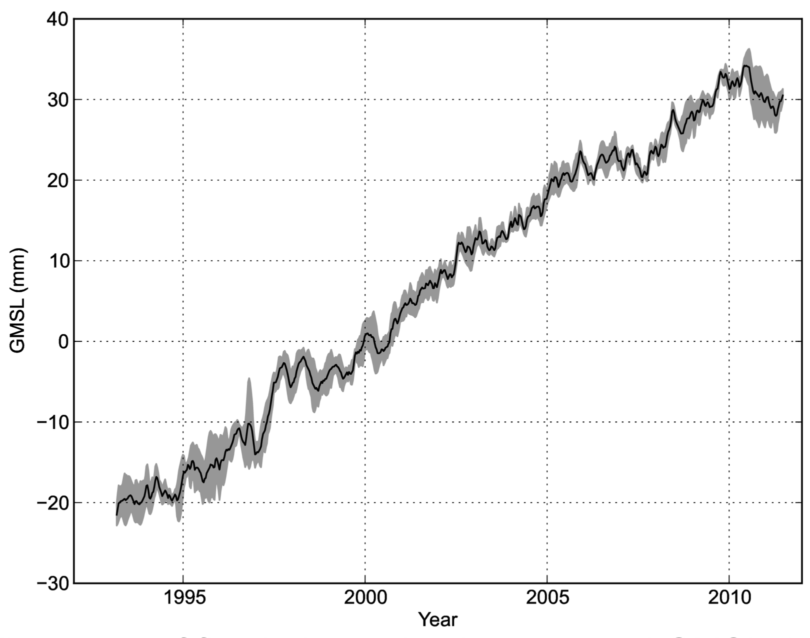
# Improving the Sea Level Data Record for Studying Climate Variability

