Observed Regional Sea Level Trends: Climate Drivers and Implications for Projecting Future Change

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Abstract

The satellite altimeter record has provided an unprecedented climate data record for understanding sea level rise and has recently exceeded 27 years in length. This record of sea level change is becoming sufficiently long that we can begin to infer how sea level will change in the future. Results from Large Ensembles (LEs) of climate model simulations reveal that (a) the trend pattern of the Forced Response (FR) of sea level due to aerosols and Greenhouse gases (GHGs) is beginning to emerge from the altimeter record, (b) this pattern is likely to continue similarly for decades into the future, (c) the altimeter record falls during an interesting period when we are transitioning from an aerosol-dominated FR to a GHG dominated FR. All of these results provide clues into the causes of regional variations in the altimeter-observed regional trend pattern. In addition, these results suggest a possible path forward for performing short-term data-driven extrapolations of the satellite altimeter record to better understand future sea level change. We will review all of these results, show initial attempts at extrapolating the measurements, and discuss potential societal implications of the results.

Background

The climate data record of sea level from satellite altimetry now spans 27 years (1993-present) (Figure 1) and are stable (Figure 2). The question remains – how much of these trends reflect natural variability, and thus might be expected to reverse in the future, and how much reflects a forced response to aerosols, ozone, and greenhouse gases, which might be expected to persist. continue into the future?

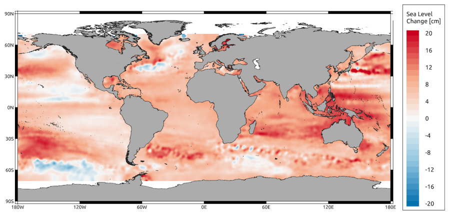

Figure 1. Regional sea level change over 1993-2019 from a combination of TOPEX/Poseidon, Jason-1, Jason-2, and Jason-3 altimeter data [*Zlotnicki et al.*, 2019].

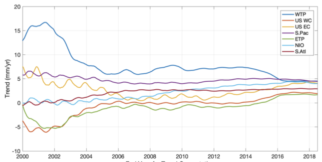

Figure 2. Sea level trends since 1993 as a function of the last year used in the trend computation for the western tropical Pacific (WTP), U.S. West Coast (US WC), U.S. East Coast (US EC), south Pacific (SP), eastern tropical Pacific (ETP), northern Indian Ocean (NIO), and south Atlantic (S. Atl).

Research Objectives

The objective of this research is to use the CESM Large Ensemble (LE) to help interpret the 27-year trends observed in the satellite altimeter record and characterize the Forced Response (FR) of sea level change due to aerosols and Greenhouse gases (GHGs). This will help inform us on how to best extrapolate the satellite altimeter and gravity data to 2040.

Previous Results

Fasullo and Nerem (2018) found that the climate model LEs show the FR during the altimeter era continues for decades into the future with only small changes. Therefore, the observed satellite altimeter trends can be used as a blueprint for the regional variations in future sea level change. This suggests a modified "pattern scaling" approach combining global mean sea level projections with observed regional sea level patterns might offer a way of better projecting regional sea level change.

CESM Large Ensemble Results

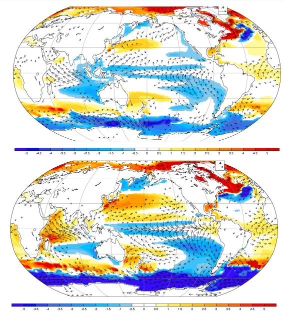

Figure 3. Mean SSH trends (global mean removed) from the CESM LE for 1993-2020 (top) and 2020–2045 (bottom) and atmospheric surface wind trends (arrows).

Contributions of Aerosols and GHGs

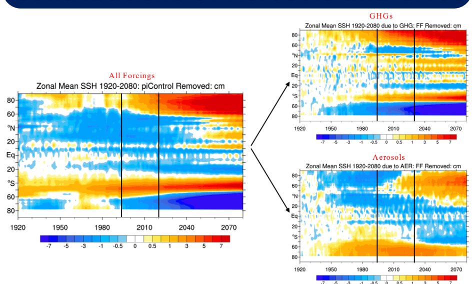

Figure 4. Zonal mean sea level from the CESM LE for all forcings (left), GHGs (top right) and aerosols (bottom right). Black lines bound the altimeter era. See: OS13A-01, Fasullo, J., and R. S. Nerem, Drivers of the Altimeter-Era Forced Response in Regional Sea Level and Consequences for the Coming Decades, Abstract OS13A-01 , presented at 2019 Fall Meeting, AGU, San Francisco, CA, 9-13 Dec, 2019.

