Multivariate Reconstruction of Sea Level from 1900 to Present

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Overview

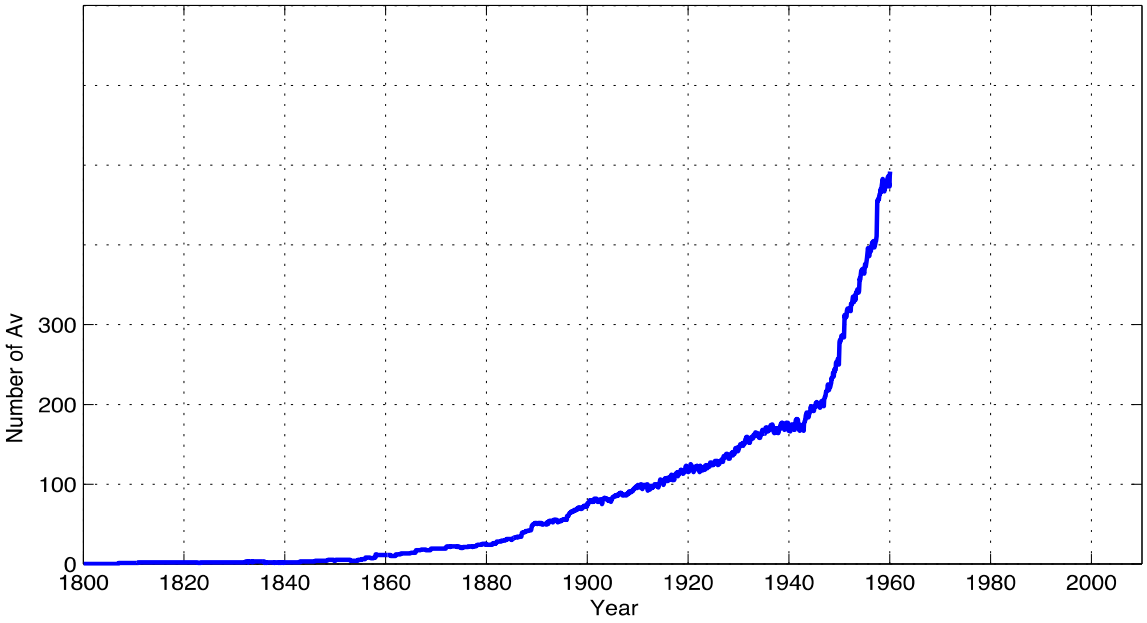
- Reconstructed sea level dataset from 1900 to 2014
  - Motivation
  - Methodology (briefly)
  - Updates from previous reconstructions
  - Uses and Applications

What is a ‘Sea Level Reconstruction’?

- Creating a sea level climate data record with sufficient duration, consistency and quality that can be used to accurately determine climate variability and change is a challenge.
  - **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)].
  - In past sea level and sea surface temperature (SST) reconstructions, generally empirical orthogonal functions (EOFs) have been used as the basis for the reconstruction.

Reconstructing Sea Level Before 1950

- **Previous reconstructions have primarily been used to study global mean sea level (GMSL) before 1950**
  - Very limited discussion in literatur regarding a sea level reconstructi of large-scale climate variability b to 1900.
  - Limits possibilities for climate monitoring and sea level studies.
- **Prior to 1950, the number of available tide gauges decreases rapidly.**
  - Difficult to reconstruct even the largest climate signals like ENSO, PDO etc.
  - Few or no tide gauges are available in the regions of high variability for signals like the ENSO and the PDO.



- Tide gauge availability in PSMSL from 1800 to 2011.

Using SST to Reconstruct Sea Level

- 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.
  - Here, 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 cyclostationary empirical orthogonal functions (CSEOFs) and a simple regression analysis (Kim et al., 1997; Kim et al, 2003).

Cyclostationary Empirical Orthogonal Functions

- Most SST and sea level reconstructions have relied on EOFs as basis functions.
  - EOFs are prone to mode mixing, particularly with regards to the annual signal.
- To address this and other problems, Kim et al. (1996; 1997; 2001) introduced the concept of cyclostationary empirical orthogonal function (CSEOF) analysis.
  - Fewer modes are needed to explain the variance when compared to EOFs.
- In contrast to EOFs, CSEOFs have time-dependent loading vectors (LV).

$$T(r,t) = \sum_n P_n(t) LV_n(r,t)$$

$$LV_n(r,t) = LV_n(r,t+d)$$

  - When studying the annual cycle, for example, the LVs would represent the one-year nested periodicity, while the principal component time series (PCTS) would describe the change in amplitude of the annual cycle over time.

Incorporating SST Into A Sea Level Reconstruction

- By performing a regression on the CSEOF PCTS, SST patterns can be created that have the same PCTS as corresponding sea level anomaly (SLA) patterns → goal of reconstruction is to reproduce PCTS back through time.

