Pacific Decadal Oscillation Contribution to Global and Regional Sea Level

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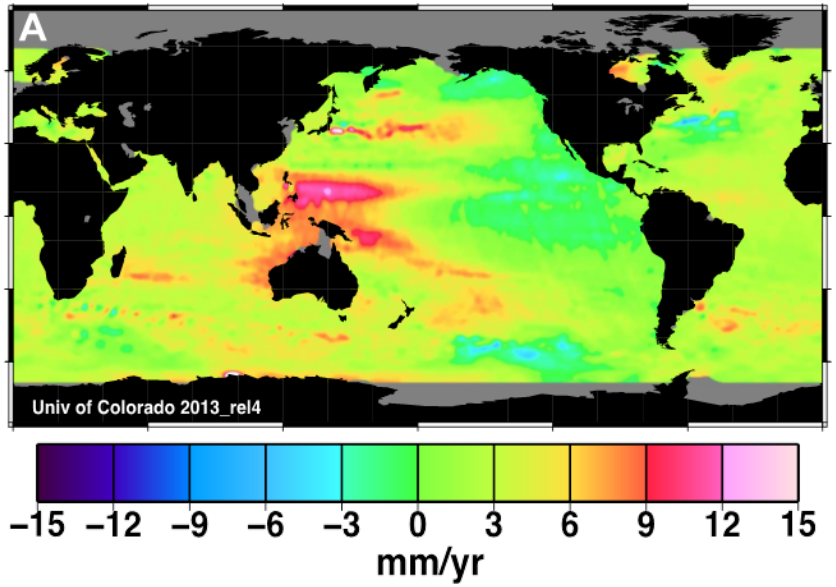
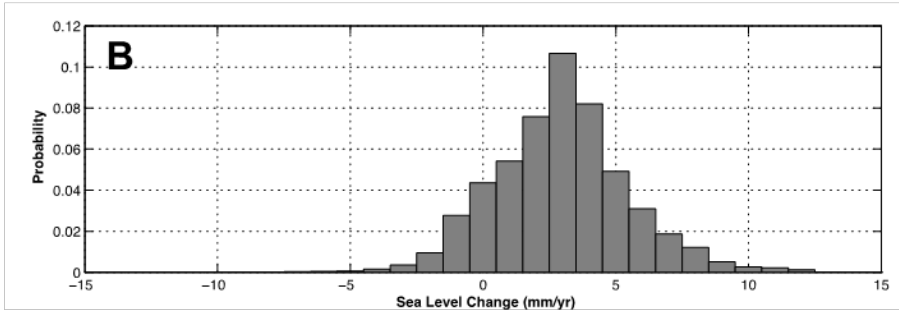
Overview

- **Climate Variability and Sea Level Trends**
- **Reconstructing Sea Level**
  - What is a sea level reconstruction?
  - Reconstructing sea level trends
- **Effect of the Pacific Decadal Oscillation on Sea Level Trends**
  - Twenty-year trend analysis using the sea level reconstruction
  - Relationship between the PDO and GMSL 1950-present
  - Improving the understanding of the historical and satellite altimetry sea level records
  - Extending the analysis back to 1900
- **Future Work and Summary**

Understanding Observed Trends in Sea Level

- Near-global coverage of satellite altimeters has improved our understanding of how sea level is changing on regional and global scales.
  - Led to first definitive estimates of global mean sea level (GMSL) rise.
  - Provided measurements of how trends in sea level vary from the global mean on regional scales.
- The satellite altimetry record, however, spans only two decades.
  - Difficult to separate the secular trend (long-period, non-periodic) from natural climate variability on decadal and longer timescales.





