EVALUATING METHODS FOR CALCULATING A SEASONAL SEA SURFACE HEIGHT CLIMATOLOGY

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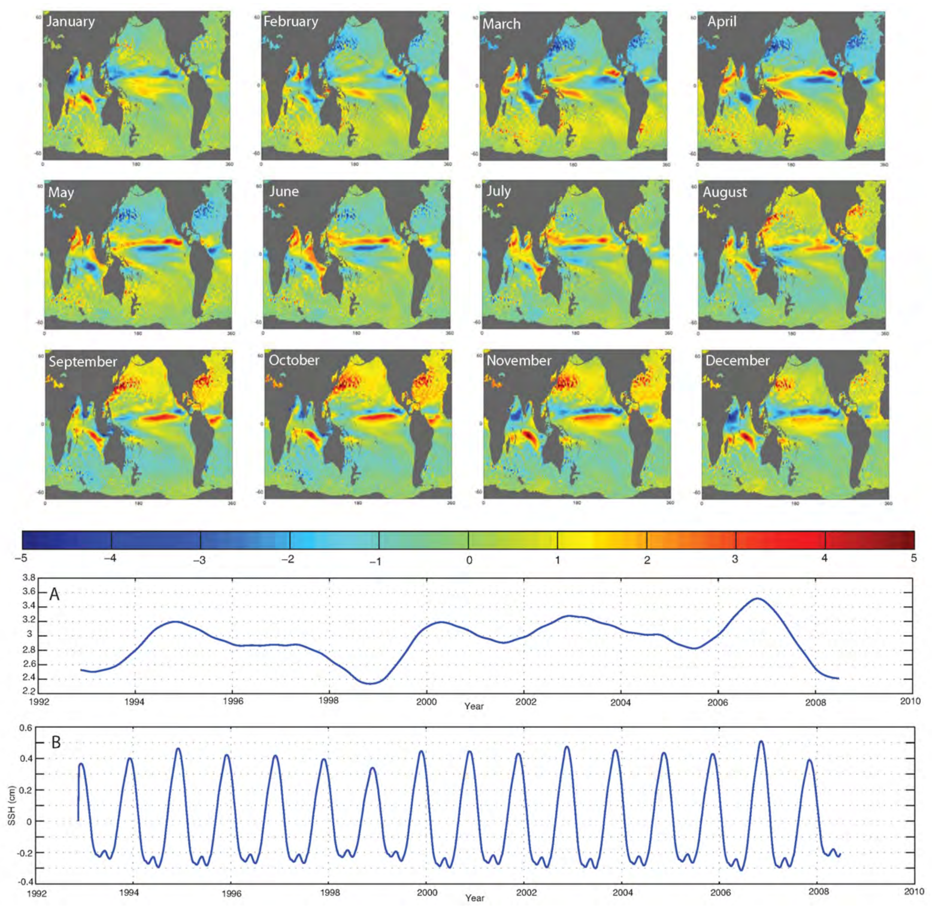


FIGURE 1. The first CSEOF mode obtained from the altimetric record explains the annual cycle signal. The top panels show the time-dependent loading vectors (LVs), while panel A shows the principal component (PC) time series. The time series in panel B is obtained when the LVs and PC time series are combined to show the global mean sea level (GMSL) associated with the annual cycle.

Abstract

Seasonal climatologies are useful for referencing measurements so that signals associated with the annual cycle do not mask lower frequency variability of interest. A variety of methods from simple averaging and least squares fitting of the data to sophisticated data adaptive methods such as cyclostationary empirical orthogonal functions (CSEOFs) can be used to calculate a seasonal climatology. We compare these methods to better understand the sea surface height (SSH) annual cycle and capture robust measures of the climatological seasonal signal. CSEOF analysis shows that the Modulated Annual Cycle (MAC) amplitude varies by approximately ±20 percent (see Figure 1). Accounting for these variations over short data records is critical to have a representative climatology. The overall goal of this work is to provide guidance for calculation of SSH seasonal climatologies to be hosted by PO.DAAC that are complementary to sea surface temperature and ocean vector wind climatologies and available in both along-track and gridded formats.

