Global Sea Level Estimates from the GCOS Tide Gauge Network

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Overview

The Global Climate Observing System (GCOS) includes a network of 180 tide gauge stations for monitoring sea level change. The stations were chosen to maximize spatial coverage, two-thirds of the ocean is within 10° of a station (**Figure 1**), and record length, 60 stations date back to at least 1950 (**Figure 2**). Two-thirds of the stations are currently in operation. The purpose of this study is to examine how well globally averaged sea level (GSL) rise rates can be estimated using the GCOS network. The performance of the network is evaluated using GSL calculated from annual means of Aviso sea surface height (SSH) (1993-2006) and SODA-POP model sea level (1958-2001).

Fig 1

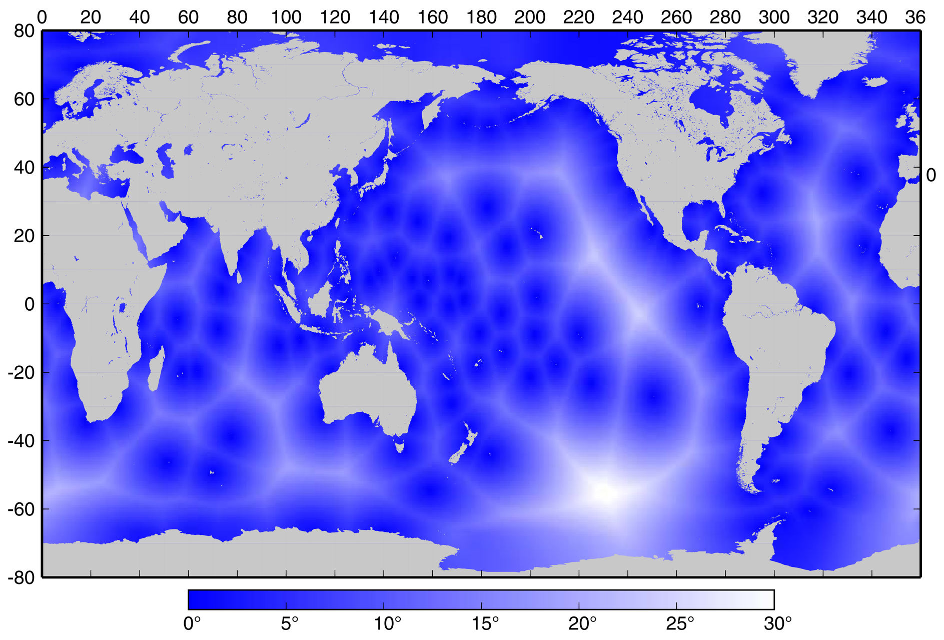
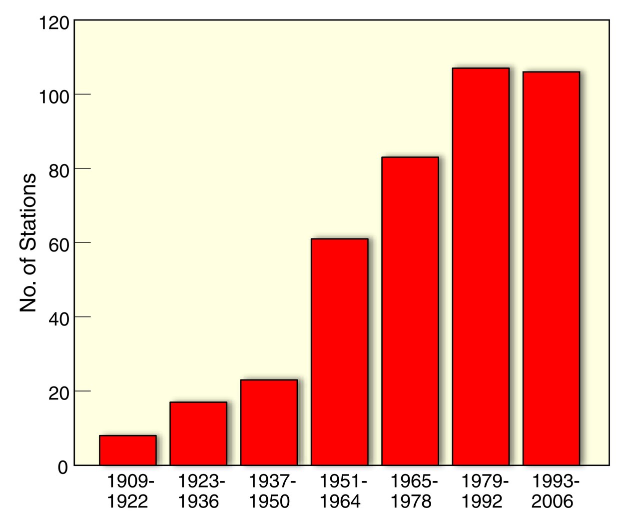


Fig 2



Average of Trends, Synthetic Tide Gauge Data

SSH linear trends (**Figure 3**) are averaged (spatially-weighted) over 10° latitude bands (Figure 4). The sum of the 10° rates yields the total GSL rise rate, which for the complete SSH dataset is 2.84 mm/yr. Contributions to the GSL rate for the 1993-2006 period are high in the tropics, and in the southern hemisphere near 40°S (**Figure 4**).

