Global and Maryland Sea Level Rise Scenarios

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Most Global Mean Sea Level Rise is accounted for by thermal expansion (30-55%), glacial loss (15-35%), and storage of ground water. Local SLR must account for ocean dynamics, redistribution of land ice mass, and vertical land movement.

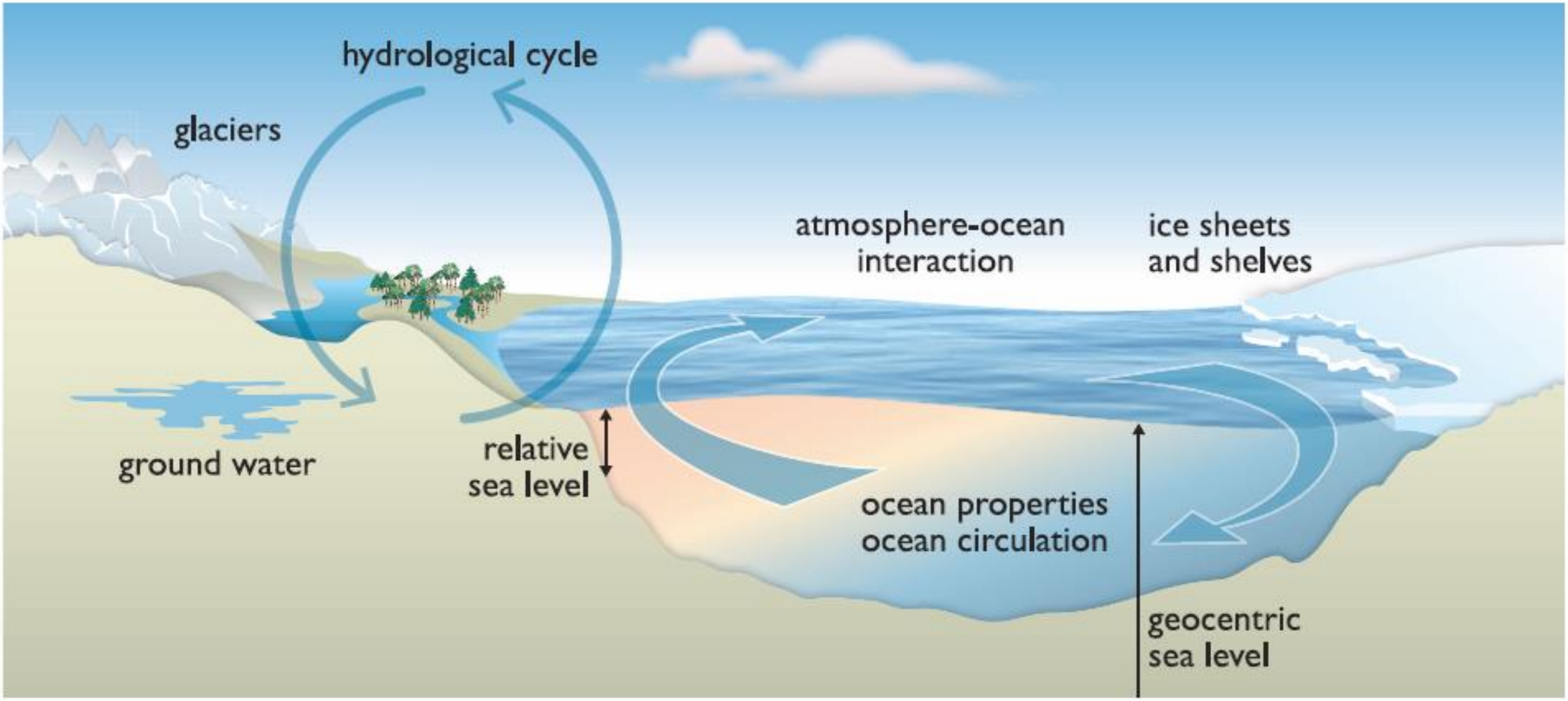


Figure 13.1 | Climate-sensitive processes and components that can influence global and regional sea level and are considered in this chapter. Changes in any one of the components or processes shown will result in a sea level change. The term 'ocean properties' refers to ocean temperature, salinity and density, which influence and are dependent on ocean circulation. Both relative and geocentric sea level vary with position. Note that the geocenter is not shown.

Source: IPCC AR5 (2013) Chapter 13

The geographic variability in the rate of sea level change (1992-2010) is evident in satellite altimetry data.

