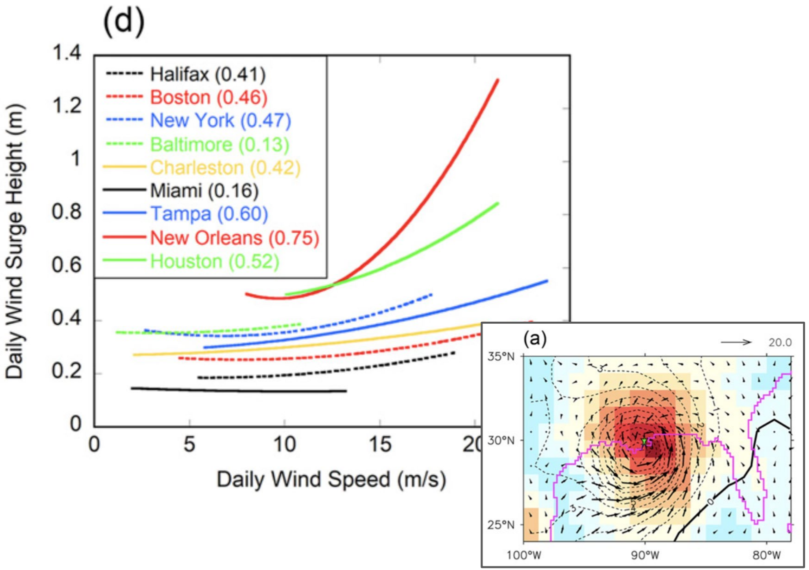


AMOC declines more under faster warming leading to enhanced Atlantic sea level rise

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

Daily Sea Level Extremes





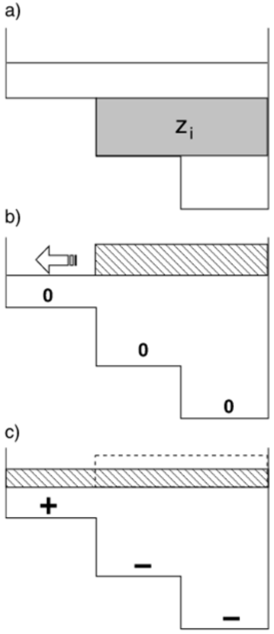
Increasing frequency of extreme sea levels projected for the US East Coast are linked to a declining AMOC and are compounded ***during Nor'Easters***

Extreme SL events along the Gulf Coast are sensitive to wind anomalies, and therefore ***changes in TC activity***

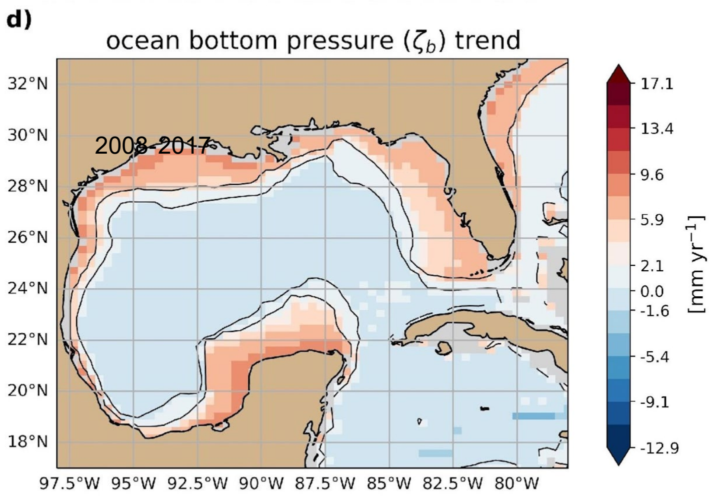
Yin et al. 2019
GFDL Co-authors: S. Griffies and S. Zhang