1. Perform CSEOF analysis on satellite-measured SLA and SST data.
2. Regress all SST PCTS on each SLA PCTS:

$$PCTS_{SLA,n}(t) = \sum_i \alpha_i PCTS_{SST,i}(t) + \varepsilon(t)$$

3. Use regression coefficients, LVR(r,t) with amplitude fluctuations described by $PCTS_{SLA}(t)$:

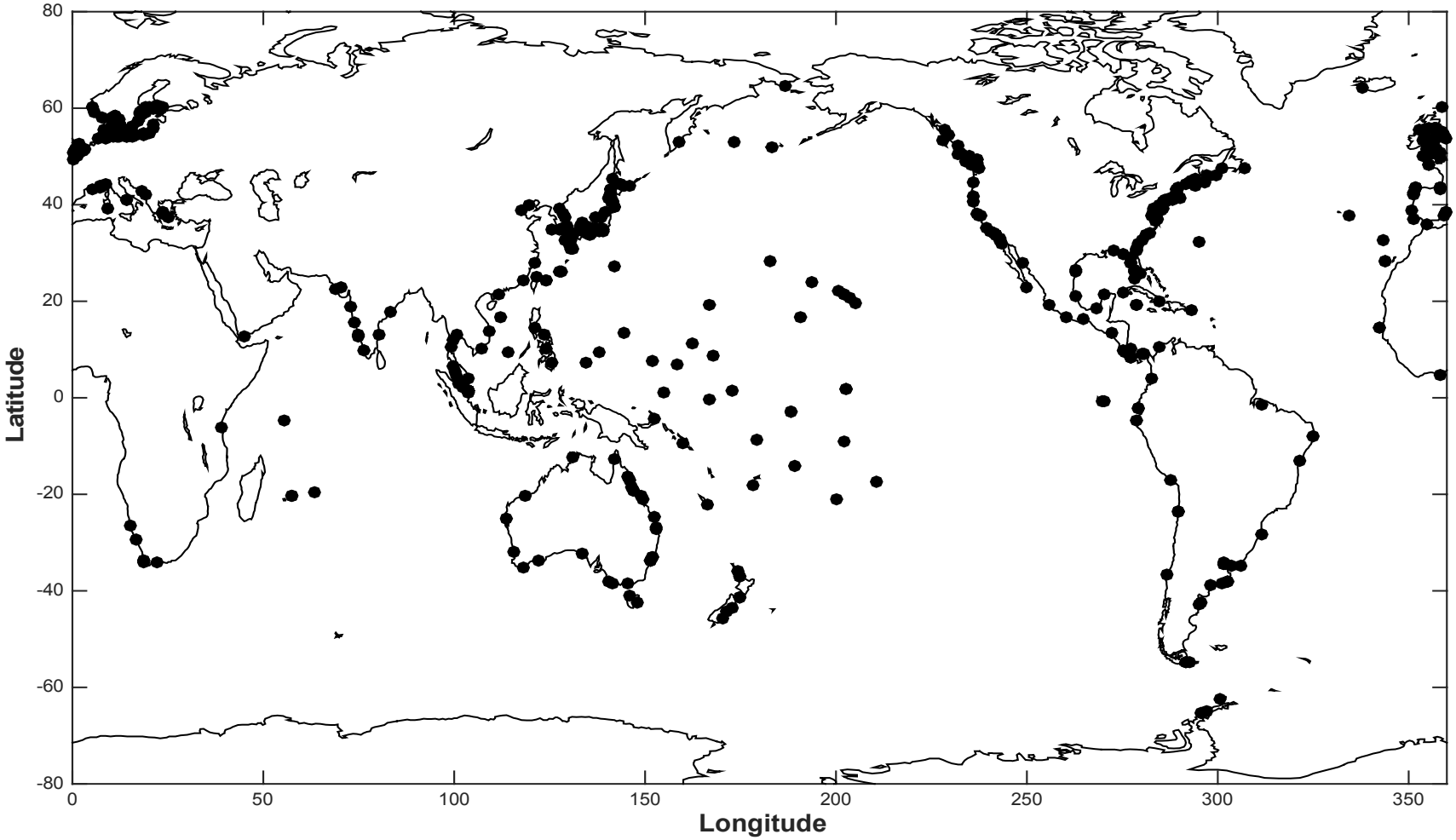
$$LVR_{SST,n}(r,t) = \sum_i \alpha_i LV_{SST,i}(r,t)$$

4. Use LVR_{SST} and LV evel measurements, respectively, to reconstruct PC time series.

Data – Sea Level and SST

- Sea Level Basis Functions: 1/2° resolution multiple altimeter AVISO dataset spanning 1993 to 2014.
  - CSEOF decomposition using 1-year nested period.
  - Used 11 modes in the reconstruction explaining 80% of the variability in the AVISO dataset.
- Sea Level Historical Data: Permanent Service for Mean Sea Level (PSMSL) tide gauges spanning 1900 to 2014.
  - Used over 400 tide gauges for global reconstruction.
- SST Basis Functions: 1° resolution NOAA Optimum Interpolation Sea Surface Temperature (OISST) spanning 1993 to 2014.
  - CSEOF decomposition using 1-year nested period.
- SST Historical Data: ICOADS 2° resolution SST anomalies spanning 1900 to 2014.
  - A monthly climatology was computed from 1960 to 1980 and removed from the data covering the period from 1900 to present in order to remove the seasonal signal from the observations.

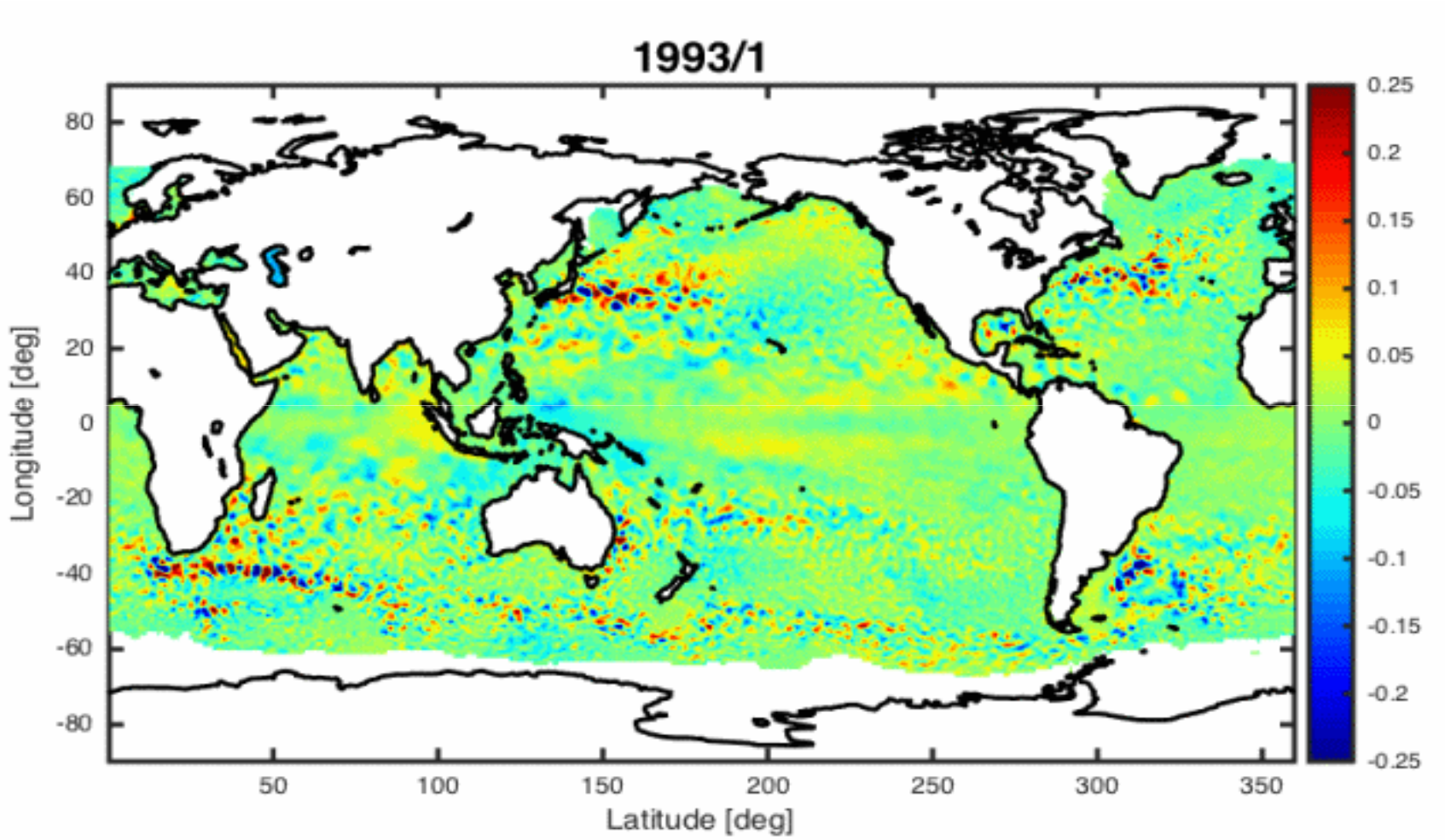
Data – Tide Gauges



Sea Level Reconstruction 1900-2014

- Final result of reconstruction process is a global sea level reconstruction from 1900 to 2014.
  - Half-degree resolution with global coverage→ previous reconstruction only covered Pacific Ocean region.
  - Monthly temporal resolution → previous reconstruction had weekly time steps
  - Reconstruction through end of 2014 → previous reconstruction extended through 2011
  - Longer time period used for computing basis functions and establishing relationship between SST and sea level → improved representation of sea level.
  - Underlying tide gauge dataset edited to remove gauges significantly impacted by vertical land motion.