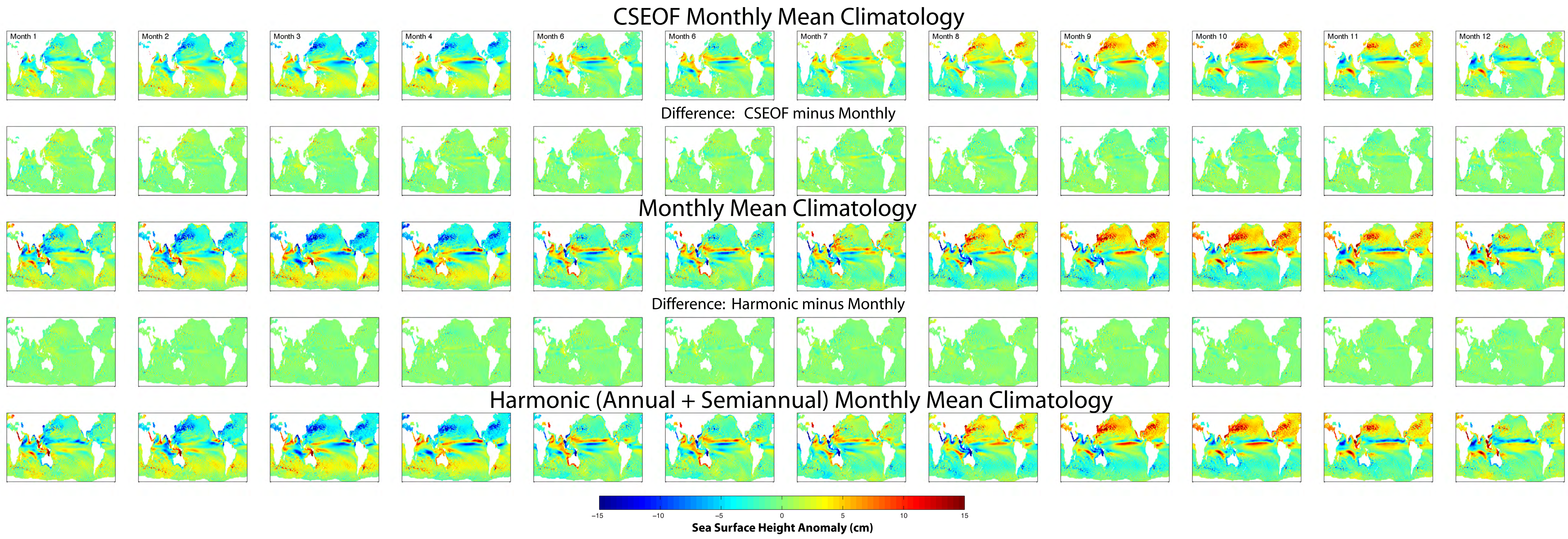
Data

The recently reprocessed and released ¼° resolution AVISO merged sea level anomaly maps at weekly intervals from 14 Oct 1992 through 4 Nov 2009 were used for the analyses shown below. The weekly maps were resampled using linear interpolation in time to 48 "pseudo" weeks coinciding with 12 four-week months spanning the tropical year. The length of the tropical year was selected as the mean J2000 epoch value, which is approximately 365.2422 days giving a "pseudo" week of about 7.6092 days. This resampling simplifies calculating monthly mean values and provides the requisite period for least-squares fitting of the annual cycle and a sampling interval that is an exact multiple of the annual cycle as required for CSEOF analysis. The maps were also subsampled to ½° resolution. The resampled dataset spans 16 years, 1993 through 2008.

Methods

Climatologies were computed only at spatial points in the AVISO dataset with complete records spanning the entire 16-year time period. The monthly mean climatology (Figure 2 middle row) was calculated by simple averaging of the resampled data after linear detrending of the temporal records at each point. Least-squares fitting of n-cycles per year (n=1,2,3, & 4) sine and cosine functions to the detrended dataset was also performed. The climatology given by the combined annual and semiannual signals (n=1,2), averaged from the corresponding weekly values, is shown in the bottom row of Figure 2. Monthly averaging of the reconstructed annual mode (mode 1) from a CSEOF analysis of the *un-detrended* AVISO dataset provided the final climatology for comparison and is shown in the uppermost row of Figure 2.

FIGURE 2. Comparison of the Monthly Mean with Harmonic and CSEOF Monthly Mean Climatologies



Results

Using the mean monthly climatology as the benchmark, relative monthly differences between the CSEOF and harmonic climatologies and the monthly mean climatology were calculated and are shown in rows two and four of Figure 2, respectively. Visual inspection of the results finds that relatively similar seasonal climatologies can be calculated using each of the methods, however, there are significant differences. These differences are largely attributable to the inherent smoothing of the time series by both the least-squares and CSEOF processing. Significant mesoscale signals can be identified in each of the climatologies. The RMS difference between each of the respectively climatologies are shown in Figure 3 below. These were computed from the "weekly" climatologies to highlight the smoothing properties of methods without the affect of the additional smoothing to compute monthly mean values from the weekly estimates. The greatest RMS differences are located in regions of strong mesoscale variability and are largest relative to the mean climatology, indicating that both the CSEOF and harmonic climatologies are less contaminated by aliased mesoscale variability.