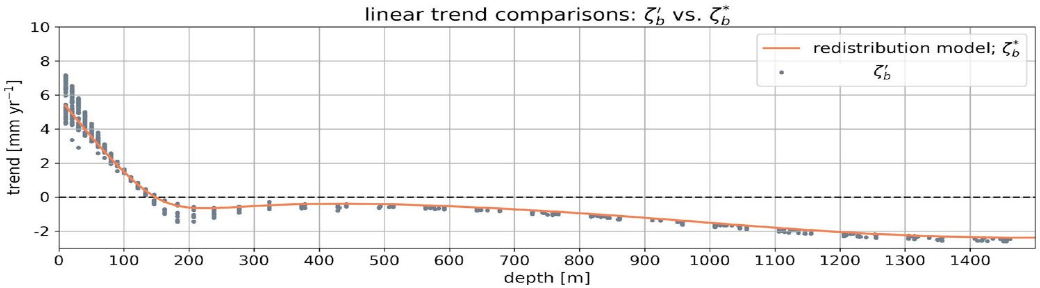
Mass Redistribution Driven by Steric Changes

GFDL: ***Dr. Jacob Steinberg***



Landerer et al. 2007
https://doi.org/10.1029/2006GL029106





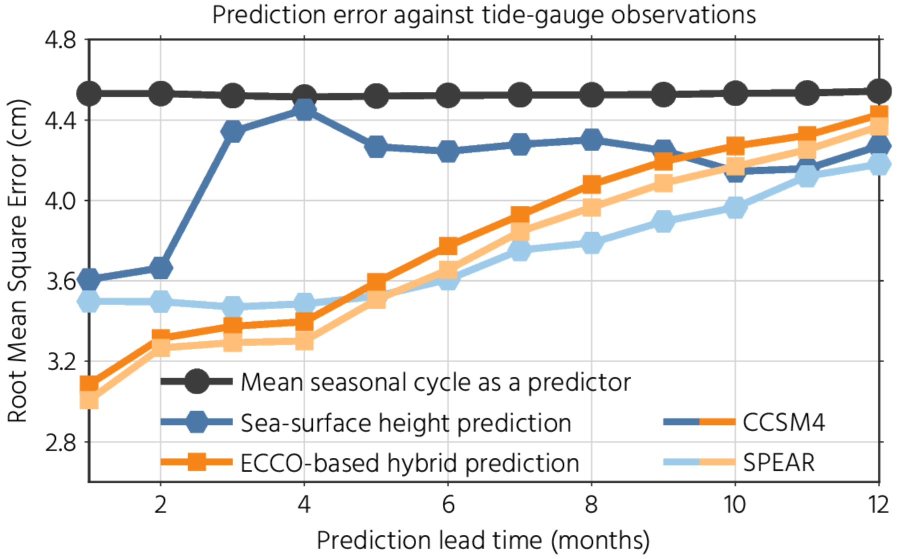
On-shelf trends predicted through mass redistribution framework are consistent with the trends simulated by ECCO

Actively exploring the mass distribution framework in 1/12º regional MOM6 configuration along the US East Coast

Steinberg et al. in review
doi:10.22541/essoar.167591128.80195286/v1

RISE: Sea Level Prediction

NOAA Partners: NOS (CO-OPS), OAR (GFDL, PSL)
GFDL: J. Krasting & L. Jia



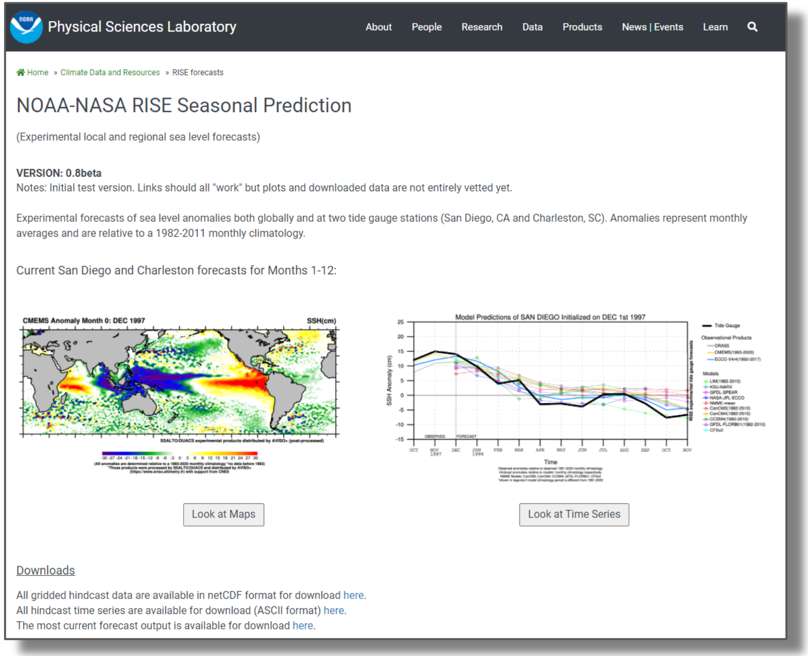
Seasonally de-biased forecasts from seasonal prediction systems (e.g. GFDL-SPEAR) and adjoint hybrid systems (ECCO) demonstrate skill on annual timescales