Sea Level Reconstruction 1993-2014

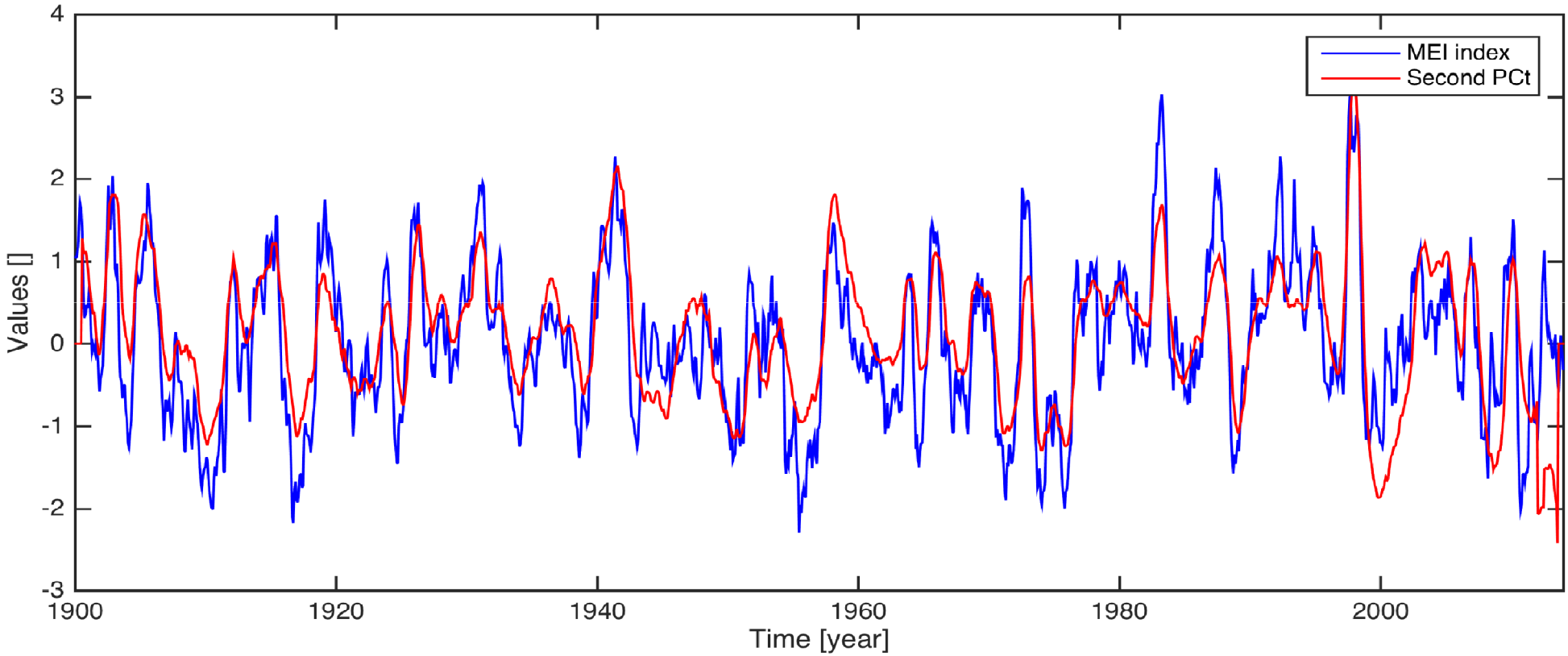


Uses and Applications

- The two main advantages of this reconstruction are (1) improved representation of climate variability and its impact on sea level, (2) realistic reconstruction of regional sea level back before 1950.
- There are many uses and applications for this long record of sea level, including:

1. Historical comparisons
2. Climate monitoring
3. Trend Analysis
4. Global mean sea level

1. Historical Comparisons
ENSO 1900-2014



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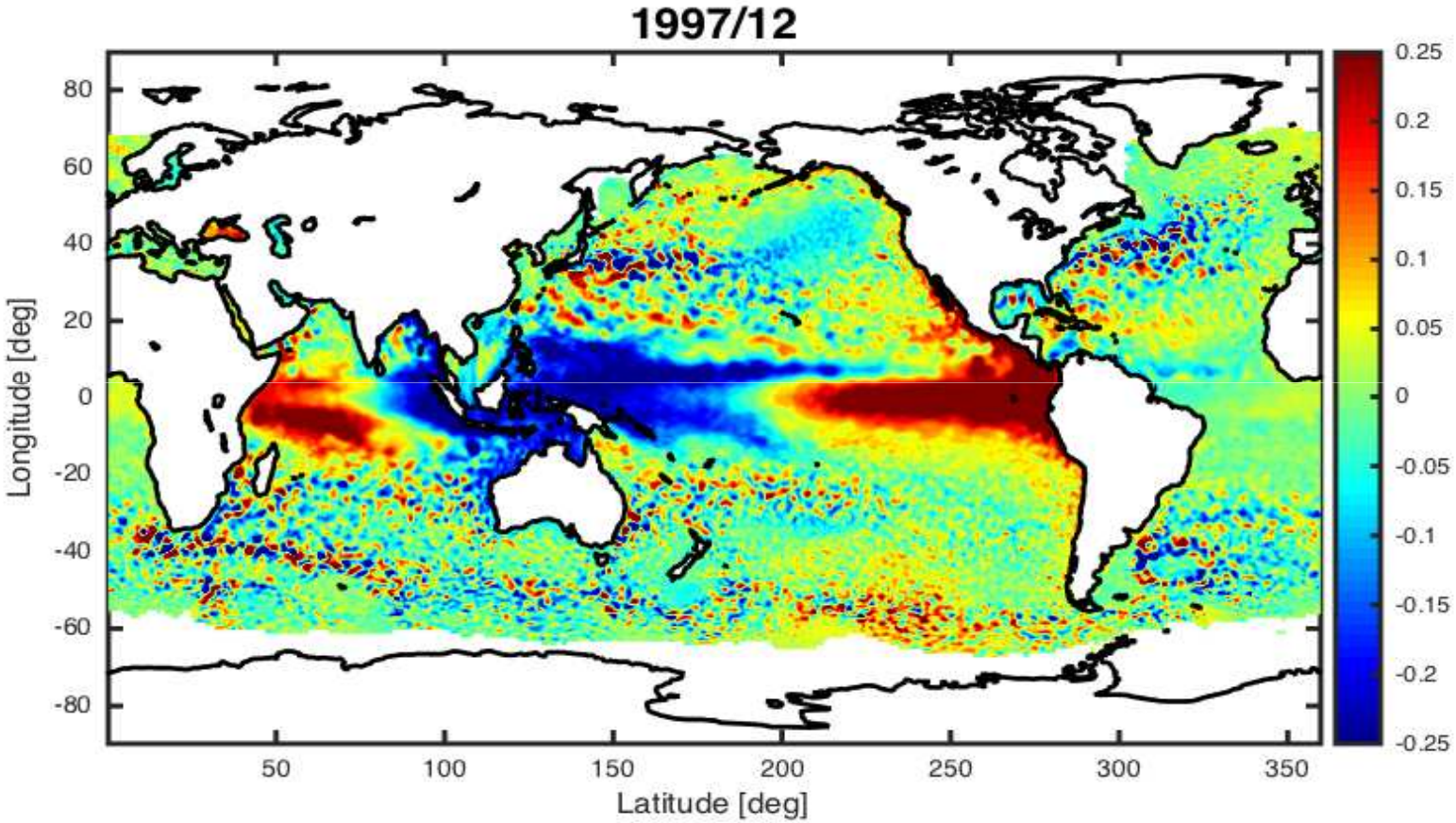