Fig 3

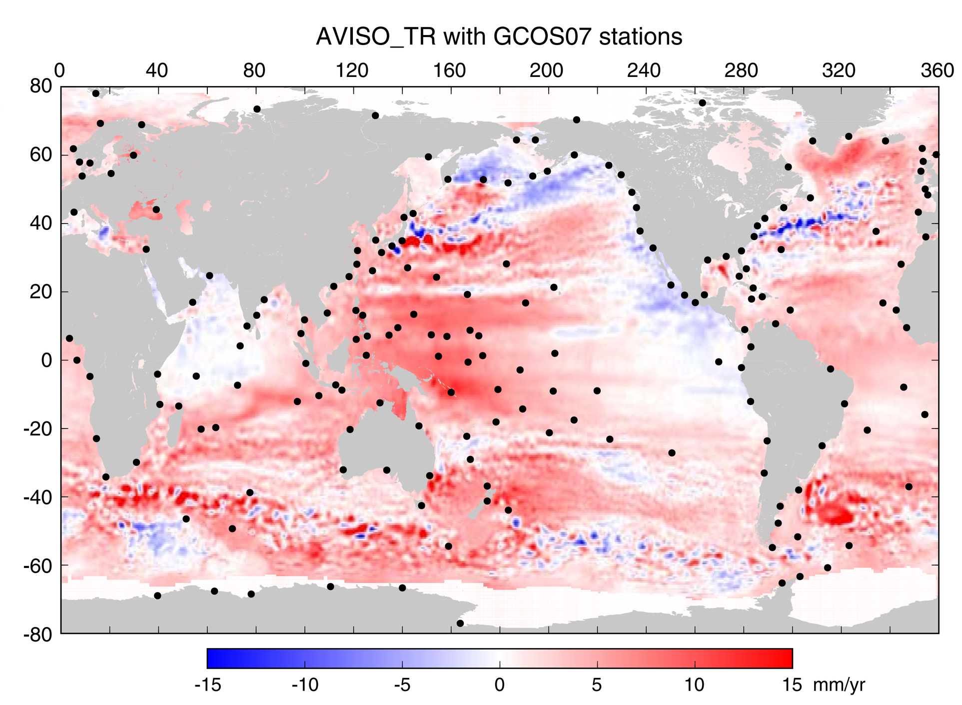


Fig 4

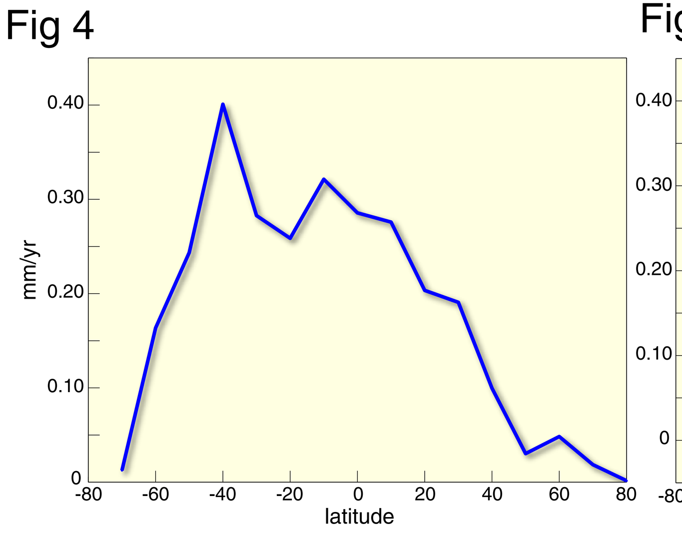
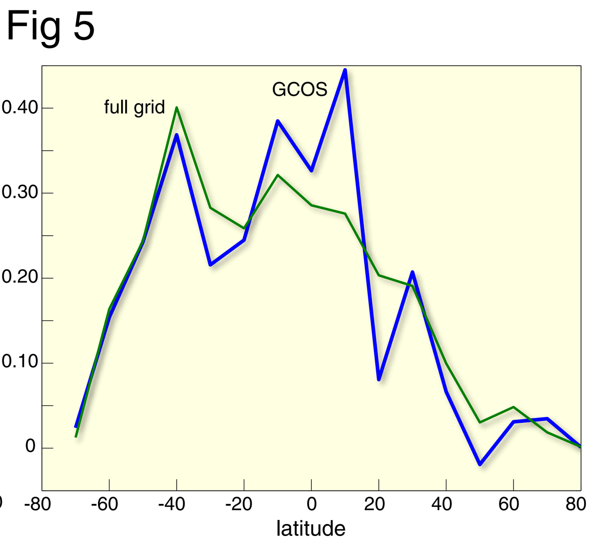
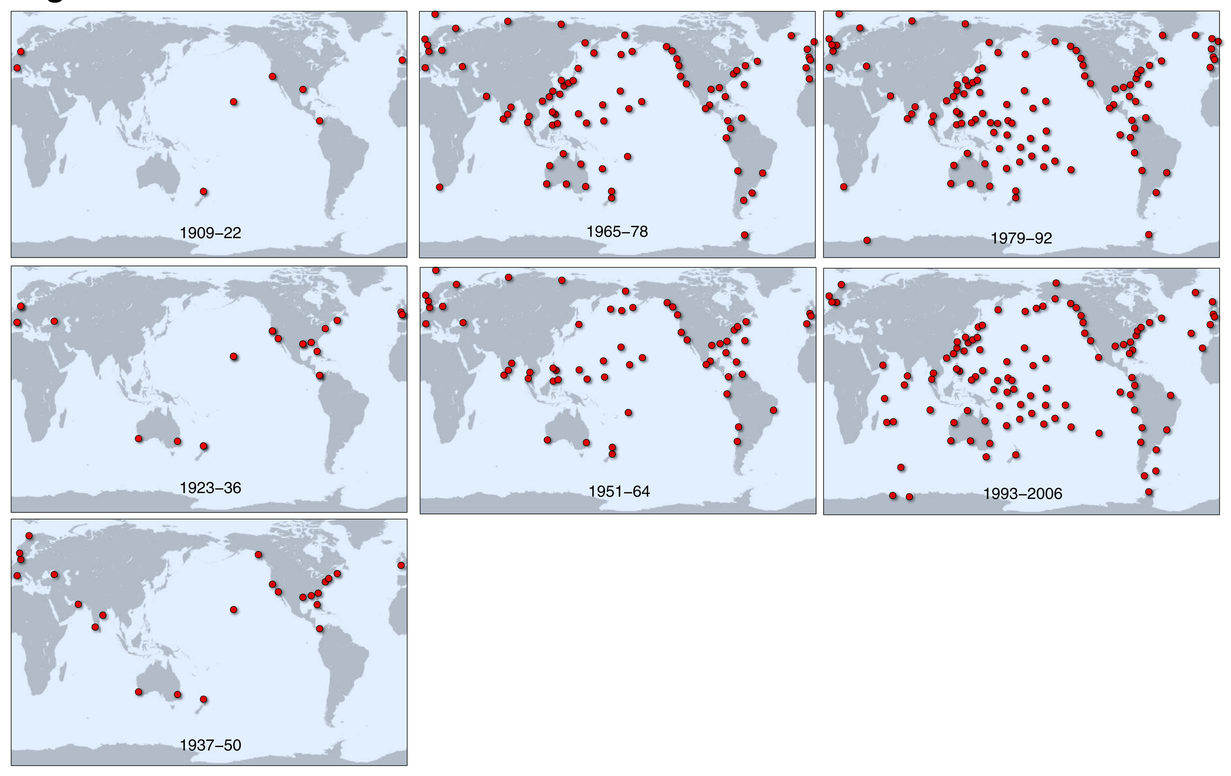