Nevertheless, the amount of mesoscale variability in all of these climatologies is a concern and some type of filtering should be applied either before or after estimating the climatology to reduce the effect of aliased mesoscale energy. The appropriate filtering method to employ is an open research question.

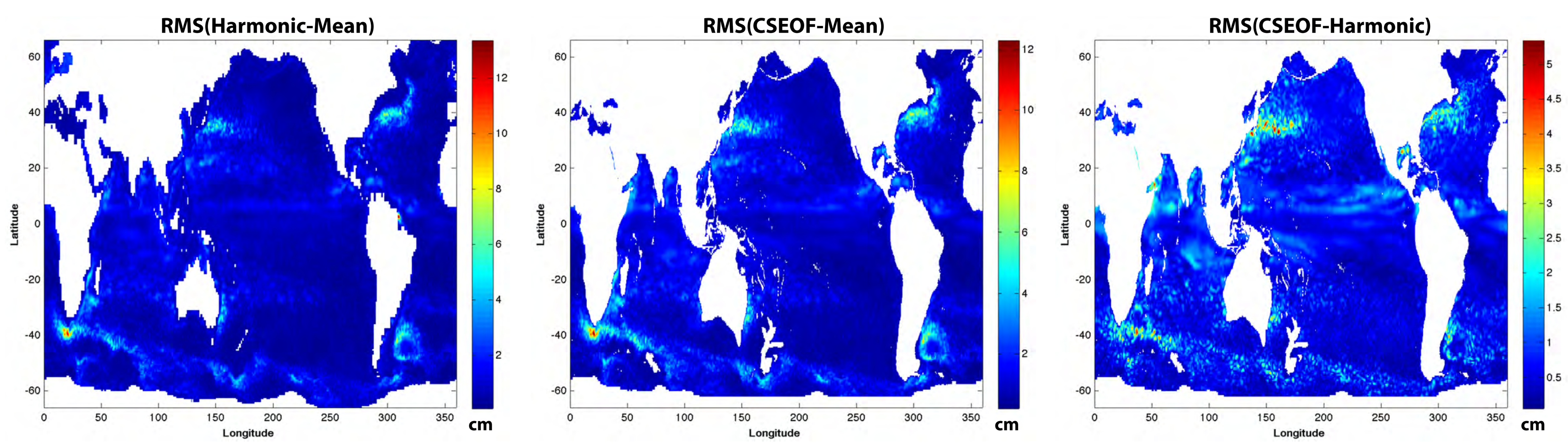


FIGURE 3. RMS of the "Weekly" Differences of the Climatologies

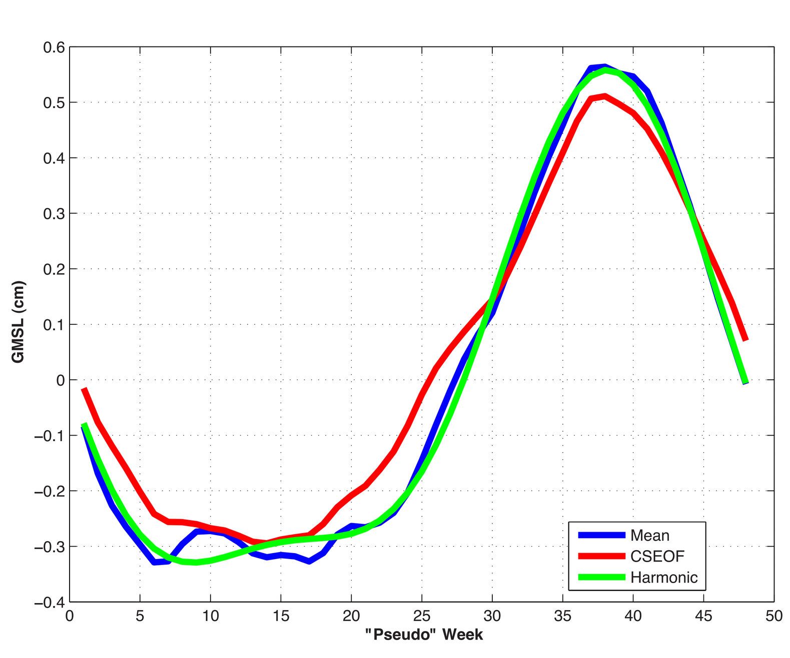


Figure 4. Global Mean Sea Level computed from each of the climatologies.