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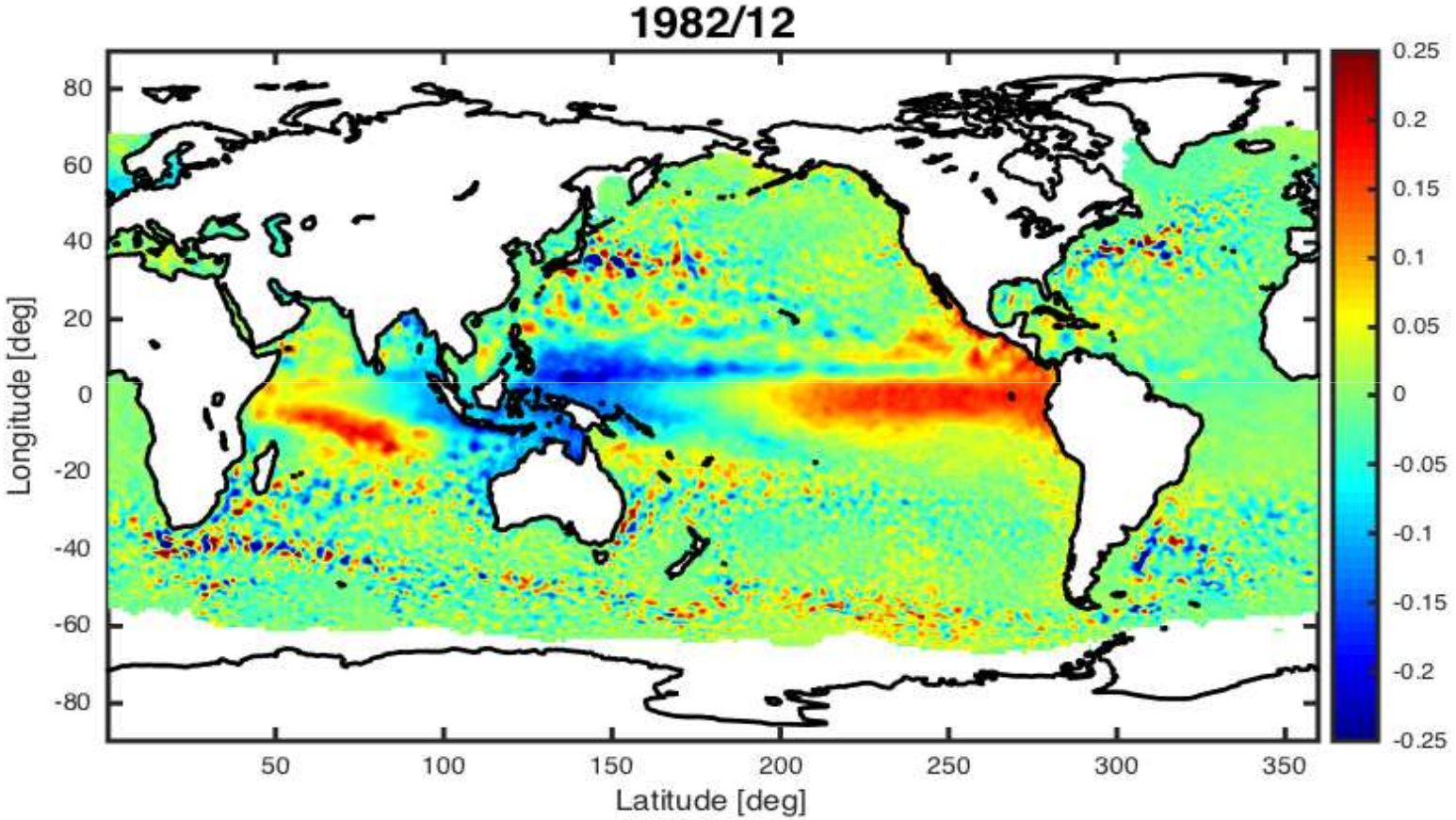
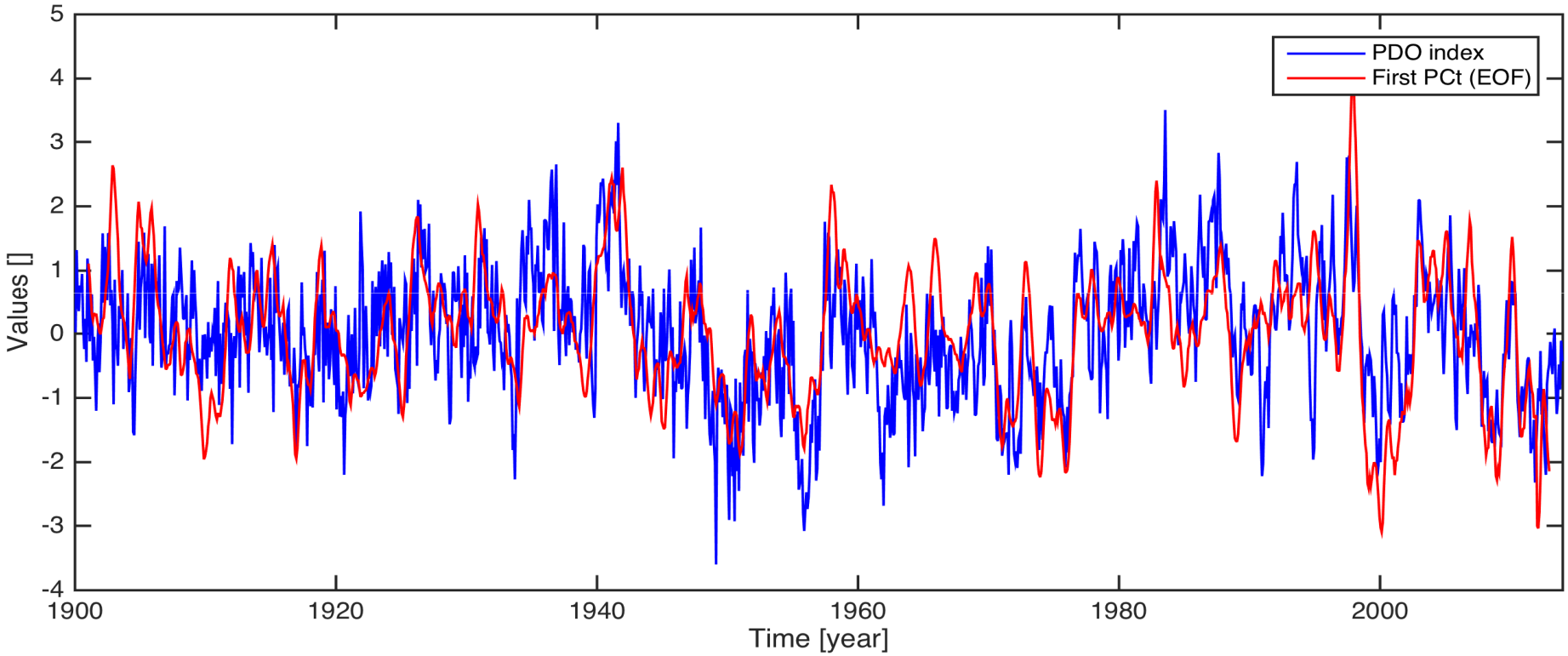