**D. Masters, R. S. Nerem, J. Choe**
**University of Colorado**
**dallas.masters@colorado.edu**

## Abstract

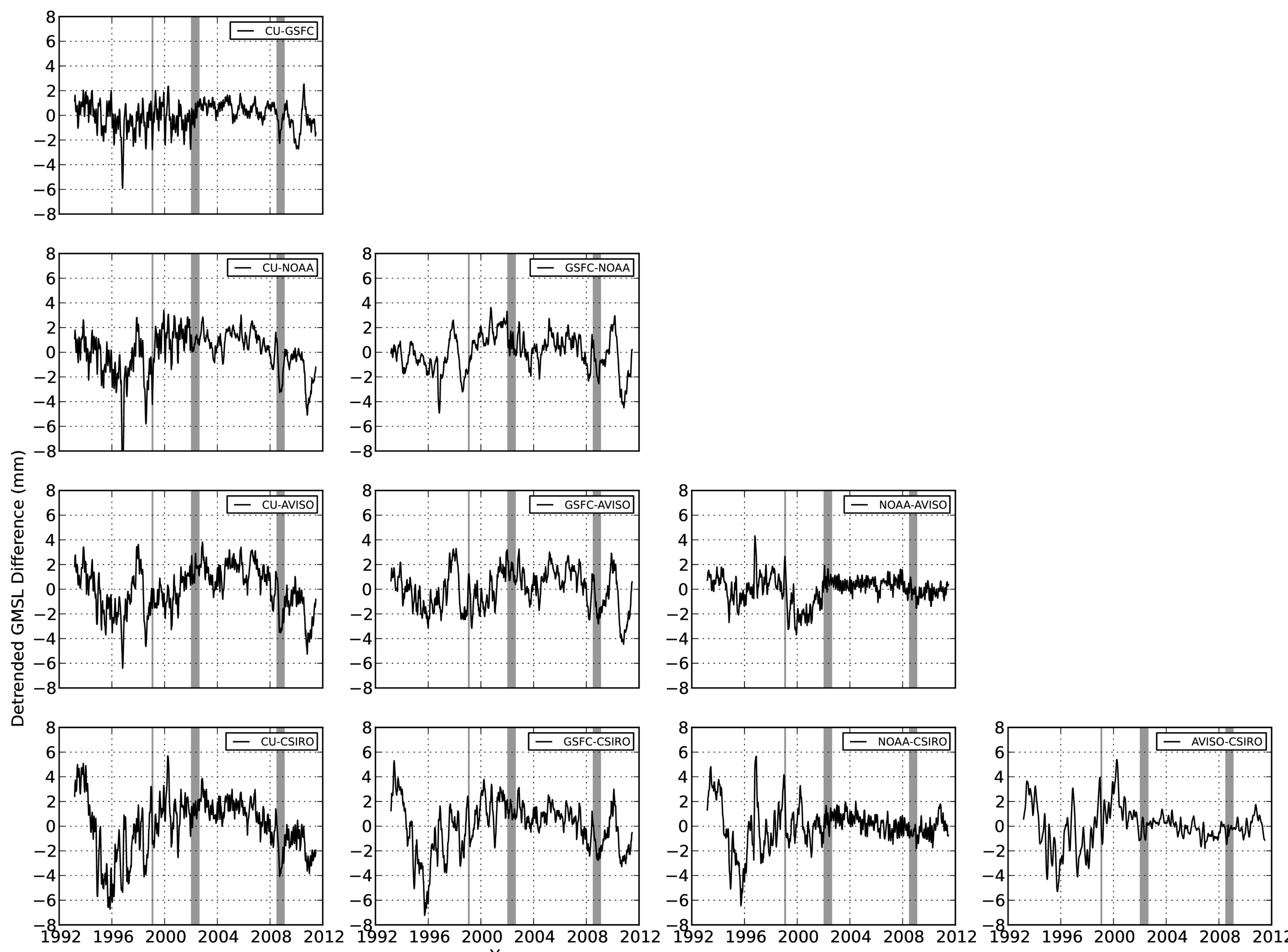
The University of Colorado has been producing and publishing a time series of global mean sea level (GMSL) since the TOPEX/Poseidon mission, and we continually refine our altimeter data processing and applied corrections. We report on recent improvements to update the processing to the latest, state-of-the-art corrections, including updated microwave radiometer drift parameters, mean sea surface, sea state bias models, orbits, etc., and efforts to test different processing techniques to improve and understand the variability in the long-term global mean sea level record. In past work, we found that choices of processing techniques, such as computing the global mean sea level from along-track versus gridded sea surface height anomaly estimates or editing shallow water areas, significantly changes the sensitivity of the GMSL time series to interannual variability, especially during strong El Nino-Southern Oscillation (ENSO) events. We also found that these different processing techniques are responsible for some of the larger interannual differences among the GMSL time series produced by different research institutions. We continue and extend this previous work by exploring modifications and improvements to our altimeter processing and by comparing the resulting sea level climate data records with other climate data records, such as sea level from tide gauges and the Multivariate ENSO Index (MEI). These efforts should help improve our interpretation of the global mean sea level time series as a climate data record and our understanding of linkages between sea level and climate variability.




The mean of five independently computed GMSL time series and the 95 percent confidence interval about the mean. Reduction of the variability among the time series would improve confidence in the GMSL as a climate data record.