Understanding Observed Trends in Sea Level

- Climate variability on decadal and longer time scales is known to contribute to sea level trends [e.g. Feng et al, 2004; Woodworth et al., 2011; Sturges and Douglas, 2011; Meyssignac et al, 2012; Chambers et al., 2012].
  - Evaluating the impact or quantifying the contribution of long time scale natural variability is a challenge using the satellite altimeter record alone → longer record is needed.
  - Additionally, semi-empirical methods have been developed for projecting sea level rise on global scales [e.g. Vermeer and Rahmstorf, 2009; Rahmstorf, 2012] → Two important requirements are a long and consistent time series in the past and an understanding of the contribution of natural variability to sea level.
- Sea level reconstructions provide a possible solution to the challenges provided by the short satellite altimeter record.

What is a ‘Sea Level Reconstruction’?

- Two methods of measuring sea level in the past century:
  - **Tide Gauges**: Long record, but sparsely distributed.
  - **Satellite Altimetry**: Short record, but near-global coverage.
- Sea level is reconstructed by fitting altimetry-derived basis functions to tide gauge data.
  - [e.g. Chambers et al. (2002), Church and White et al. (2004), Ray and Douglas (2011) Hamlington et al. (2011), Meyssignac et al. (2011; 2012)].
- Simply stated, a sea level reconstruction is a dataset with the spatial coverage of the satellite altimetry and the record length of the tide gauges.
- We have used cyclostationary empirical orthogonal functions (CSEOFs) to create a sea level reconstruction from 1950 to present (available from NASA JPL/PO.DAAC).
  - Provides a better representation of climate variability and is less sensitive to changes in the tide gauge sampling back through time.

Variability of Regional Sea Level Trend Patterns

- With our longer sea level record from the reconstruction, we focus on four specific questions:

1) How have regional sea level trend patterns changed during the past few decades?
2) What are the characteristic timescales of changes in the sea level trend pattern?
3) What are the factors driving the changes to the trend pattern?
4) How does this affect our interpretation of sea level trends, both regionally and globally?

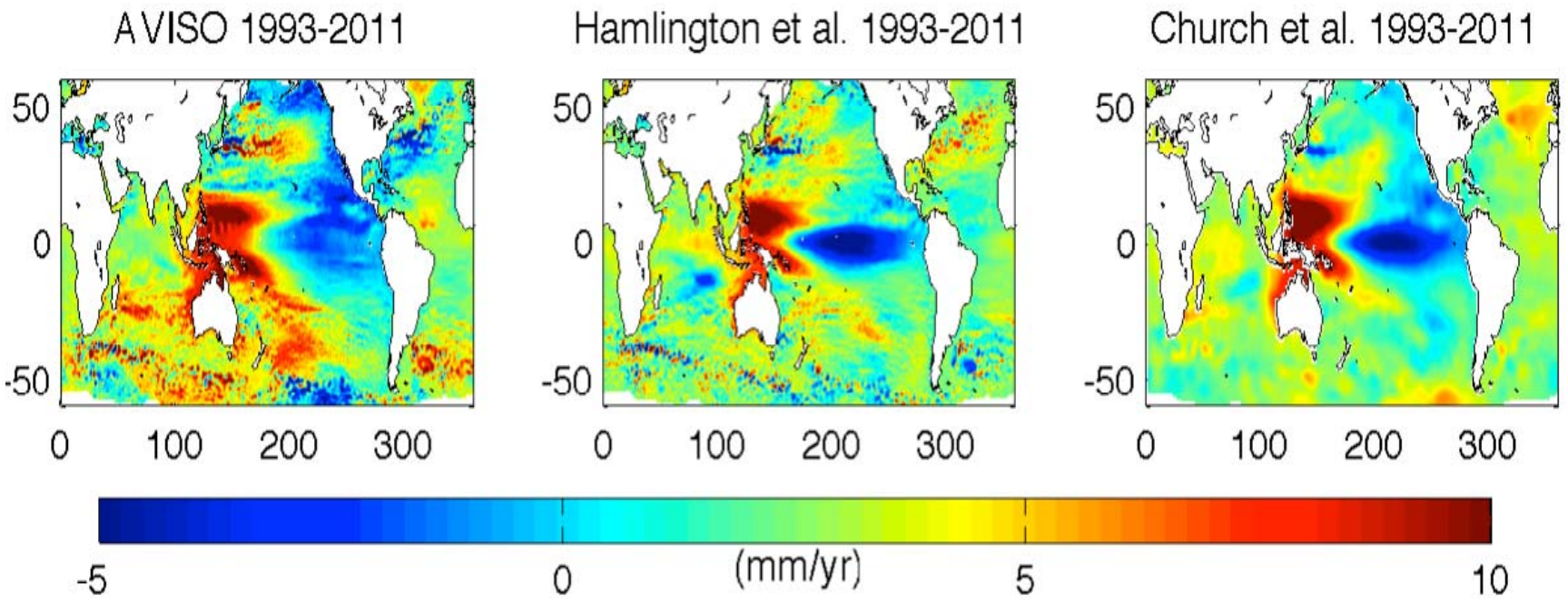
Variability of Regional Sea Level Trend Patterns