1. Historical Comparisons
Pacific Decadal Oscillation 1900-2014

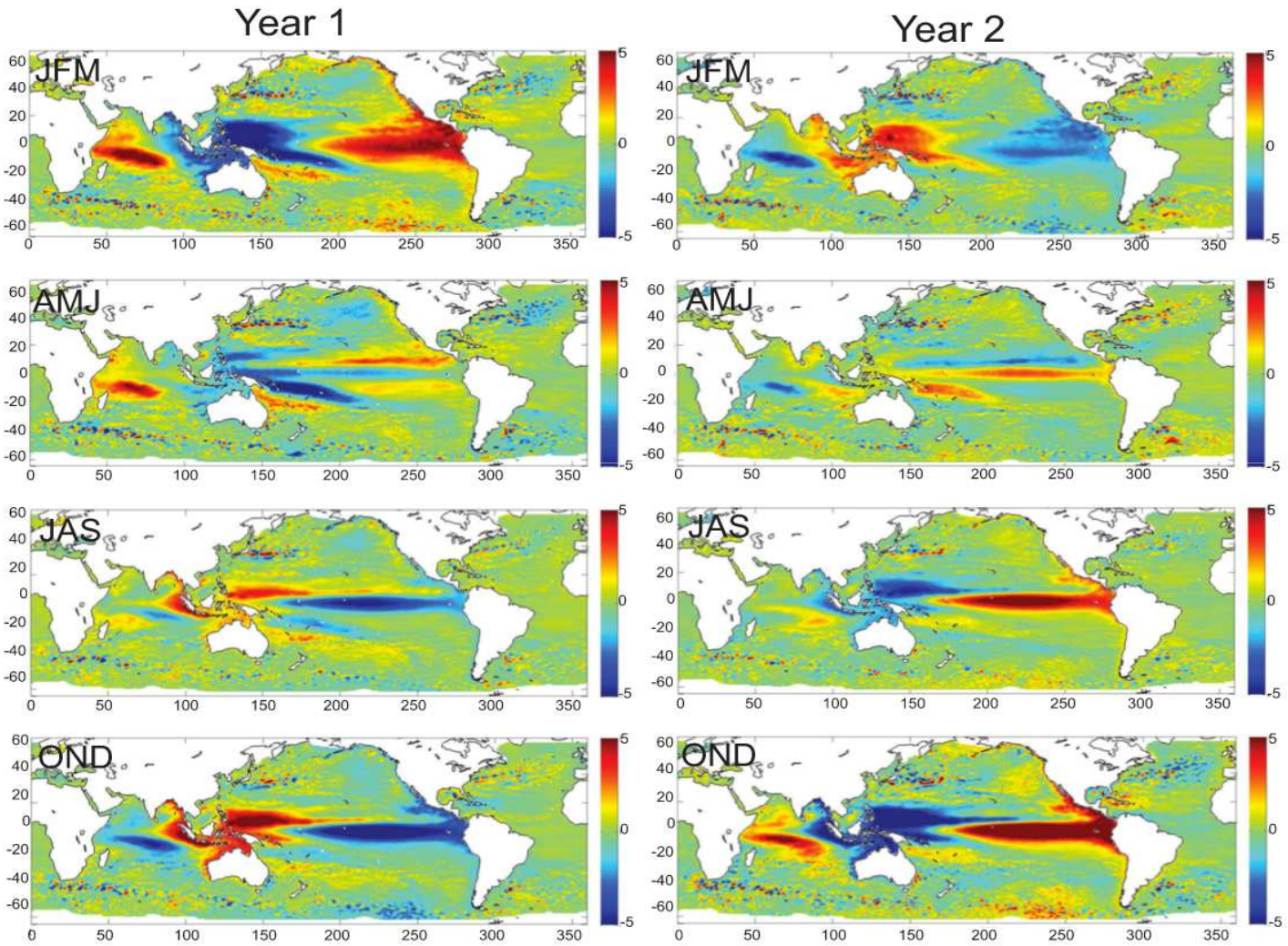


1. Historical Comparisons
Climate Variability 1900-2014

Reconstruction	TG-only	SST-only	TG-SST
MEI 1950-2010	**0.92** (0.95)	**0.92** (0.94)	**0.95** (0.97)
MEI 1900-2010	**0.77** (0.80)	**0.84** (0.89)	**0.86** (0.91)
EMI 1950-2010	**0.72** (0.84)	**0.75** (0.87)	**0.82** (0.91)
EMI 1900-2010	**0.34** (0.48)	**0.58** (0.75)	**0.64** (0.80)
PDO 1950-2010	**0.62** (0.73)	**0.54** (0.66)	**0.67** (0.77)
PDO 1900-2010	**0.49** (0.60)	**0.55** (0.60)	**0.59** (0.68)

(*Numbers in parentheses represent correlations after 1 year smoothing is applied)