The final comparisons we show in this preliminary study is global mean sea level (GMSL) computed from each of the climatologies using equal area weighting of the values from locations where the ocean is at least 1000 meters deep. GMSL computed over the "weekly" climatologies are shown in Figure 4.

The harmonic and mean annual cycles show very good agreement, with the harmonic providing an excellent smoothed approximation to the weekly mean curve. The CSEOF GMSL annual cycle does not agree nearly as well, exhibiting a smaller amplitude of the annual cycle than either the harmonic or mean. The reason for the difference is unknown at this time, however, results derived using CSEOF analysis of a detrended dataset increased the disagreement. This was the primary reason that an "un-detrended" dataset was used in this study.

Figure 5. Maximum, Minimum and RMS Difference of MAC minus Mean Annual Cycle

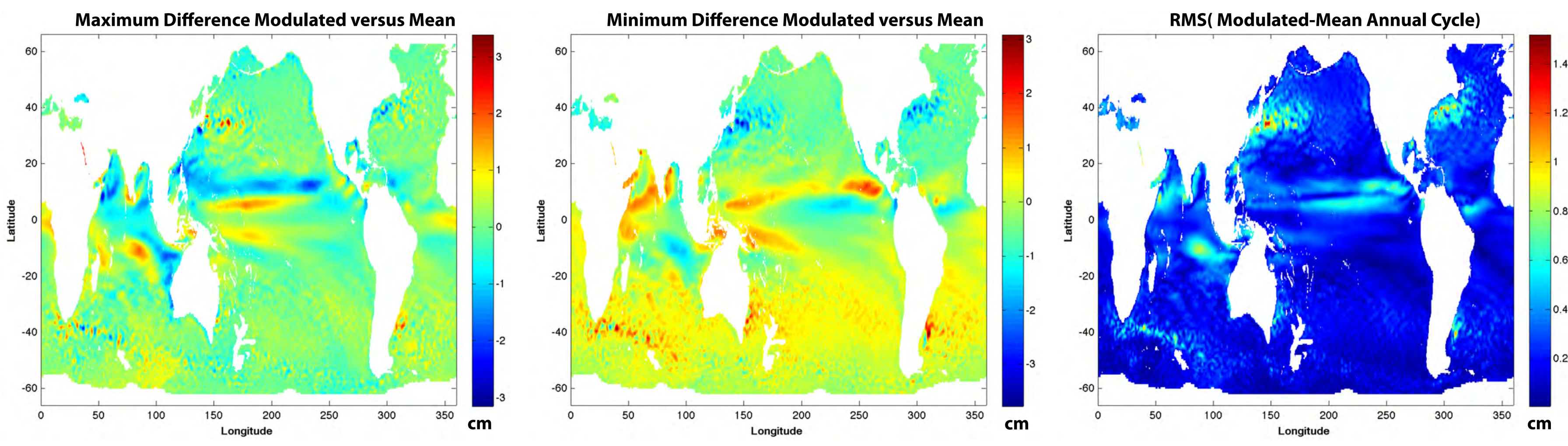


Figure 6. Amplitude of the MAC

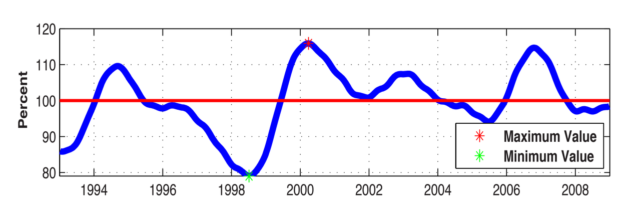


Figure 7. Mean Sea Level Signals MAC - Mean Annual Cycle

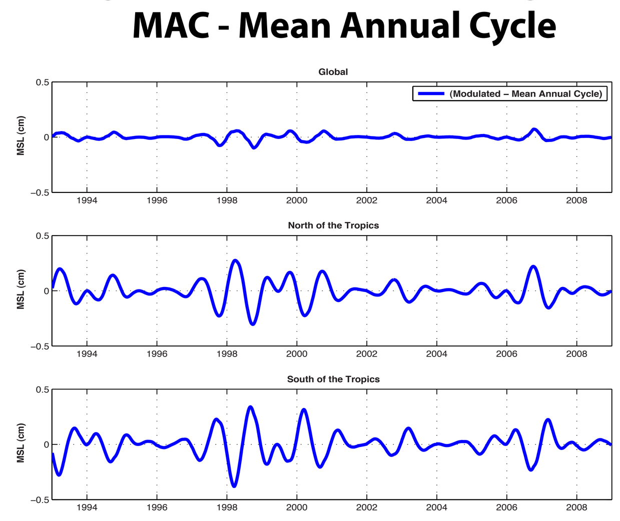
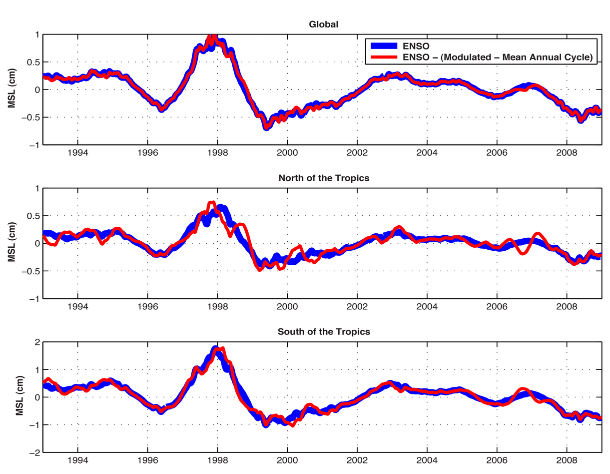


Figure 8. Impact on a realistic ENSO signal of referencing to a mean climatology

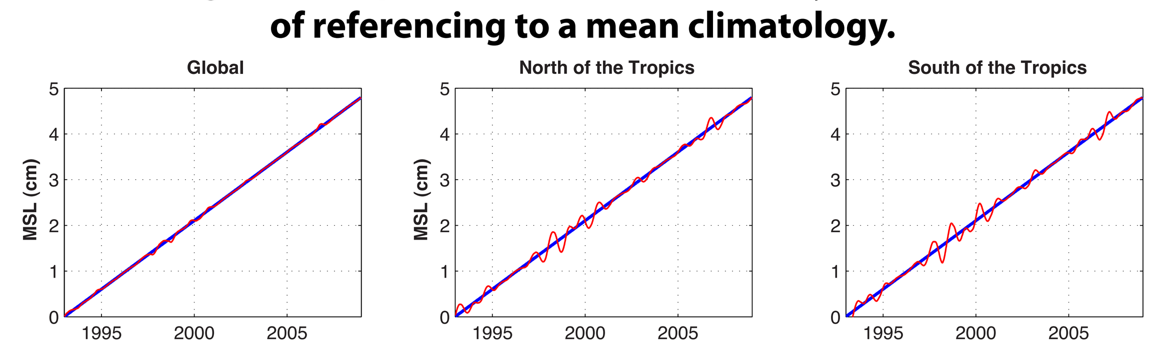


What about the "Modulated Annual Cycle" (MAC)?