Next-Generation Sea Level Prediction System

- 5-year joint development effort
- Will cover weather to climate timescales
- Goal: to become operational

RISE Pilot Locations

RISE Products & Ensemble Comparison Website



Matthew Newman
(NOAA/PSL)

https://www.psl.noaa.gov/forecasts/RISE/

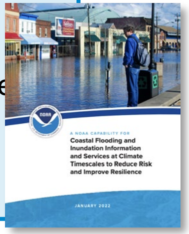
Addressing Sea Level with the Next-Gen Models

Bipartisan Infrastructure Law (BIL)

- Study and improve sea level processes in regional MOM6
- Explore sub-seasonal to annual predictability using SPEAR & Regional MOM6
- Improving tidal representation in MOM6
- Develop a coupled regional model

Coastal Inundation at Climate Timescales Initiative

- Development of GFDL's modeling systems for sea level applications
- Conduct basic research into processes that drive sea level its predictability
- Increases in HPC capacity



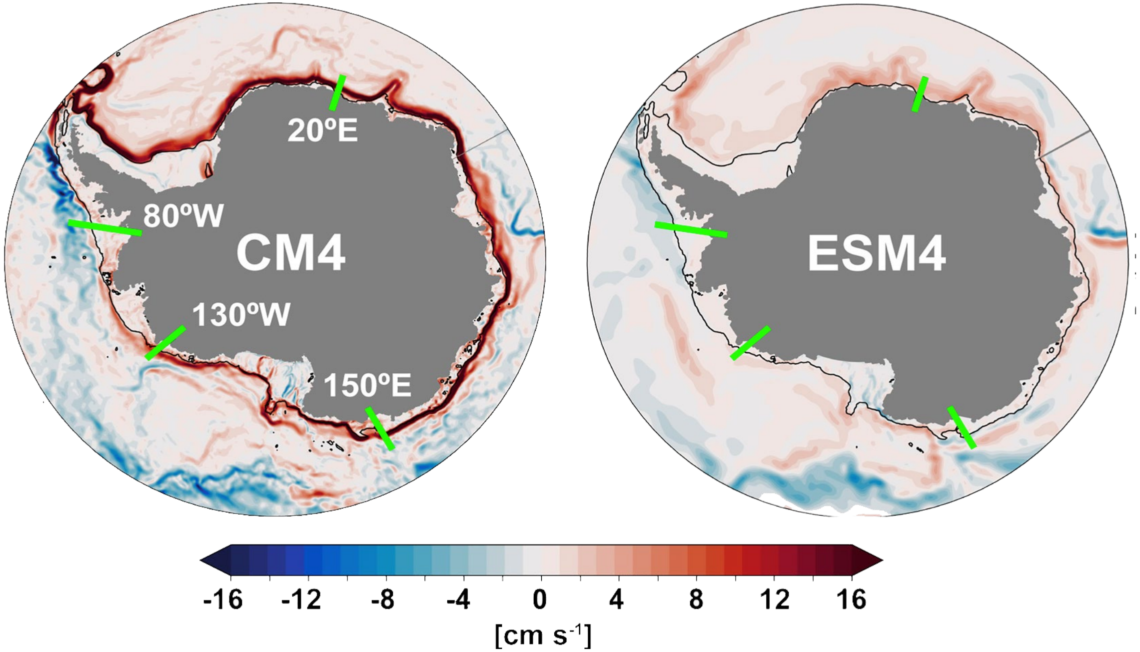
Anticipated Developments for OM5 Relevant to Sea Level