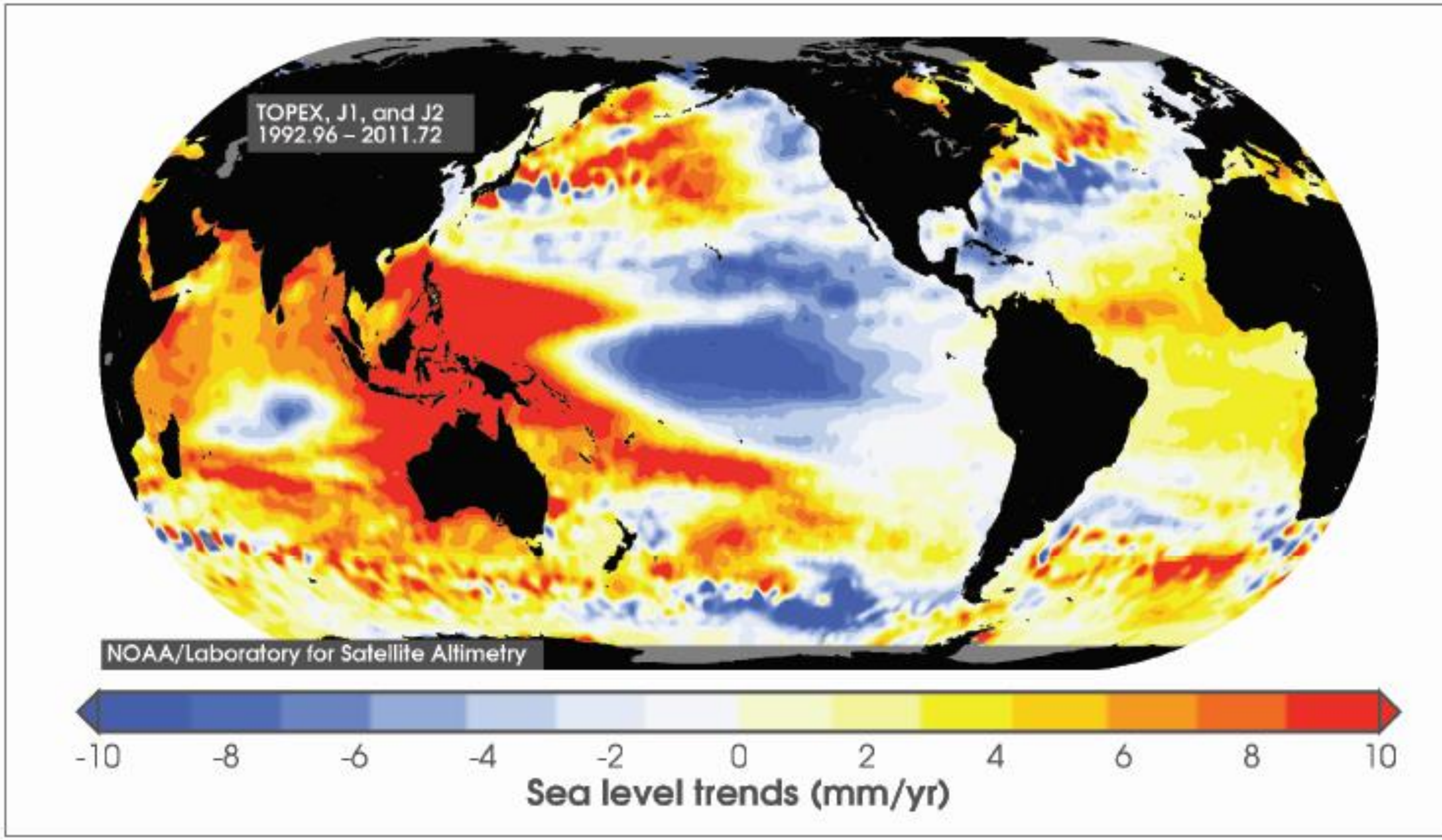


Figure 2. Geographic variability in the rate of global sea level change (1992 to 2010) based on three satellite records: TOPEX, Jason 1 and Jason 2 (Figure source: NOAA Laboratory for Satellite Altimetry – Accessed November 2, 2011).

Parris et al., 2012 (Global SLR Scenarios for U.S. NCA)

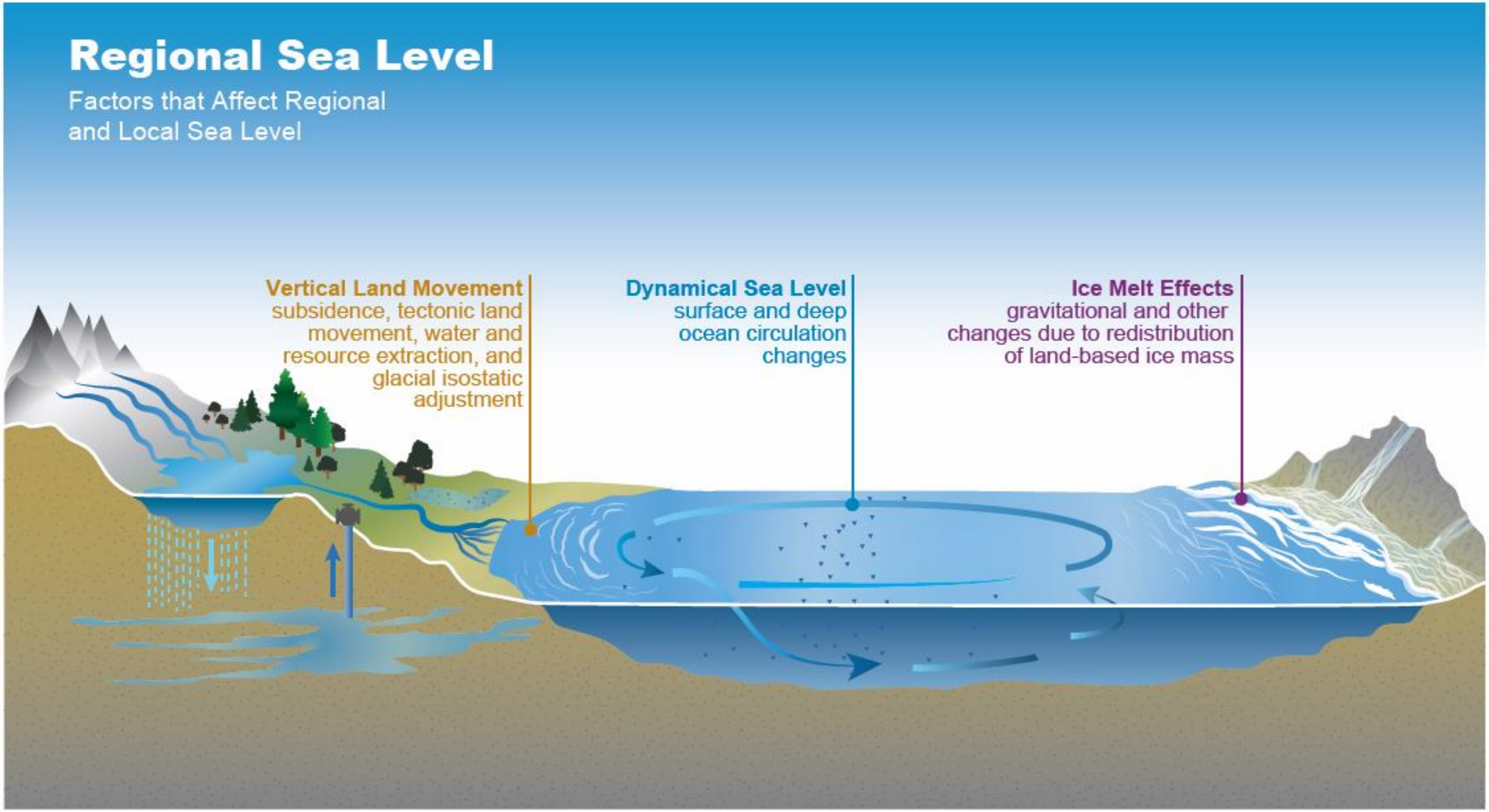


Figure 2.6 Regional and Local Adjustments to Sea Level
(adapted from IPCC 2001)

The rate of SLR in the Mid-Atlantic exceeds the global average computed from tide gauge records (1.7 mm/yr), mostly due to Vertical Land Movement associated with glacial isostatic adjustment.