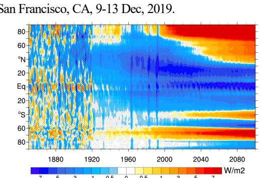

Figure 5. Ensemble zonal-mean net upward surface shortwave flux anomalies for the LE. Regions where anomalies are less than twice the standard error are stippled. Aerosols have a distinct spatial structure and are mainly in the NH. They reduce the net surface flux and cool the ocean but mainly in the NH. This is the reason the altimeter era trends exhibit a blend of spatial patterns.

Causes of Regional Variations

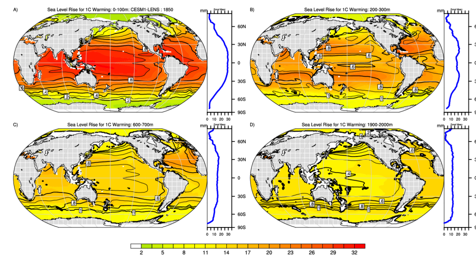

Figure 6. Estimated change in sea surface height (mm) for a 100m deep 1C warming across various ocean depths based on the simulated LENS 1850 control state and the equation of state (McDougall et al. 2009). Corresponding zonal means are plotted as blue lines. In (A), contour lines indicate the fraction of rise relative to the western equatorial Pacific maximum. In (B-D), contour lines indicate the fraction of rise relative to the 0-100m layer amount (A) at the same latitude and longitude (at 0.1 intervals from 0 to 1).

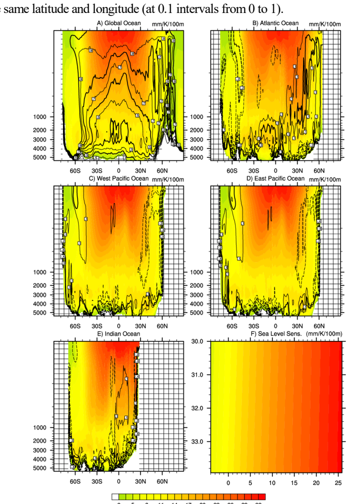

Figure 7. Estimated change in SSH (mm) for a uniform 1C warming across a 100m layer at various depths and longitudes averaged across different ocean basins (A-Global, B-Atlantic, C-West Pacific, D-East Pacific, E-Indian) based on the LE 1850 control state. Also shown in F) is the broader relationship between estimated rise (mm), temperature (C), and salinity (g/kg). Contour lines in (A) depict the fractional change in rise relative to the co-located surface layer (at 0.1 intervals from 0 to 1) and in (B-E) represent the fractional change relative to the global ocean at the same latitude and depth (at 0.1 intervals from -1 to 1 and dashed where negative).

Extrapolating Sea Level Change

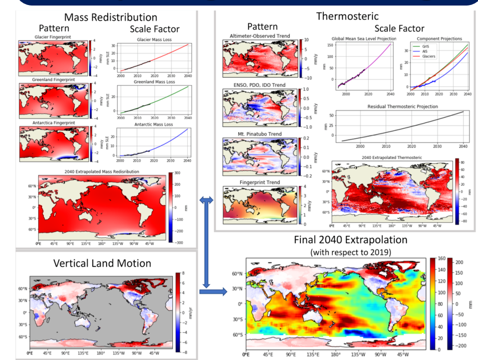

Figure 8. Extrapolation of satellite altimetry and satellite gravity measurements to project sea level change in 2040. The patterns of observed sea level change are used to characterize the pattern of sea level change in 2040. The observed patterns of ice mass loss from GRACE are used to compute the gravitational fingerprints of sea level change.

Conclusions

- The CESM Large Ensemble shows distinct patterns of sea level change related to aerosols and GHGs that are complex and extend into the mid 20th Century.
- The patterns of sea level change are driven by changes in ocean heat content (OHC), which themselves are modulated by variations in the thermal expansion coefficient (with location and depth) and by effects due to ocean circulation and winds.
- For short-term extrapolations to 2040, we can extrapolate the observed altimeter trend to approximate regional variations.
- We produce an extrapolation of sea level change to 2040 based on (a) extrapolating the GRACE record of ice mass loss for Greenland, Antarctica, and mountain glaciers; (b) extrapolating global mean sea level from satellite altimetry using a quadratic fit to GMSL over 1993-2019, and (c) extrapolating the regional sea level trends from altimetry over 1993-2019.

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(2) Fasullo, J., and R. S. Nerem, Drivers of the Altimeter-Era Forced Response in Regional Sea Level and Consequences for the Coming Decades, Abstract OS13A-01 , presented at 2019 Fall Meeting, AGU, San Francisco, CA, 9-13 Dec, 2019.

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