- Meyssignac et al. [2012] was the first to look at the decadal to multi-decadal variability of regional sea level trend patterns using sea level reconstructions.
  - Question: Has the altimetry-observed spatial pattern of regional trends been observed at other times in the past or is it unique to the current time period?
  - Computed 17-year sea level trend patterns from 1950 to 2009 for the tropical Pacific Ocean.
  - The first rotated EOF principal component time series (PCTS) of these trend patterns was shown to correlate reasonably well with a smooth NINO3 Index (correlation of 0.63).

Variability of Regional Sea Level Trend Patterns

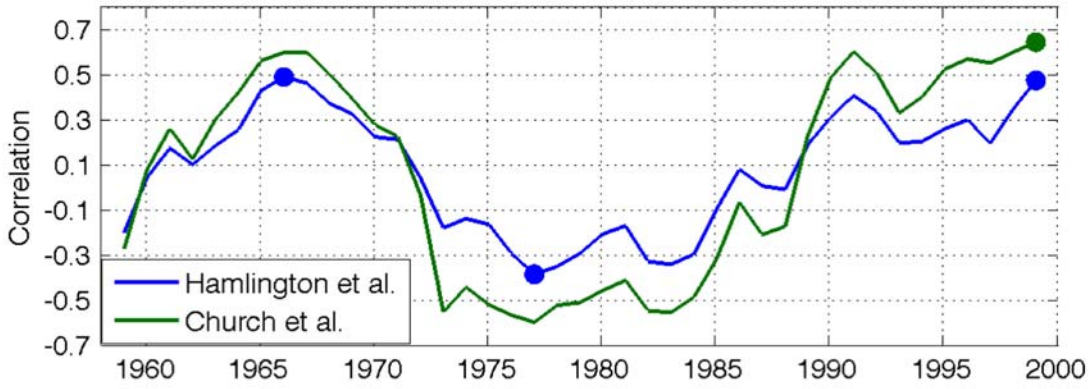
- To study the problem further, we extended the analysis to the global pattern of sea level trends.
- Two different sea level reconstructions were used:
  - Hamlington et al. [2011] Cyclostationary Empirical Orthogonal Function (CSEOF) reconstruction (HRSL).
  - Church and White et al. [2004; 2011] EOF Reconstruction (CRSL).
- Twenty-year trend maps were computed from two reconstructed datasets (CSEOF and EOF reconstructions).
- Resulted in 41 trend maps from 1950 to present for each reconstruction.