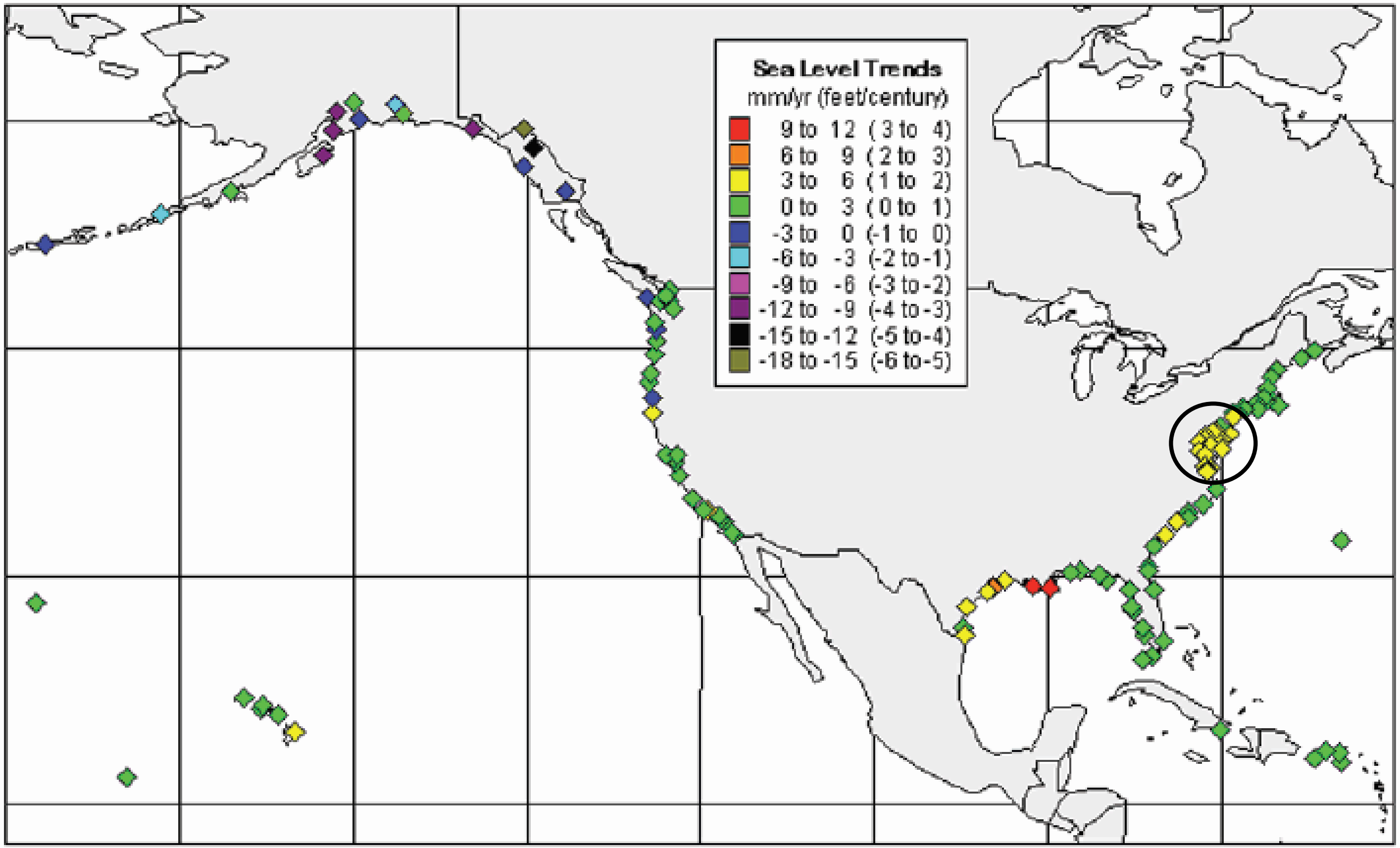
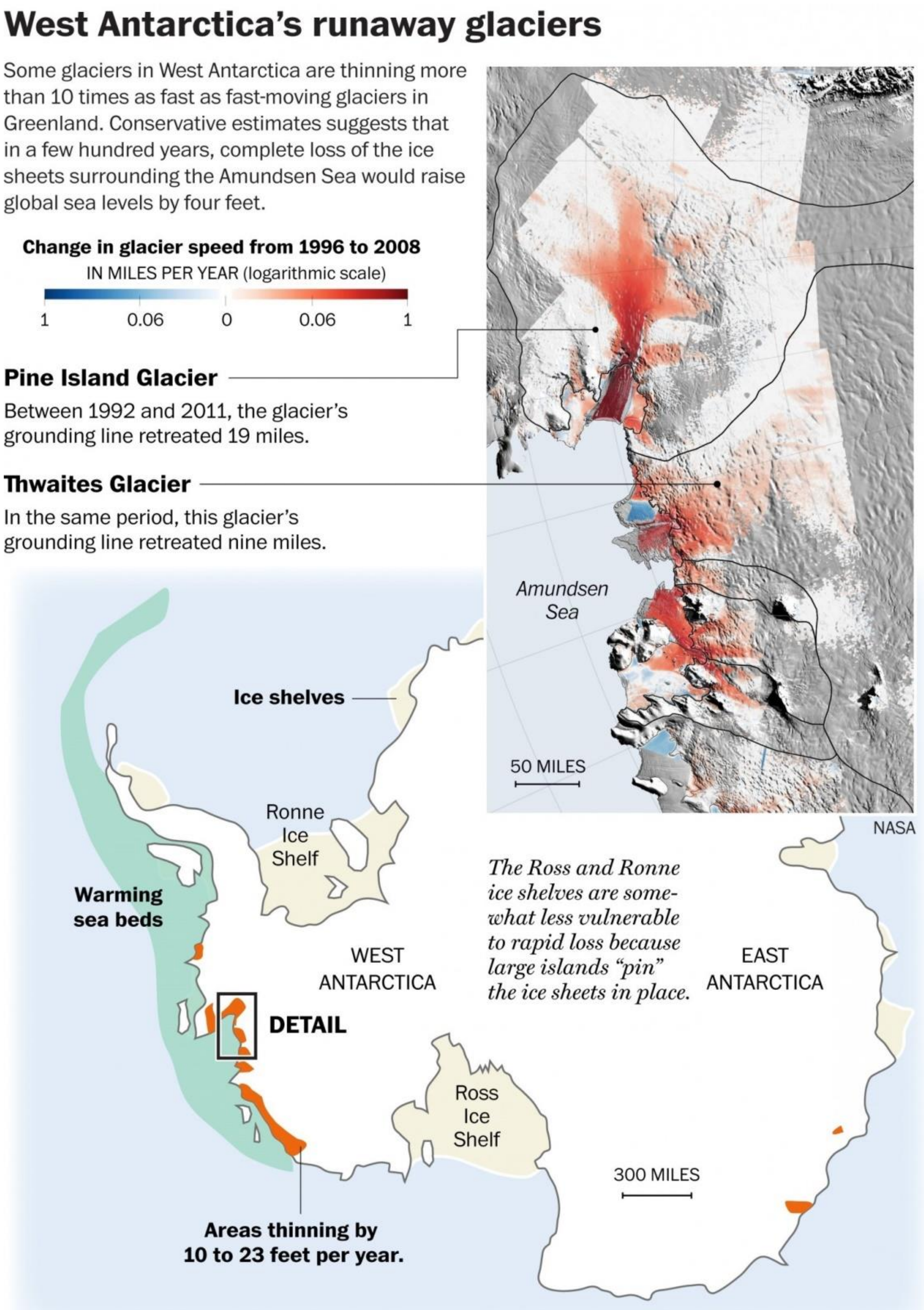


Figure 3. Relative Sea Level (RSL) Variations of the United States (1854 to 2006). Derived from 128 National Water Level Observation Network Stations. Source: Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), Center for Operational Oceanographic Products and Services (CO-OPS) - http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml (accessed August 16, 2012).