## Comparison of GMSL Estimates

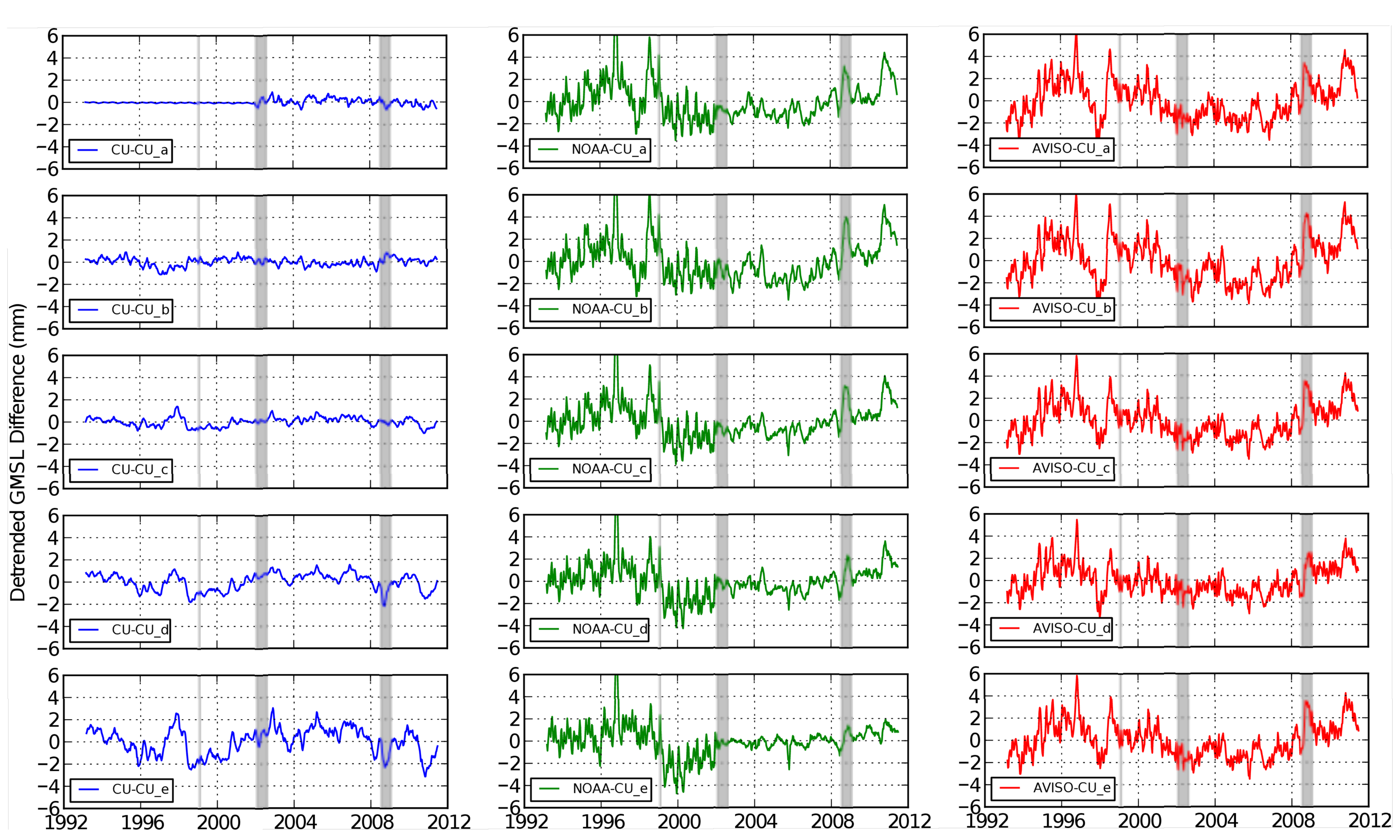
Masters, D., R. S. Nerem, C. Choe, E. Leuliette, B. Beckley, N. White, and M. Ablain. "Comparison of Global Mean Sea Level Time Series from TOPEX/Poseidon, Jason-1, and Jason-2." Marine Geodesy (2012): 120830133821002.




The differences among five independent GMSL time series after removing the seasonal signals and detrending. CU-GSFC and NOAA-AVISO each have the smallest differences and indicate the similarities between the series because they are derived from the mean of along-track versus gridded SSHA. Residual annual signals in CU-GSFC are most likely due to different outlier removal and included inland water bodies. The T/P era of NOAA-AVISO shows considerable variability compared to the Jason-1/2 eras, and this is most likely the result of using different wet tropospheric and sea state bias corrections and the handling of the switch from T/P Side A to Side B altimeter. The long-period signal in the CU-NOAA and CU-AVISO series are due to computing the mean from along-track versus gridded SSHA (as is evident in the opposite figure). The largest differences among all of the series occur at strong ENSO events in 1997-98 and 2010-11, indicating that the choice of algorithm and other constraints plays a large role in determining the sensitivity of each series to interannual signals.