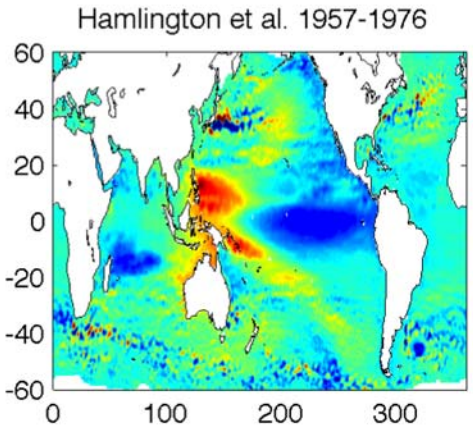
Reconstructed Regional Sea Level Trends

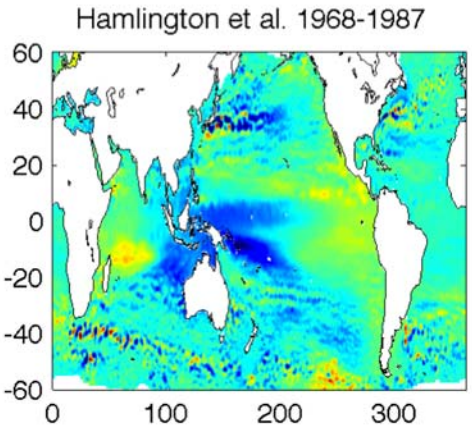


Regional Sea Level Trends

- Correlation between the regional trend map from the AVISO dataset and twenty-year trend patterns from two sea level reconstructions, HRSL (blue) and CRSL (green).
- Twenty-year trend patterns from the HRSL dataset are also shown for two different periods associated with extrema in the correlation time series.
- Question: What is the dominant 20-year spatial pattern of trends?