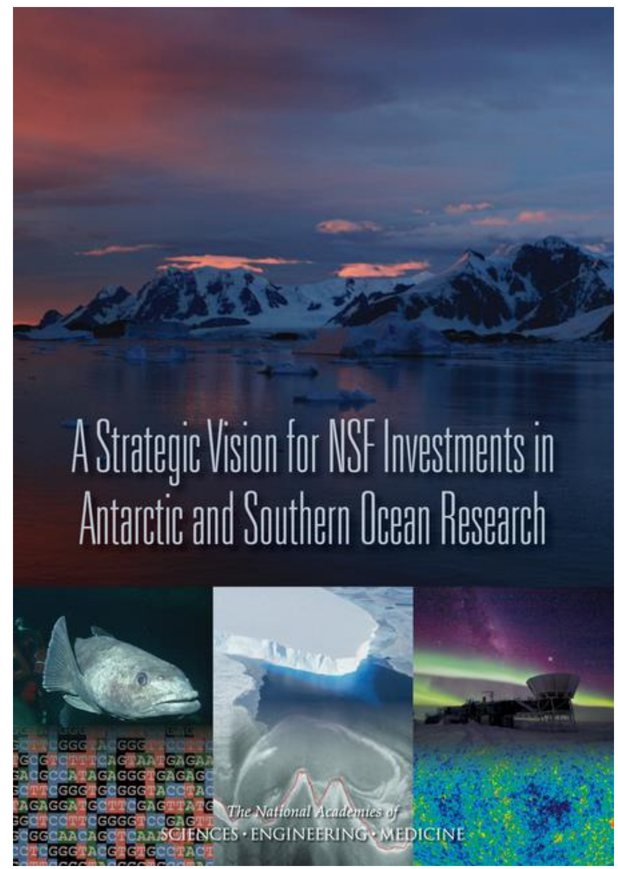
Parris et al., 2012 (Global SLR Scenarios for U.S. NCA)



Rapid changes in ice sheet dynamics are not well modeled.

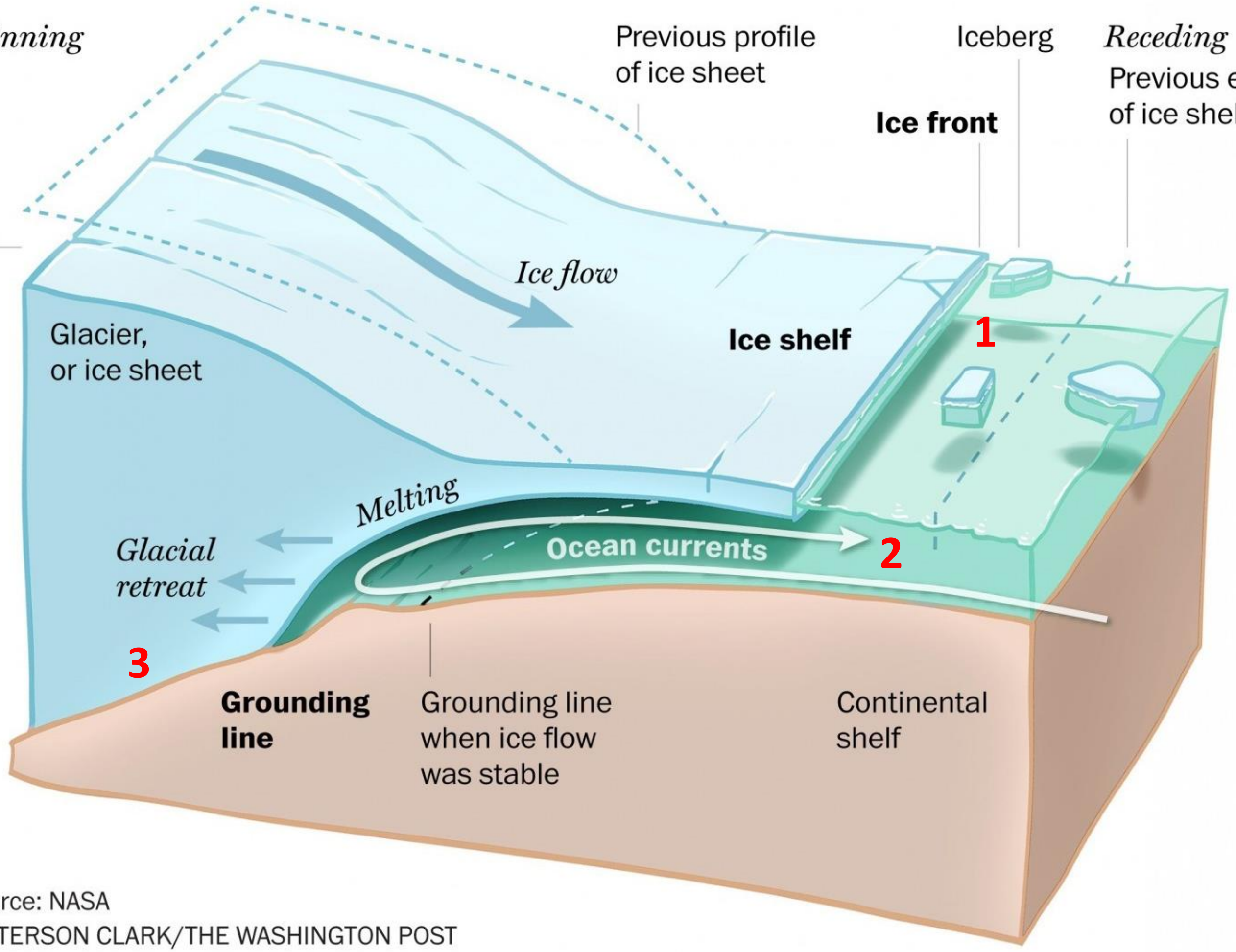
"The National Academies of Sciences recently concluded that the National Science Foundation should make research on Antarctica's sea level implications its top priority, with a particular emphasis on West Antarctica."

https://www.washingtonpost.com/news/energy-environment/wp/2015/09/29/scientists-declare-an-urgent-mission-study-west-antarctica-and-fast/



The problem with a retrograde bed

The bedrock under the front of some Antarctic glaciers slopes down and away from the sea bed, making the glaciers especially vulnerable to collapse. Warm, circumpolar deep water flows in under the glacier's ice shelf, melting the glacier's base, causing it to race into the sea at a faster pace, which leads to thinning and recession of the ice sheet.



Source: NASA
PATTERSON CLARK/THE WASHINGTON POST

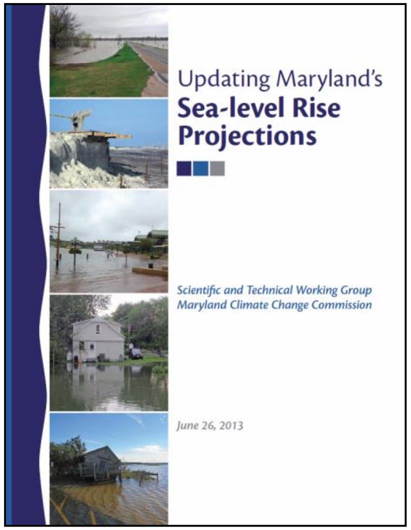
Knowledge Gaps

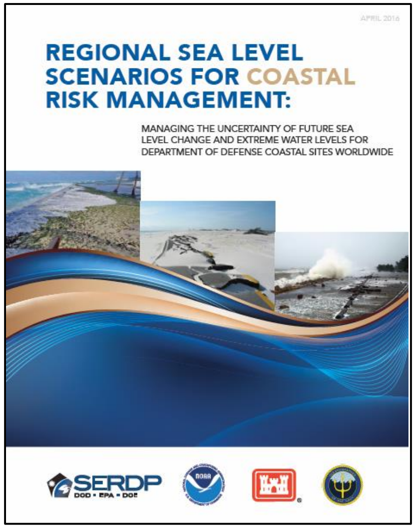
1. Physics of glacial calving
2. Interaction of ice sheets with ocean waters at periphery
3. Interaction of ice sheet with bedrock

https://www.washingtonpost.com/news/energy-environment/wp/2015/09/29/scientists-declare-an-urgent-mission-study-west-antarctica-and-fast/
See also https://eos.org/features/on-the-rocks-the-challenges-of-predicting-sea-level-rise