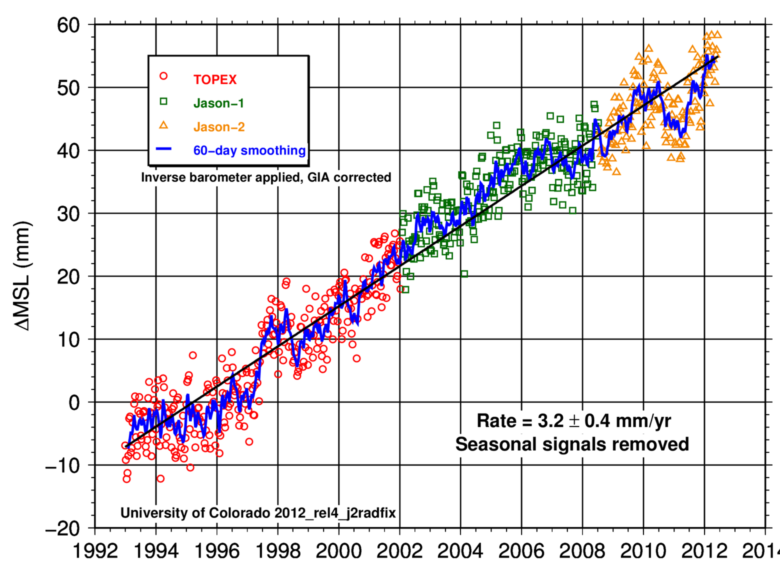
Least-squares estimated annual, semi-annual, and trend components of the recomputed CU GMSL time series and the nominal NOAA and AVISO time series.

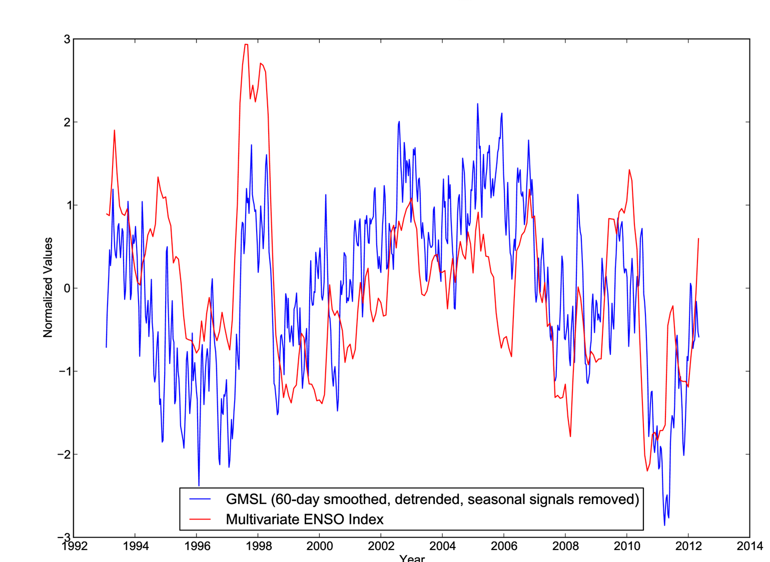
| Time Series | Annual Component | | Semi-Annual Component | |
|---|---|---|---|---|
| | Amplitude (mm) | Phase (deg) | Amplitude (mm) | Phase (deg) |
| CU (nominal) | 4.6 | 284 | 1.1 | 206 |
| CU_a (J1/2 GDR orbit) | 4.6 | 283 | 1.1 | 204 |
| CU_b (cosine weighted) | 5.0 | 285 | 1.0 | 198 |
| CU_c (no min. depth) | 4.9 | 292 | 1.2 | 215 |
| CU_d (3°x1° grid, cosine weighted) | 5.0 | 288 | 1.3 | 221 |
| CU_e (3°x1° grid, cosine weighted, J1/J2 GDR orbit, no min. depth) | 5.5 | 296 | 1.3 | 230 |
| NOAA | 5.8 | 299 | 1.3 | 231 |




Differences between the nominal CU, NOAA, and AVISO detrended series and the recomputed CU series based upon the table above. In CU-CU_a, we note that using the GDR orbit rather than the GSFC std0905 orbit in Jason-1/2 has a minor effect and slight negative trend. Weighting the along-track SSHA by the cosine of the latitude (CU_b) also has a minor effect, mostly during the ENSO events. A larger effect is noted in CU-CU_c when the minimum depth criterion is relaxed, especially at the 1997-98 El Niño. The largest single effect is in CU-CU_d and results from computing the mean of gridded rather than along-track SSHA. A long period signal is evident in CU-CU_d that is also evident in the NOAA-CU_[a-c] and AVISO-CU_[a-c] differences. When all of the modifications are applied in CU_e, the CU-CU_e difference is greatest and many of the features that were evident in the CU-NOAA and CU_AVISO differences are now visible. Additionally, the NOAA-CU_e difference has been minimized, especially in the Jason-1/2 eras. An unexplained long period signal is still evident in the AVISO-CU_e difference.