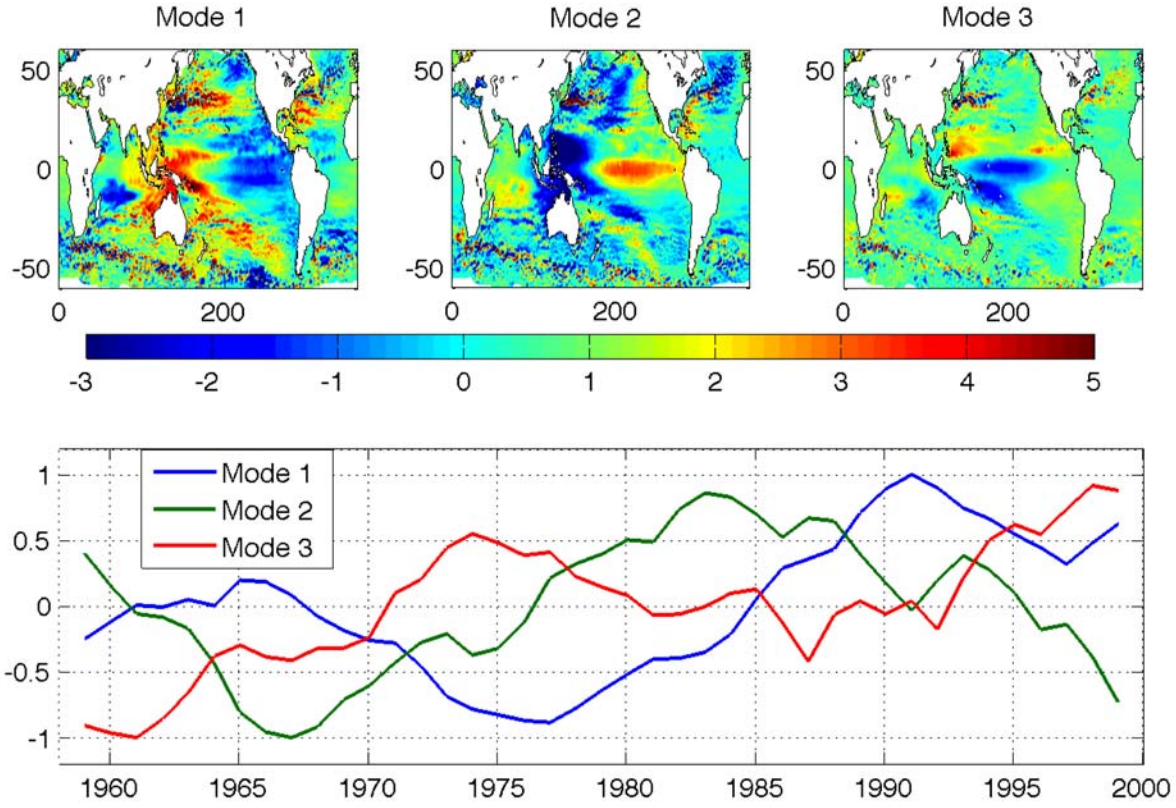




Regional Sea Level Trends

- To determine the dominant twenty-year trend pattern over the past 60 years, we performed the following test:
  1. Remove the GMSL linear trend from the reconstructed dataset.
  2. Create twenty-year trend maps from the reconstructed dataset → 41 trend maps from 1950 to present.
  3. Perform an EOF decomposition of the resulting twenty-year trend maps.
  4. Evaluate the contribution of each individual EOF mode to twenty-year trends in GMSL.
- Resulting first three EOFs explain 40%, 31% and 13%, respectively, of the total variance.

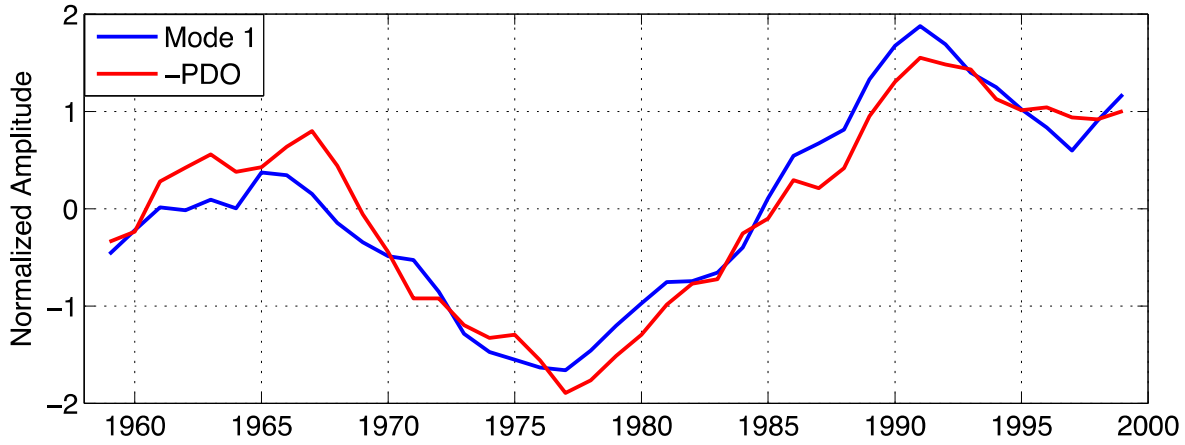
Regional Sea Level Trends

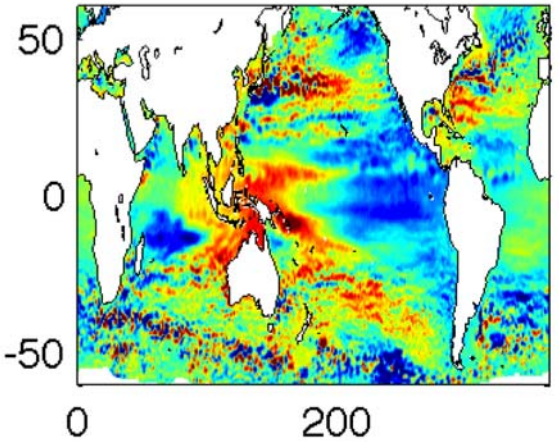


- Can we attribute these modes to natural climate variability?

Relationship to the PDO

- Comparing the first mode with the twenty-year trends in the PDO yields a correlation over the past 60-years of 0.96.
- Qualitatively, the spatial pattern of the first mode agrees well with the PDO in the North Pacific.