Recent Sea Level Studies

- 2007 IPCC Assessment Report 4 (AR4)
- 2008 Updating Maryland's SLR Projections
- 2011 USACE Guidance
- 2012 NRC Report on MSLR Processes,
  NOAA Sea Level Rise Scenarios for
  National Climate Assessment (NCA)
- 2013 IPCC AR5,
  MD Update of 2008 Assessment,
  Updated USACE Guidance
- 2014 National Climate Assessment
- 2016 SERDP Report on Regional Scenarios
  (CARSWG Report)





DoD Coastal Assessment Regional Scenario Working Group (CARSWG) Study

Plausible, scientifically credible future scenarios with regard to sea level and extreme water levels to assist decision makers and others in making robust choices to manage their risks

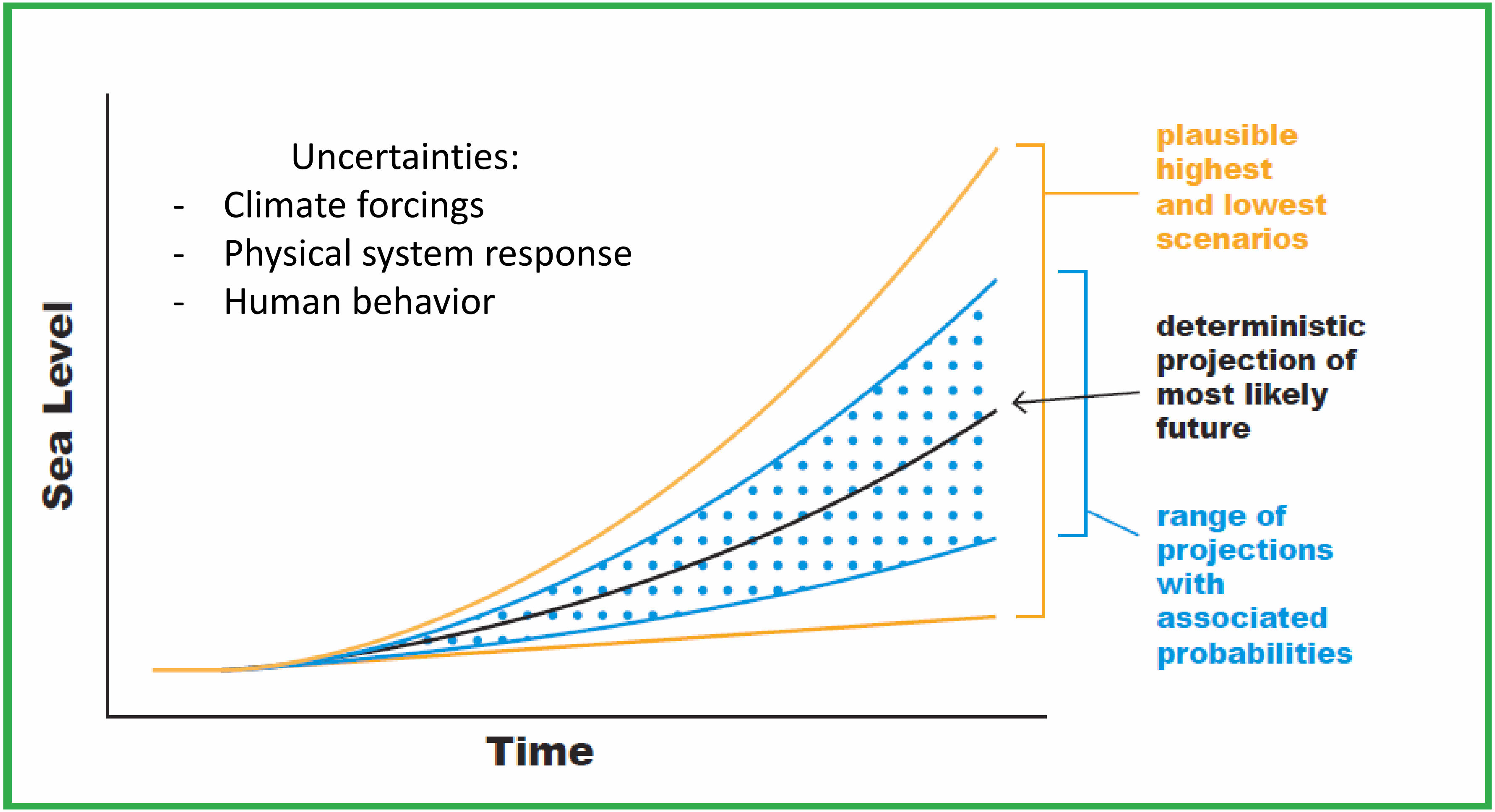


Figure 2.8 Conceptual Depiction of Differences Between Deterministic, Probabilistic, and Scenario-Based Approaches