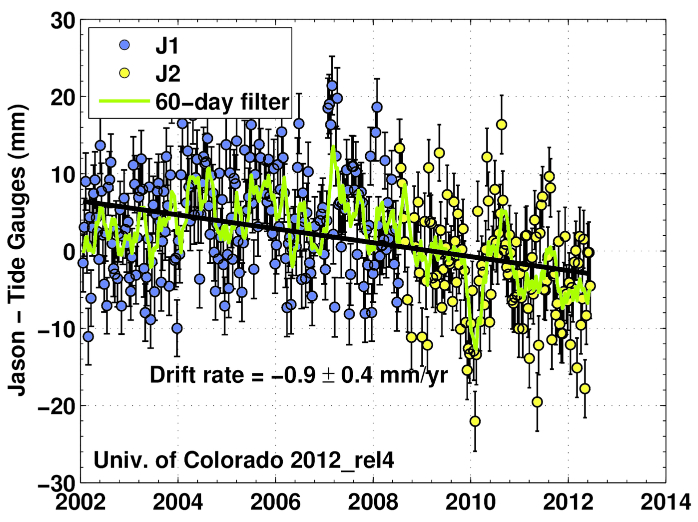
## Improving the CU Sea Level Record

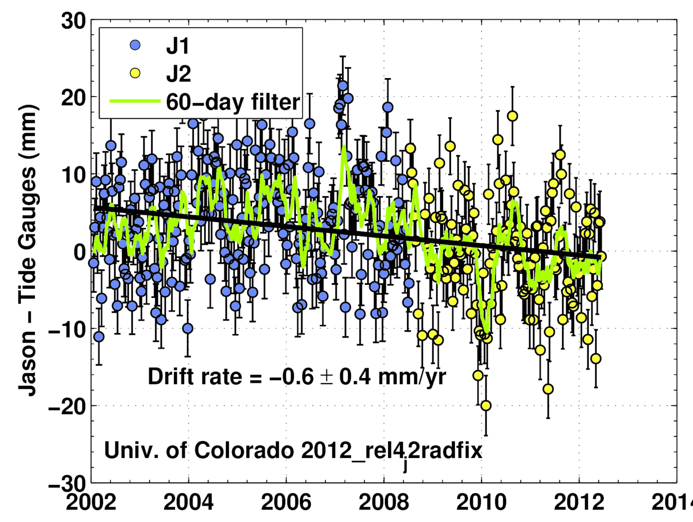


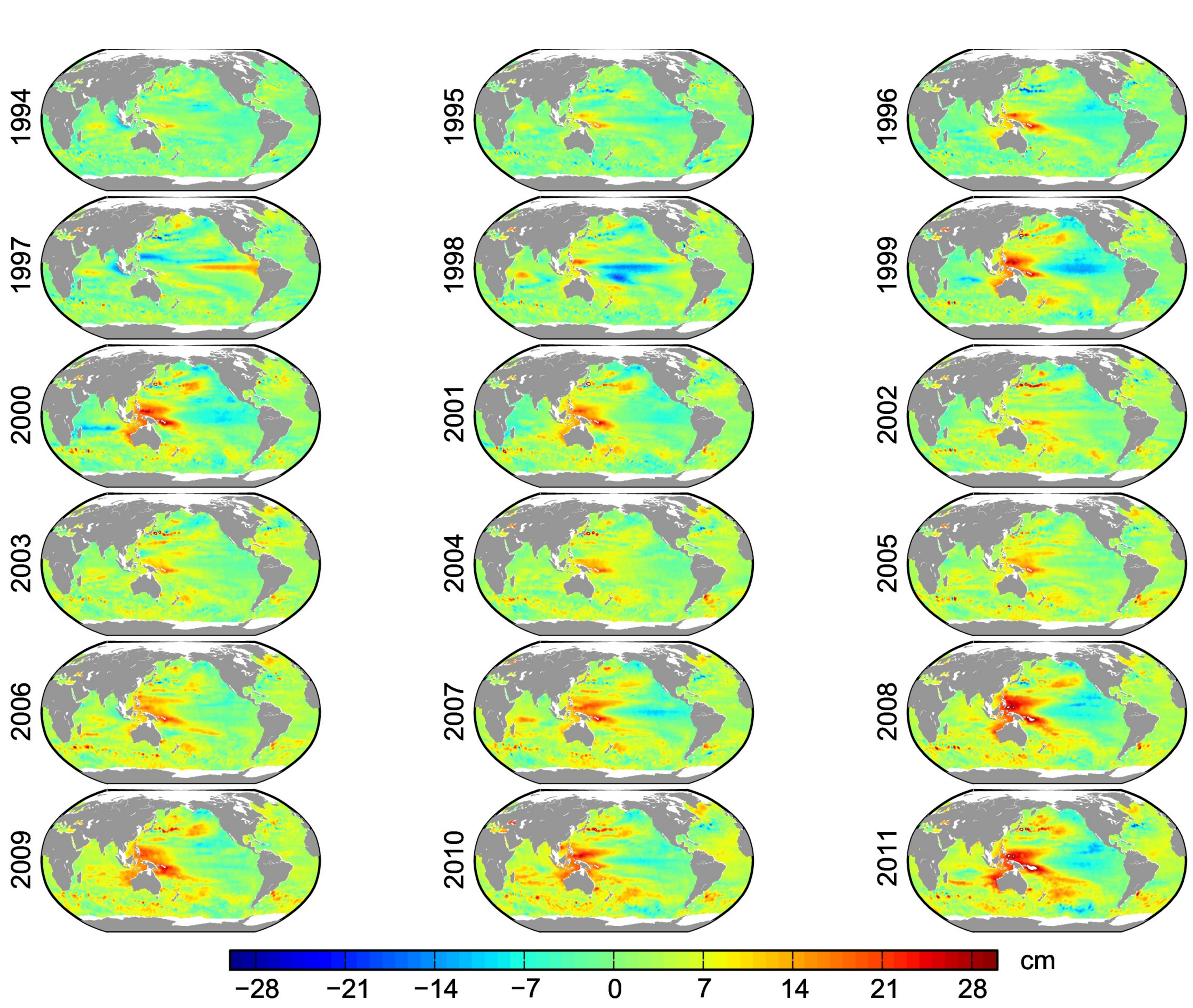

We recently updated the 20-year GMSL estimate (left) to include the Jason-2 radiometer corrections as used on GDR-D. This had the minor effect of increasing the rate of sea level over the Jason-2 era (see tide gauge calibration below). Further improvements to our GMSL estimates using updated GDR-D-class corrections are ongoing.

The Multivariate ENSO Index (MEI) (right) is the unrotated, first principal component of six observables measured over the tropical Pacific (Wolter & Timlin, 1993,1998). To compare the global mean sea level to the MEI time series, we removed the mean, linear trend, and seasonal signals from the 60-day smoothed global mean sea level estimates and normalized each time series by its standard deviation (right). The normalized values plotted above show a strong correlation between the global mean sea level and the MEI, with the global mean sea level often lagging changes in the MEI.




Jason-era tide gauge monitoring plots show the effect of updating the Jason-2 radiometer with GDR-D-class corrections (Brown, 2012). The drift rate is reduced from -0.9 to -0.6 mm/yr. Further work is needed to mitigate other causes of the drift. (Tide gauge cal from G. Mitchum).




The difference of annual means of sea surface height anomalies with respect to the 1993 mean show the regional signals of sea level change and the global increase in sea level evident from 1994-2011. Sea level has increased in the western south Pacific and eastern Indian Ocean basins while the eastern Pacific has decreased relative to 1993. Strong ENSO events (1997-98, 2010-11) are also visible in Pacific basin.

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