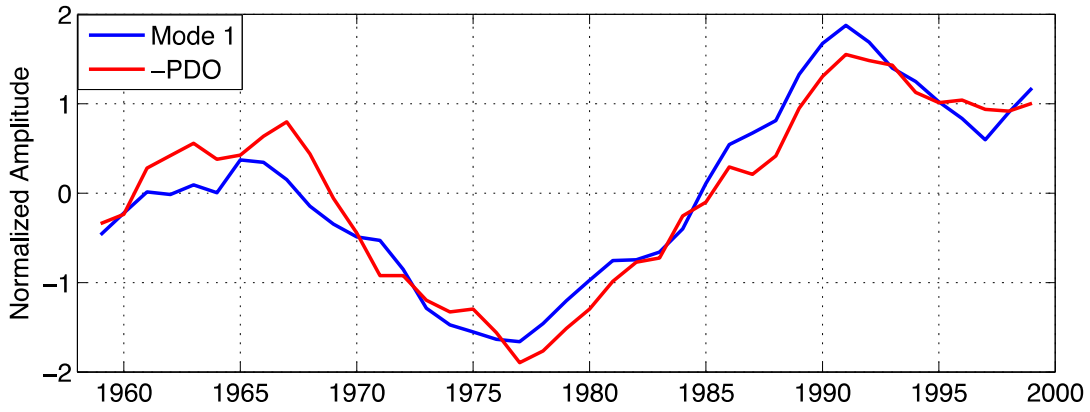




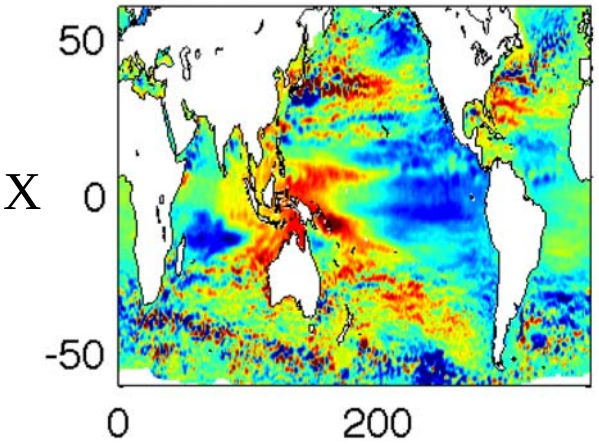
Contribution to GMSL

- The contribution of mode 1 (and by extension, the PDO) to GMSL can be evaluated as follows:

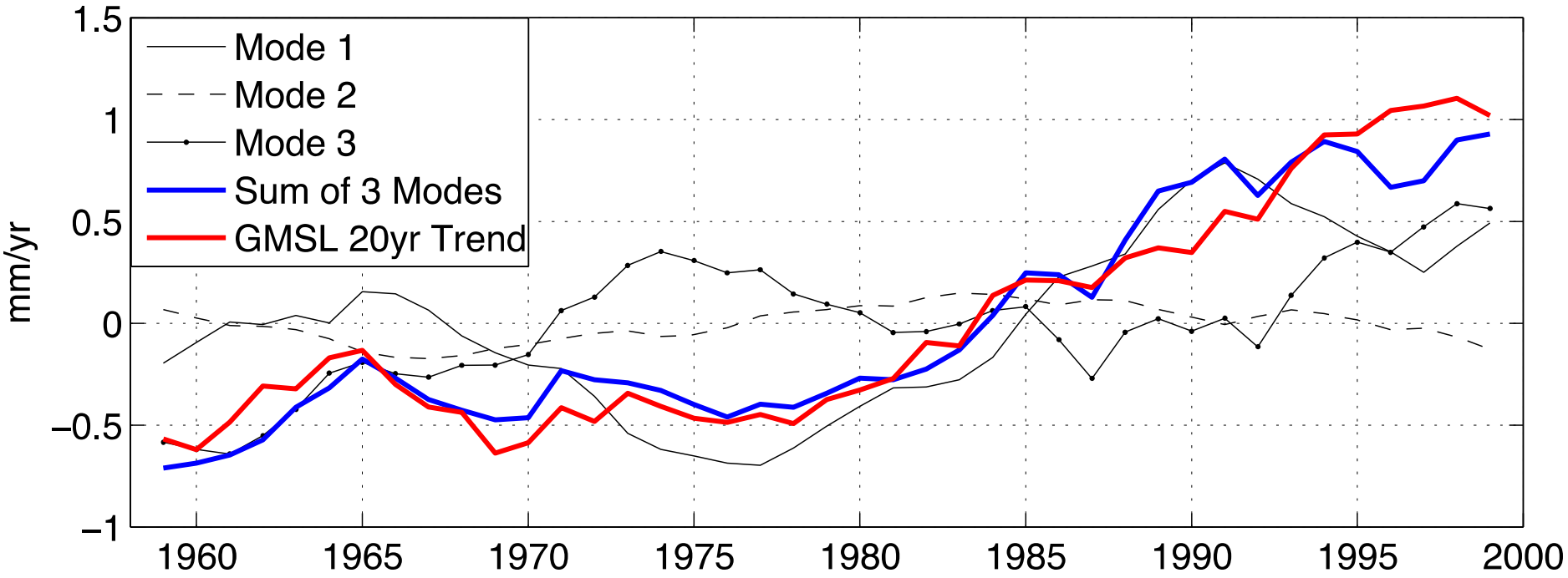
Mode 1 PCTS



Global Mean of LV



Contribution to GMSL



What does this mean for sea level in the past 60 years?

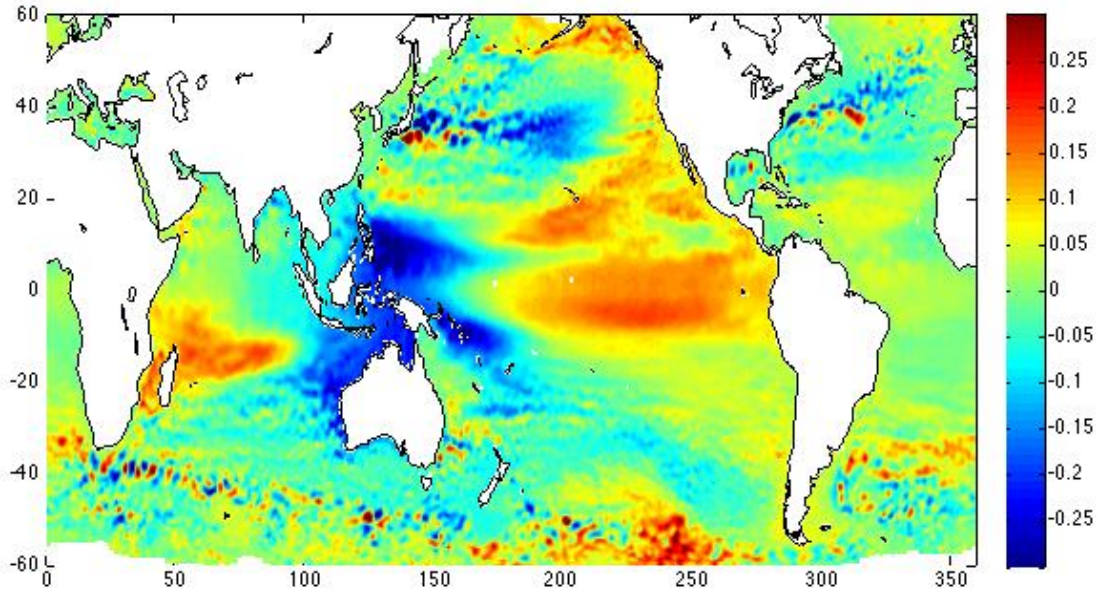
- In the past twenty years, when the PDO started to shift from positive to negative phase, the PDO contributed 0.49 ± 0.25 mm/yr. to GMSL.
  - → Trend in GMSL is 2.7 mm/yr. as opposed to ~3.2 mm/yr. once the contribution from the PDO is removed.
- From 1968 to 1987, when the PDO went from negative to positive, the PDO lowered the trend in GMSL by 0.70 ± 0.26 mm/yr.
- Regional trends associated with the PDO range from +/- 5 mm/yr.
- Removing the contribution from the PDO, decreases the estimated acceleration in GMSL over the past 60 years from 0.04 mm/yr^2 to 0.02 mm/yr^2.