Fig. Source: CARSWG Report

Global Mean Sea Level Rise Scenarios Considered by the CARSWG

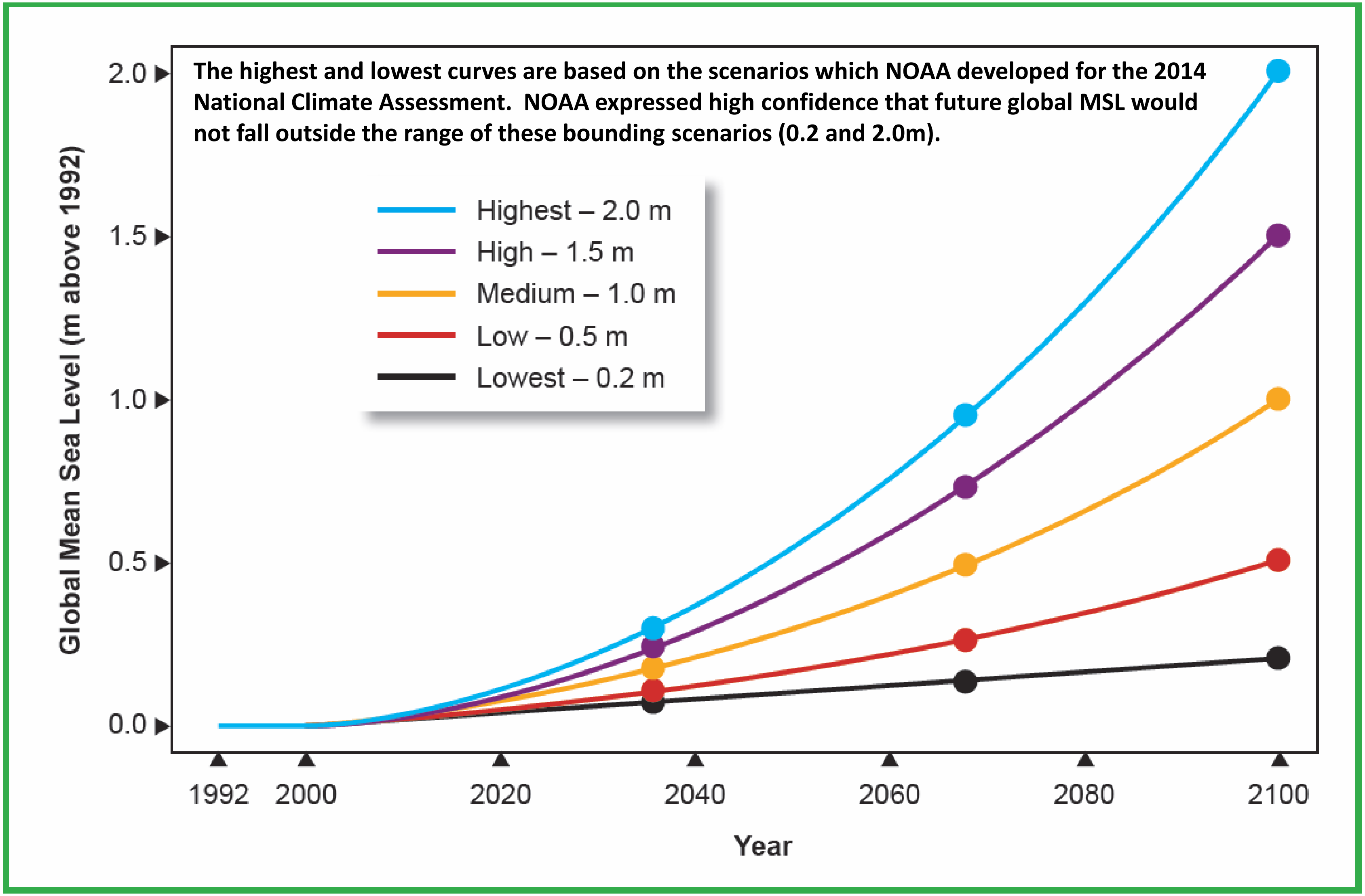


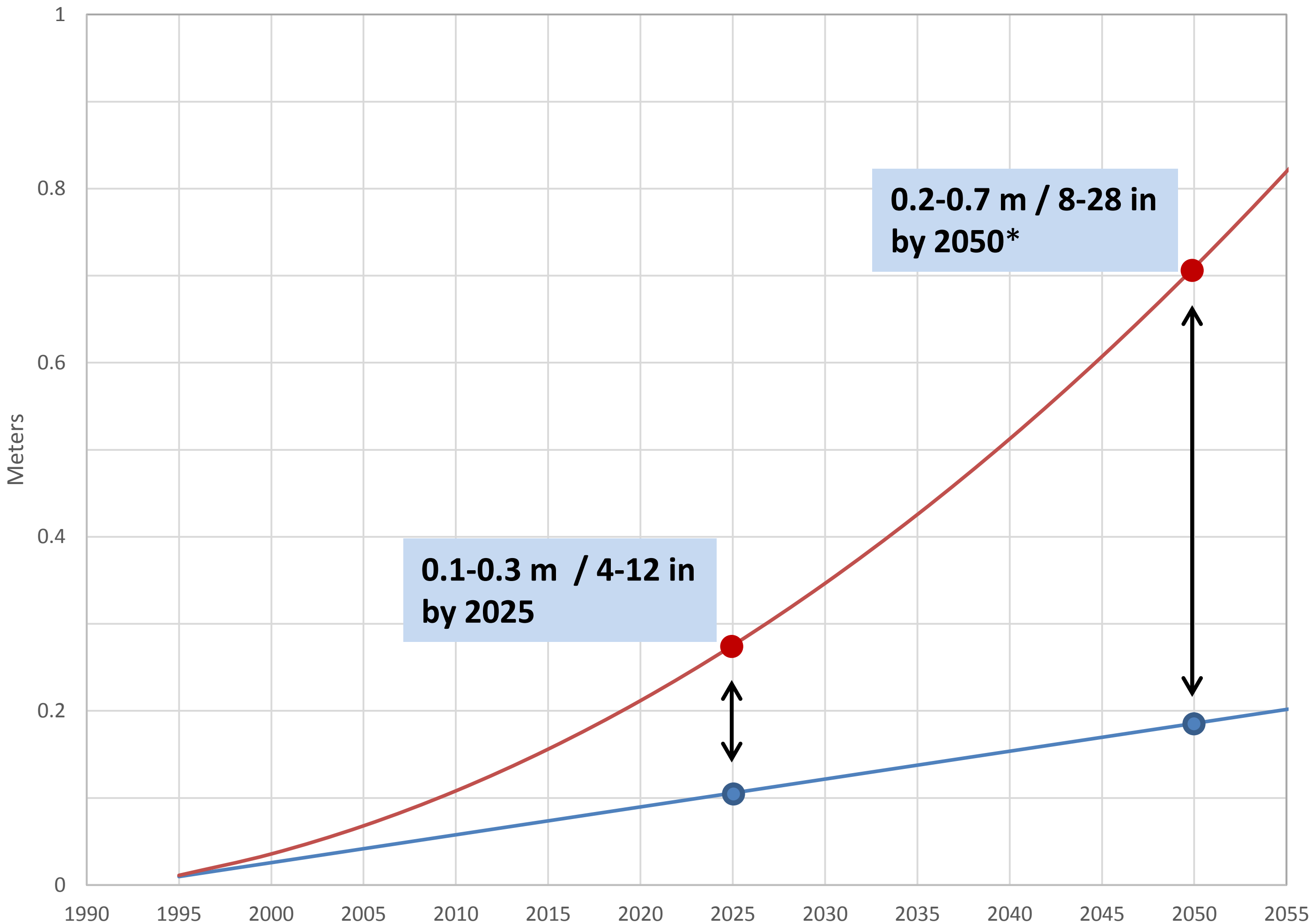
Fig. Source: CARSWG Report

Table 3.3 Rationale and/or Correspondences for the Five Global SLR Scenarios

Global SLR Scenario by 2100	Rationale/Correspondences to RCP-Based SLR Simulations
0.2 m (0.7 ft)	▪ Linear extrapolation of the long-term (since 1900) global tide gauge record (Church and White 2011) ▪ Within the 99% probability range of Kopp et al. (2014) for RCP 2.6 (relative to 2000) ▪ Meehl et al. (2012) derived an ensemble mean value of 0.25 m for RCP 2.6 using one coupled atmosphere-ocean global climate model in the middle of the range of climate sensitivities (relative to 1986 to 2005) ▪ Church et al. (2013a) identified 0.26 m as the 5th percentile of the range of projections from process-based models for RCP 2.6 considered "likely" (2/3 probability)
0.5 m (1.6 ft)	▪ Approximate upper bound (95th percentile) for the RCP 2.6 likely range of Church et al. (2013a) ▪ Approximate median value for the RCP 4.5 likely range of Church et al. (2013a) ▪ Approximate lower bound (5th percentile) for the RCP 8.5 likely range of Church et al. (2013a)
1.0 m (3.3 ft)	▪ Approximate upper bound (95th percentile) for the RCP 8.5 likely range of Church et al. (2013a)
1.5 m (4.9 ft)	▪ Approximate value using semi-empirical approaches (Jevrejeva et al. [2014], Meehl et al. [2012]), with the latter estimate explicitly tied to RCP 8.5)
2.0 m (6.6 ft)	▪ Physically plausible glacier and ice-sheet loss by the end of the century and estimated ocean warming (Pfeffer et al. 2008) ▪ Approximately equal to low probability but plausible estimates of Jevrejeva et al. (2014) and Kopp et al. (2014) associated with RCP 8.5