- *Coupled Interactive Antarctic & Greenland ice sheets*
- *Improved sea ice-ocean coupling*
- *Non-Boussinesq implementation*
- *Improved vertical coordinate and interpolation schemes*
- *Representation of explicit tides*
- *Mixing associated with non-local internal tide breaking*
- *Additional updates and improvements to physics*

Southern Ocean Response to Antarctic Meltwater

Beadling et al. 2022, JGR Oceans

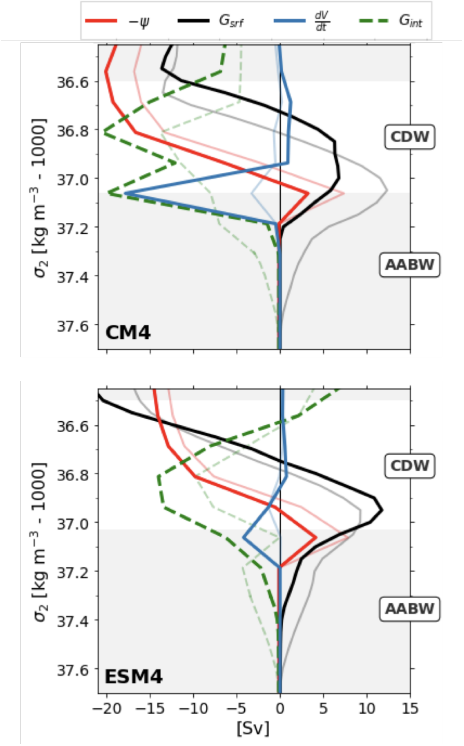
Antarctic Slope Current Response to Meltwater Forcing

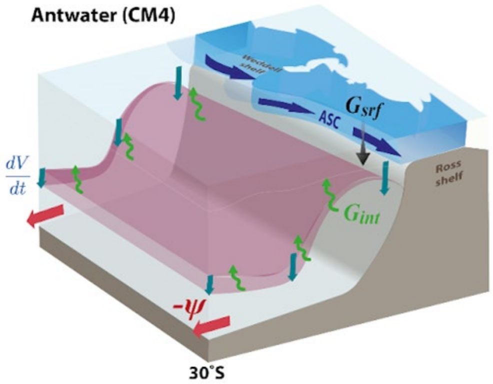


Antarctic meltwater ***strengthens currents*** *that isolate the shelf from warm water intrusions*

Southern Ocean Response to Antarctic Meltwater

Tesdal et al. 2022, JGR Oceans



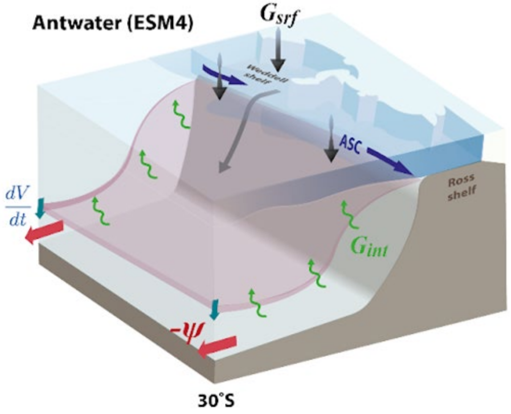


Effects of Antarctic melt perturbation in **CM4** (0.25˚, more resolved ASC)

- ➢ Dense Shelf Water formation is shutting down
- ➢ Strong deflation of AABW
- ➢ AABW consumption amplified by interior mixing

Effects in **ESM4** (0.5˚, less resolved ASC)

- ➢ Dense Shelf Water reduced by ~50%
- ➢ Deflation of AABW four times smaller compared to CM4



Both models have the same response in AABW transport at 30˚S

Take-home Points

- It’s possible to get the global mean steric SLR right through compensating biases, particularly in ventilating water masses
- Long term AMOC response matters - particularly for US EC sea level
- Steric changes and heat anomalies and their interplay with mass redistributions being investigated on shorter time scales
- Planned improvements to MOM6 and GFDL OM5/CM5 are targeting sea level applications