A significant advantage of the CSEOF method is that it gives an estimate of the "Modulated Annual Cycle" or MAC, which in the altimeter record is nearly ±20% of the mean amplitude. In Figure 5, we show the instantaneous extremes of the MAC relative to the mean annual cycle determined from the 16-year AVISO altimetry record. The "maximum" occurred in the 12th "week" of 2000 and "minimum" in the 25th "week" of 1998 according to the annual cycle principal component time series shown in Figure 6. The patterns of variability associated with these extrema are on the order of a few centimeters and large in scale and the overall total energy associated with the signal is relatively weak as is seen in the RMS plot (Figure 5). Nevertheless, the signal is clearly seen in mean sea level (MSL) averages poleward of the tropics (Figure 7), although it barely affects GMSL because of the phase difference of the signals between the hemispheres.

It should be noted that this signal arises whenever a MAC signal is present and a dataset or climate signal is referenced relative to the mean climatology. Figure 8 shows the impact of this referencing on a realistic ENSO signal given by the second CSEOF mode. The impact is relatively pronounced north of the Tropics where the mean ENSO signal is of the same order of magnitude as mean signals associated with the MAC minus the ocean annual cycle. Similarly, the effect is seen on simulated 3 mm/year MSL trends poleward of the tropics (Figure 9). It remains to be seen if sufficiently accurate and robust climatologies can be produced using the CSEOF method so that accounting for this signal is necessary or even possible.

Figure 9. Impact on a simulated 3mm/year trend of referencing to a mean climatology.



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