Fig. Source: CARSWG Report

Highest and Lowest CARSWG Scenarios Adjusted for Approximate Maryland VLM (1.5 mm/yr)

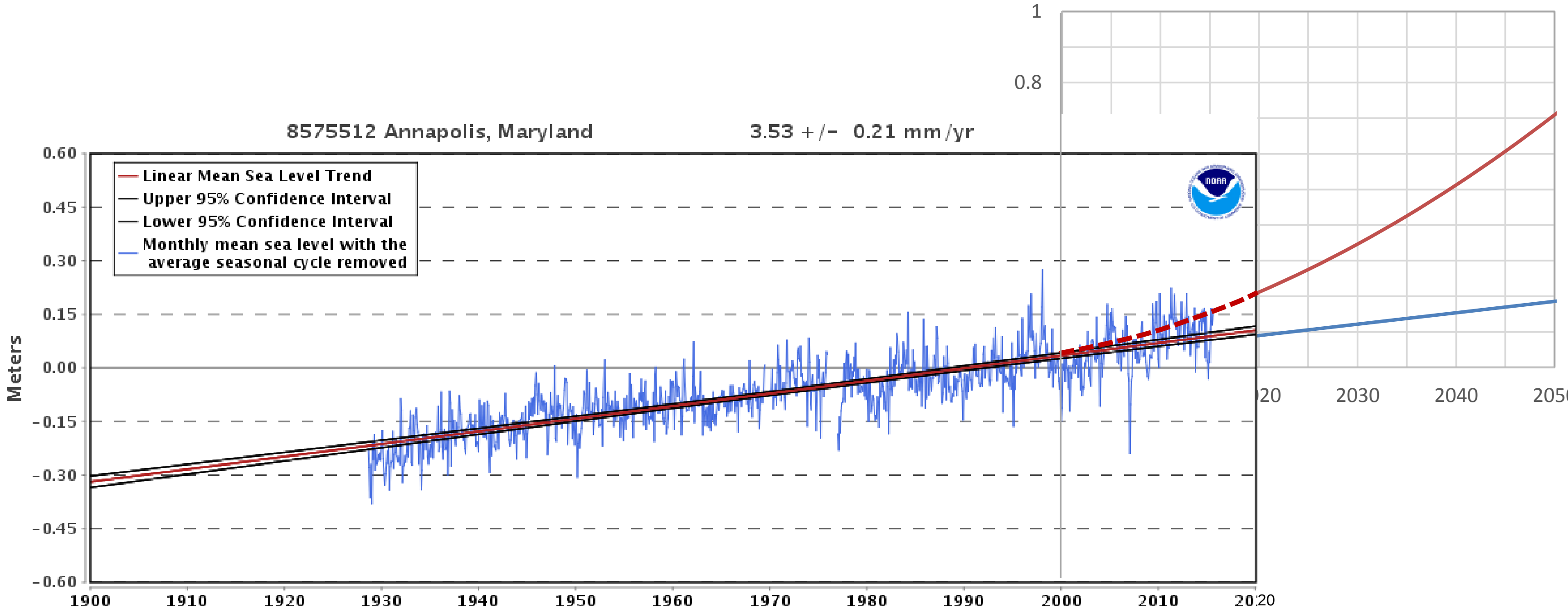


Based on max plausible glacier and ice sheet loss by 2100 and estimated ocean warming (Pfeffer et al. 2008). Corresponds roughly to upper bound of RCP 8.5 (Jevrejeva et al. 2014 and Kopp et al. 2014)

Linear extrapolation of historical trend in tide gauge data (global average), adjusted for vertical land motion. Corresponds roughly to lower bound of RCP 2.6

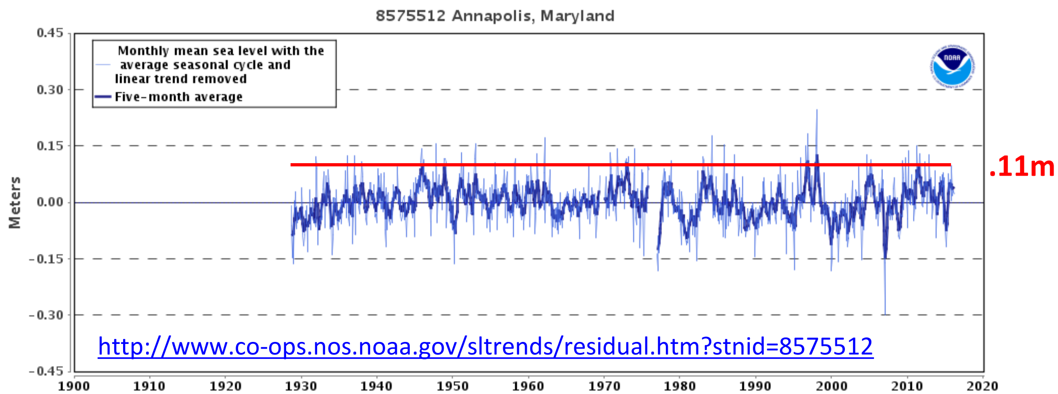
* These values do not include regional adjustments to MSL from dynamic sea level or land ice mass, which for periods of 2035 and earlier, are probably negligible compared to interannual / decadal variability and model uncertainty. The high scenario values beyond 2035 should be further adjusted for dynamic sea level and land ice mass changes, which will likely increase the 2050 MSL value by approximately 0.1-0.2 m (this adjustment is pending access to the CARSWG database).