2. Climate Monitoring



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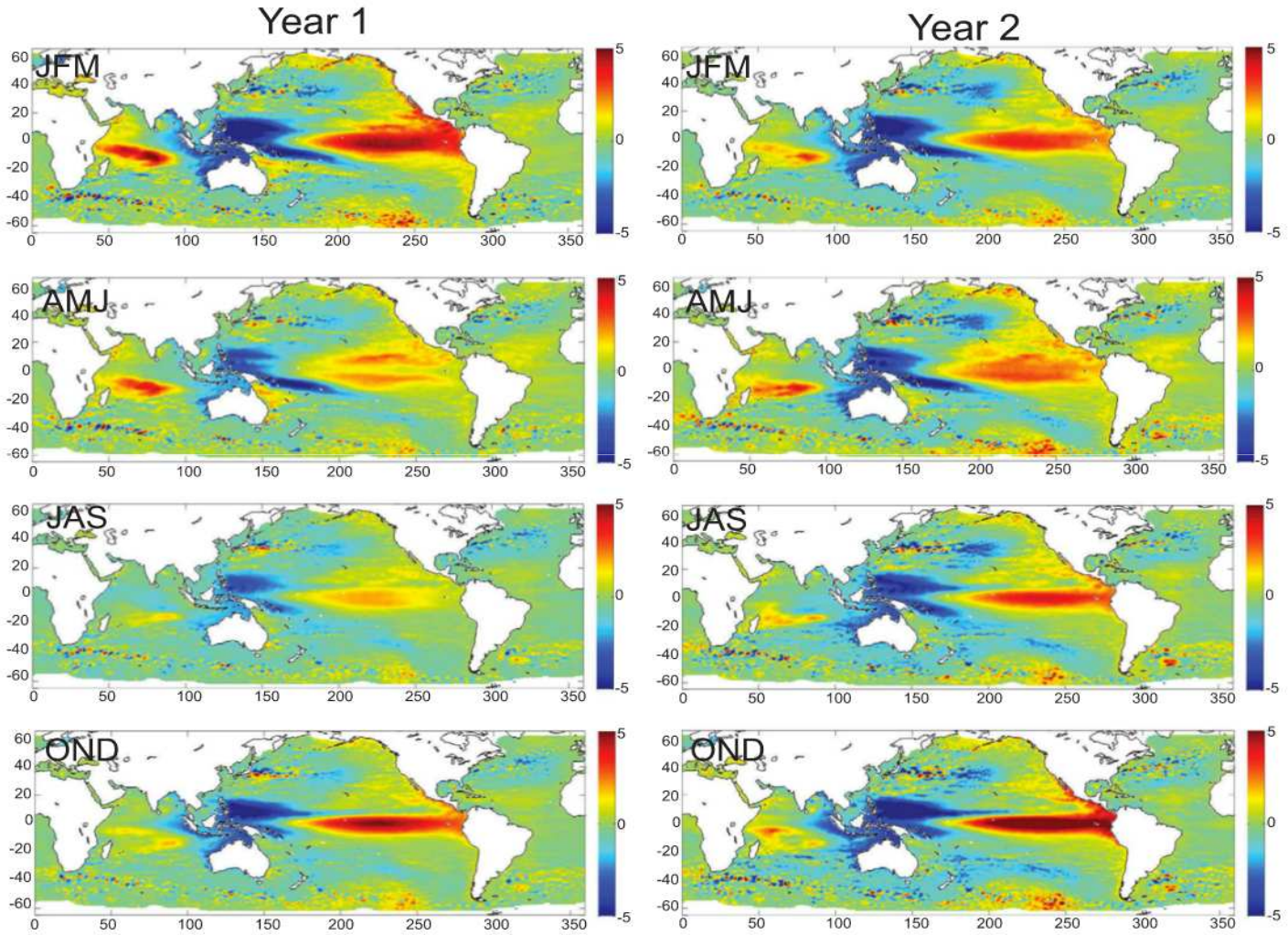
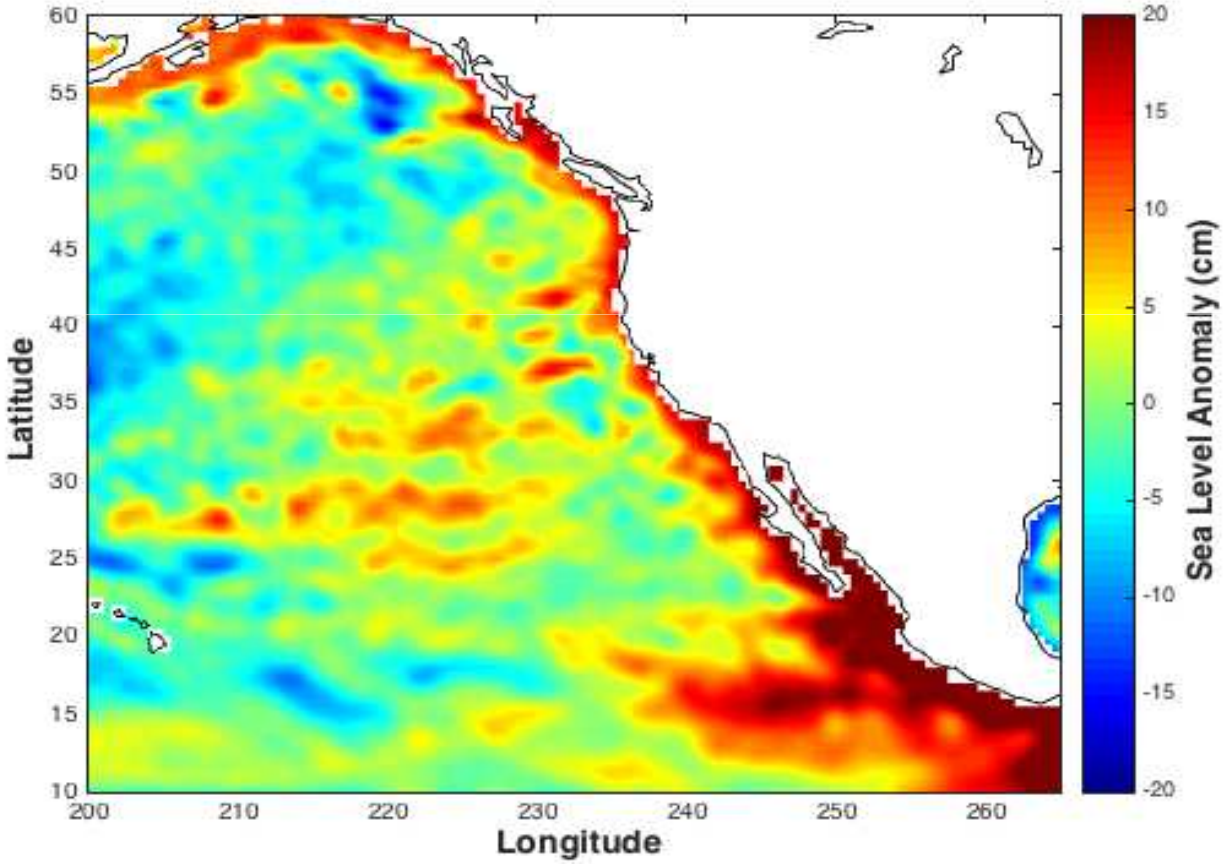
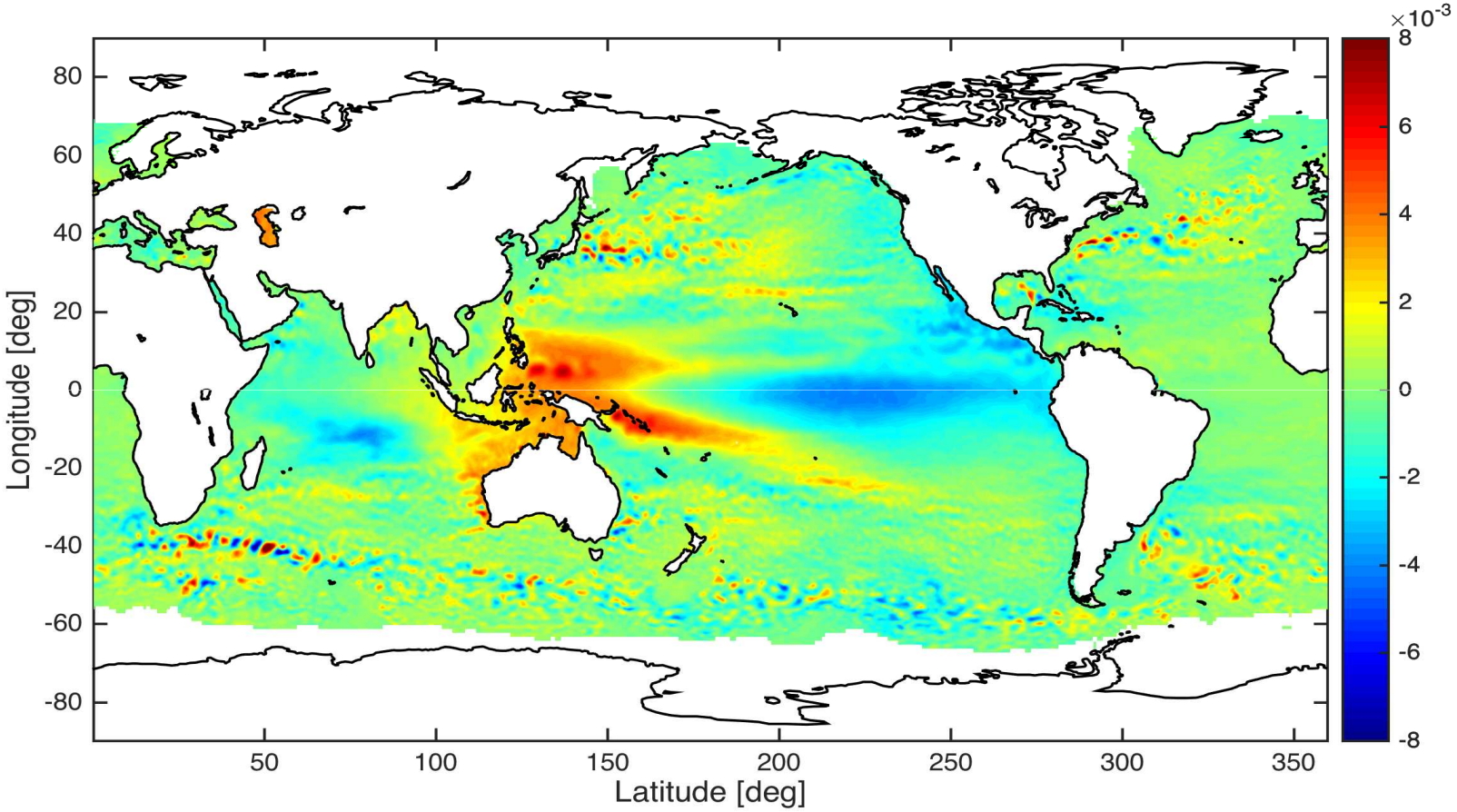