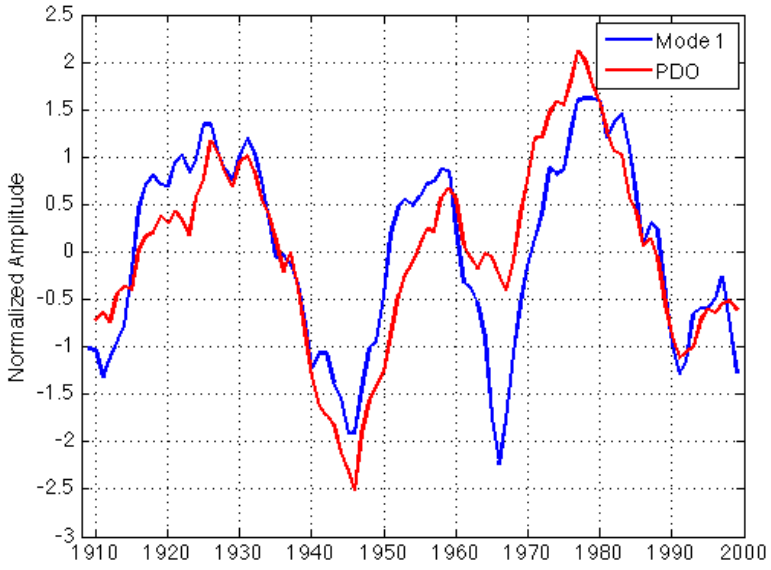
Extending the Analysis to 1900-Present

- Reconstructions are limited by the historical data that is available and can be included in the procedure.
- Finding a way to include other climate variables can provide for a more accurate sea level reconstruction back to the turn of the century.
  - Satellite and historical sea surface temperature (SST) measurements are used to create an improved sea level reconstruction from 1900 to present.
  - Motivation: many more SST measurements than tide gauge measurements prior to 1950.
  - This reconstruction technique relies on CSEOFs and CSEOF regression analysis [Hamlington et al. 2012; Kim et al. 2001].
- Results in a sea level reconstruction with improved representation of climate variability like the PDO back to 1900 [Hamlington et al. 2012].

PDO vs. Sea Level in the Past Century

- Using the bivariate reconstruction, we can conduct the same analysis over the past century.
  - Correlation of 0.86 between mode 1 and 20-year trends in PDO.





Future Work

- **How does the PDO affect GMSL?**
  - Precipitation pattern (E-P) changes? Land-water storage variations? Low frequency thermosteric variability?
  - Combination of all of the above?
  - Comparison to models could help with attribution.
- **How does this change our understanding of regional sea level trends?**
  - The PDO has lowered sea level trends in the eastern Pacific in the past twenty years, while it has caused an increase in trends in the western Pacific.

Summary

- Sea level reconstructions provide the opportunity to extend the sea level record.
  - Lower frequency climate variability can be extracted from the longer records.
  - The PDO is estimated to have contributed 0.5 mm/yr. to the GMSL trend in the past twenty years.
  - The PDO also contributes significantly to regional sea level trends.
  - While the focus here is on the PDO, similar tests and studies could be conducted to extract other climate variability.
- Estimating and removing climate variability provides an improved understanding of the changes in sea level resulting from climate change.
  - Better interpretability of the short satellite records.