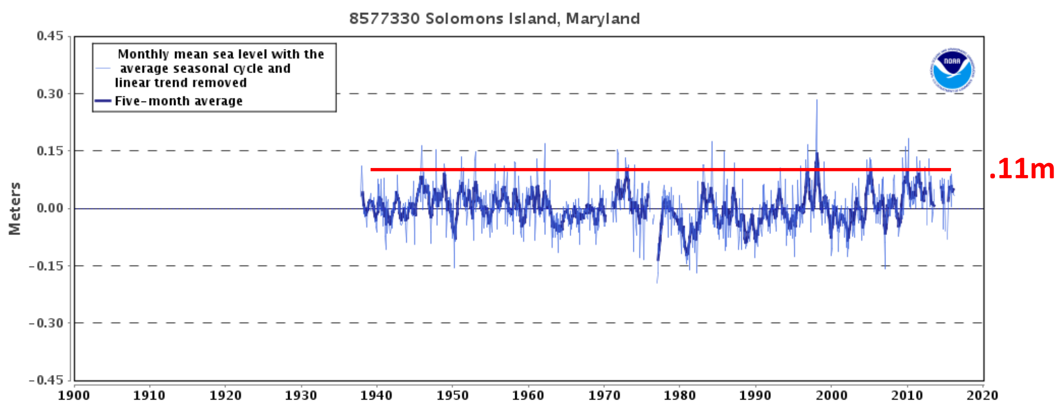
Comparison of Mean Sea Level Trend in Annapolis Tide Gauge Data to CARSWG Highest and Lowest Scenarios (Adjusted for MD VLM)

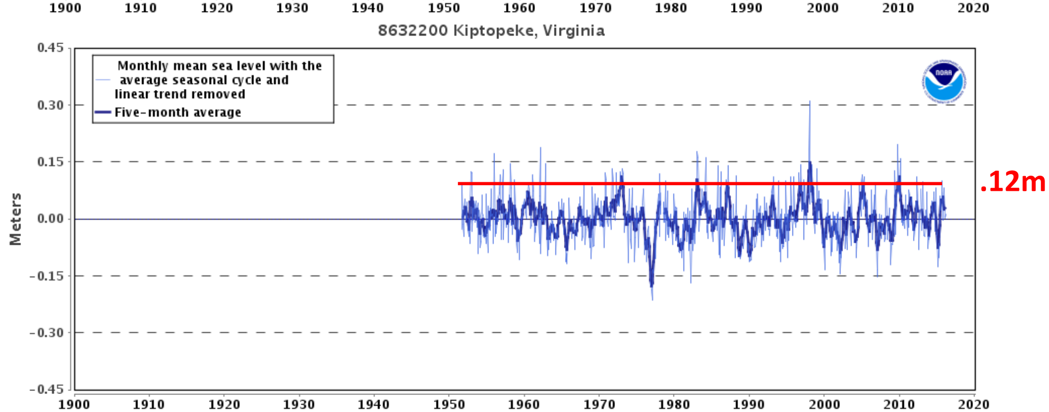


The lower bound for sea level rise scenarios should be based on historical trends dating back at least 50 years, as shorter record lengths (such as satellite altimetry measurements) may be affected by interannual / decadal variability.

Final Adjustment for Short Term Scenarios: Interannual Variability (IAV)







For scenarios extending to 2035 or less, CARSWG recommends computing two standard deviations of the detrended annual MSL residuals, and adding this value to the computed range of MSL rise.

This is considered to be a conservative estimate of the variability that results from interannual / decadal oscillations (ENSO, NAO, etc.), which are significant for scenarios extending 20 years or less.

This is a site specific correction, but for Chesapeake Bay, it increases MSL by approximately 0.11m / 4 inches.

Plausible Ranges of Maryland SLR

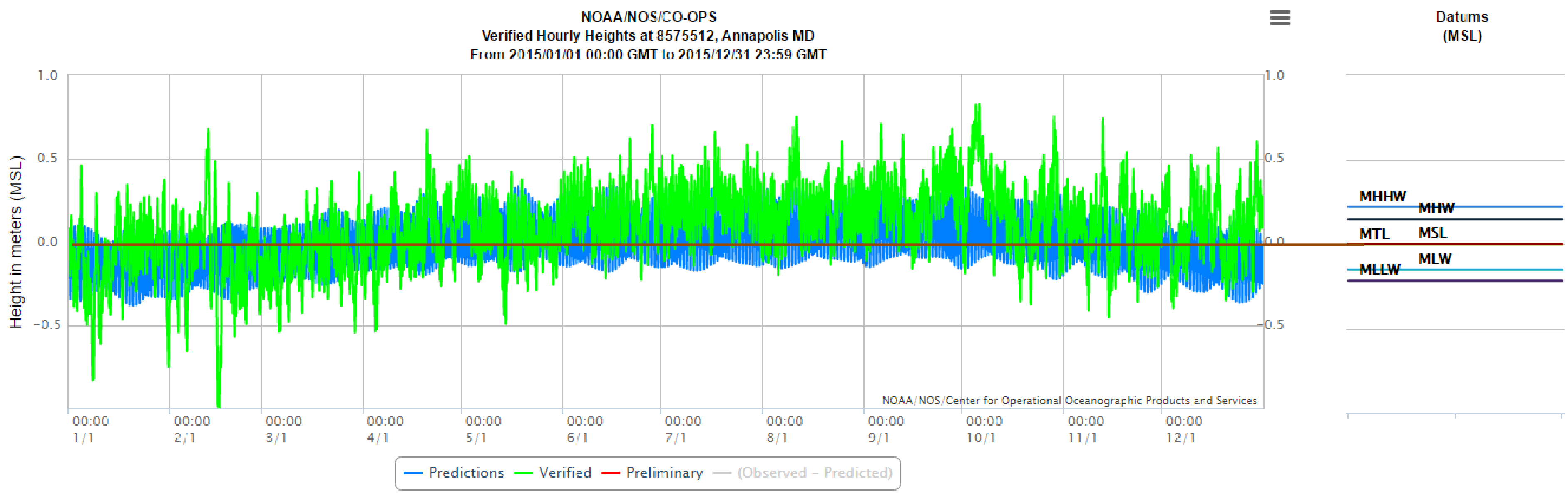
Study	2025 Range	2050 Range
2013 Maryland Update (Note 1)	N/A	0.3 - 0.7 m 12 - 28 in
2016 CARSWG Guidance (Notes 2 & 3)	**0.1 - 0.4 m 4 - 16 in**	**0.2 - 0.7 m 8 - 28 in**

Notes:

1. 2013 MD Update accounts for ocean dynamics, land ice, and VLM.
2. This application of the CARSWG guidance accounts for VLM. Best guess VLM value of 1.5 mm/yr (per 2013 MD Update) was used for adjustment. 2025 range was also adjusted for interannual variability of MSL.
3. CARSWG upper bound for 2050 should be adjusted for dynamic sea level and land ice changes (adjustment is pending access to CARSWG database).

Astronomical Tides, Storm Surge, and other Sea Level Anomalies

2015 Predicted and Verified Hourly Water Levels for Annapolis
Relative to Mean Sea Level



Still Water Level = Tide (astronomical + MSL seasonal cycle) + Nontidal Residual (storm surge + sea level anomaly)

To assess risk of exposure to Extreme Water Levels, probability estimates of exceeding specified extreme sea levels are required. This step in risk analysis is beyond the scope of this brief.

References

2013 Maryland Report http://www.umces.edu/sea-level

2013 IPCC 5th Assessment Report http://www.ipcc.ch/report/ar5/wg1

2014 USACE Guidance
http://www.publications.usace.army.mil/Portals/76/Publications/EngineerRegulations/ER_1100-2-8162.pdf

2014 USACE Calculator http://www.corpsclimate.us/ccaceslcurves.cfm

2014 National Climate Assessment http://nca2014.globalchange.gov/

NOAA Mean Sea Level Trend for Annapolis
https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8575512

2016 SERDP Report (CARSWG Study)
https://www.serdp-estcp.org/content/download/38961/375873/version/3/file/CARSWG+SLR+FINAL+April+2016.pdf