2. Climate Monitoring

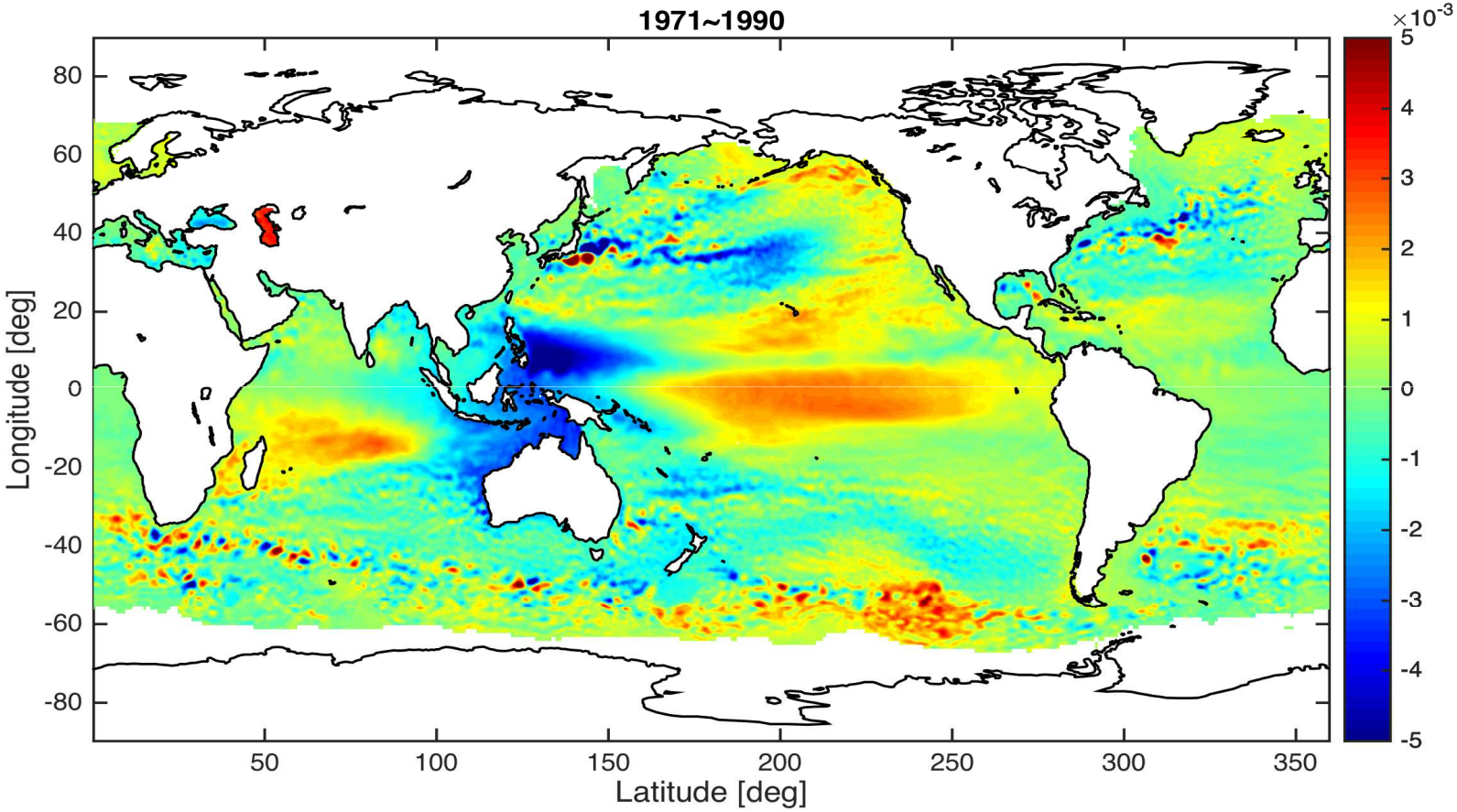
2015/2016 West Coast Sea Level



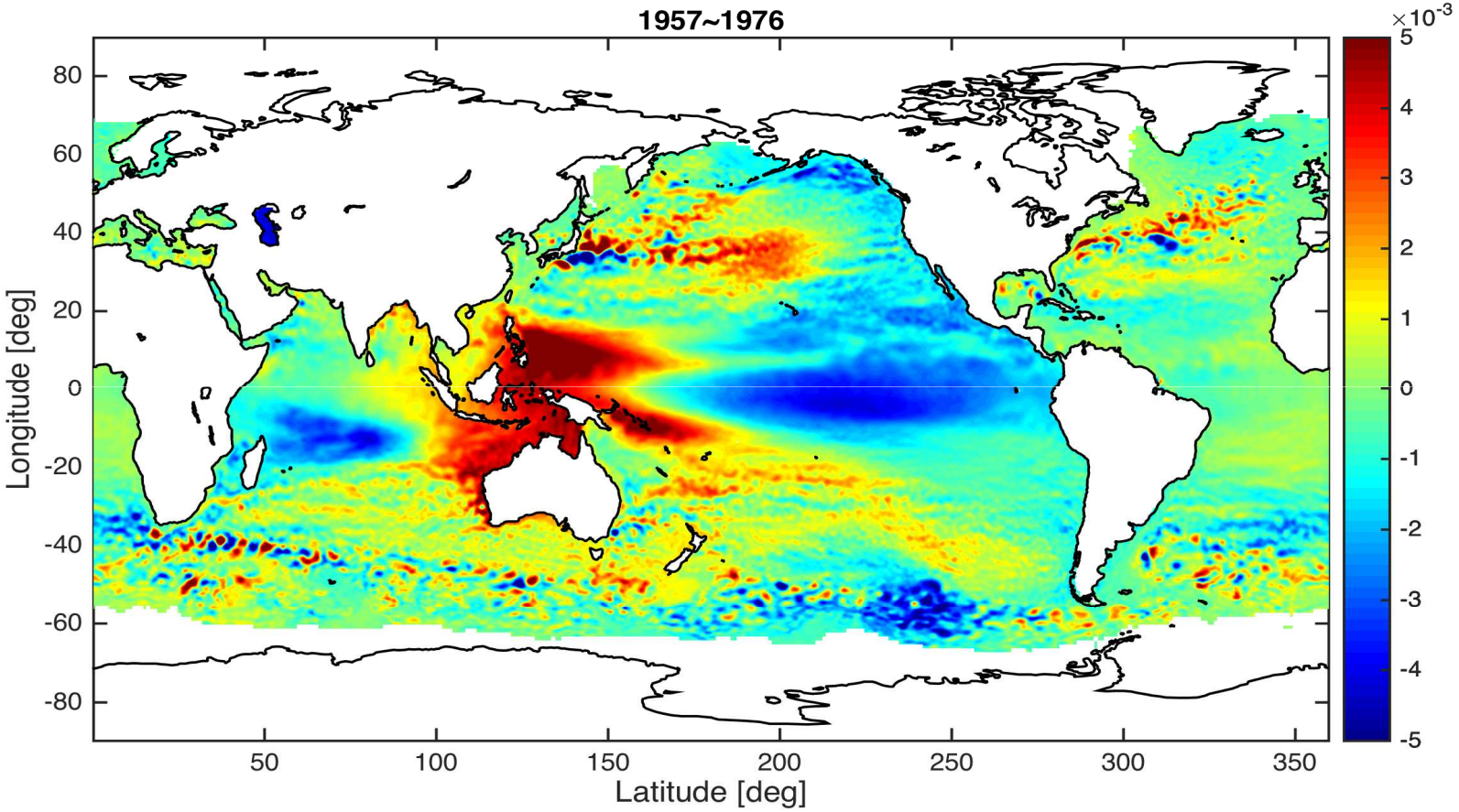
3. Trend Analysis
Regional Sea Level Trends 1993-2014



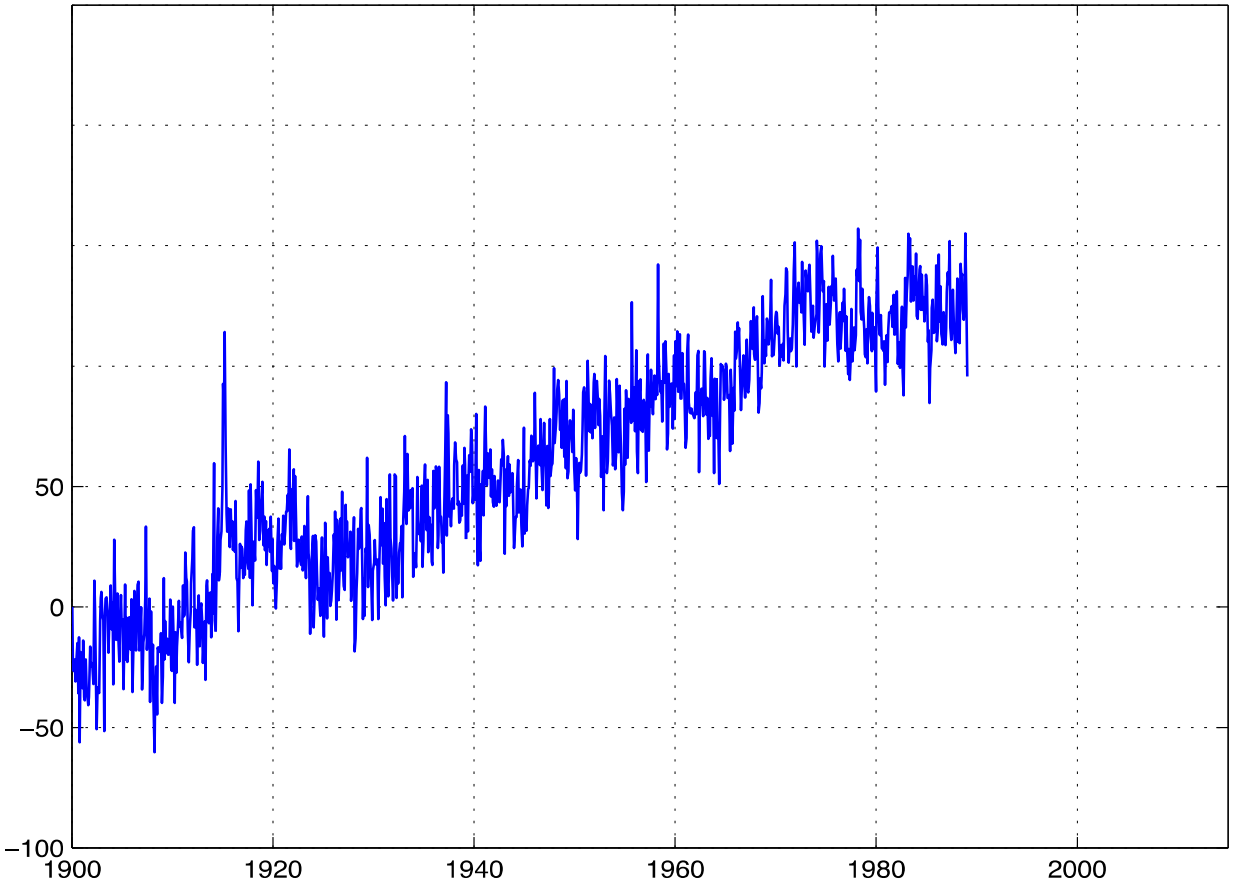
3. Trend Analysis
Regional Sea Level Trends 1971-1990



3. Trend Analysis
Regional Sea Level Trends 1957-1976



4. Global Mean Sea Level



Summary

- This reconstruction will be available through NASA JPL/PO.DAAC (soon).
- It will also be hosted through the CCAR Ocean Data System (CODS) (see Bob Leben's poster for further details).
  - Climate monitoring and other secondary products (GMSL) will also be available through CODS.
- Reconstruction will be setup to update monthly as new tide gauge, altimetry and SST data become available.
- Ongoing work: inclusion of more climate variables (sea level pressure), and improved error estimates.