Fig 5



We sub-sample the SSH data at the ocean grid points closest to the GCOS stations, which we then treat as synthetic tide gauge data that are free of land motion contamination. Averages of the synthetic GCOS trends (mean or median) over 10° bands yields a nosier version of the meridional trend pattern obtained from the complete dataset (**Figure 5**); however, the corresponding total GSL rate is similar (2.81 mm/yr compared to 2.84 mm/yr for the entire dataset). The same analysis performed on the 41 year SODA-POP dataset yields similar results with the GSL rate of the synthetic GCOS data within 0.1 mm/yr of the total SODA-POP rate. We conclude that a fully operational GCOS network, uncontaminated by land motion, can provide useful estimates of the total GSL trend with low bias error.

Fig 6



When fewer GCOS stations are available, this method for estimating GSL rise is compromised. To illustrate this, we repeat the computation of the 1993-2006 GSL trend using subsets of the GCOS network that actually were in operation over different 14 year periods (**Figure 6**). For many of the earlier periods, data are not available in some of the 10° bands, particularly in the southern hemisphere (**Figure 7**). Even when data are available over all bands, the estimated trends are systematically lower than the actual 2.84 mm/yr rate (**Table 1**).

Fig 7

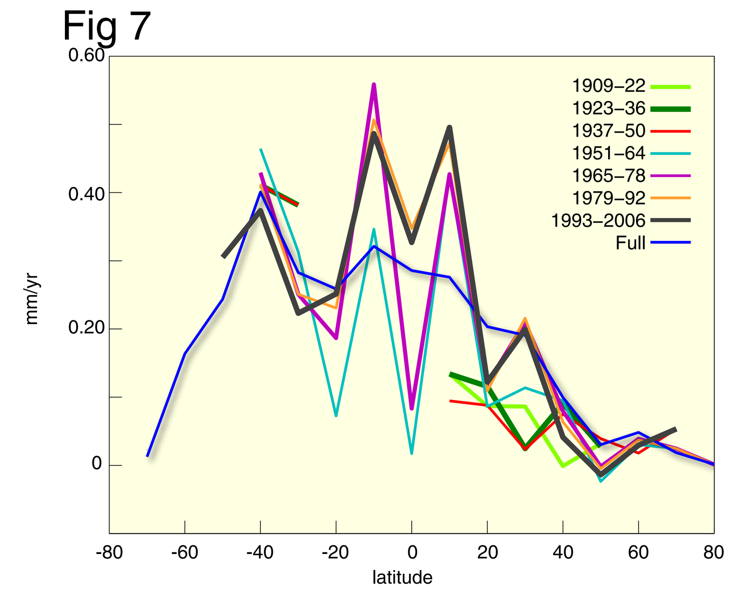


Table 1

period	trend from mean	trend from median
1909-1922	0.75	0.75
1923-1936	1.19	1.21
1937-1950	1.18	1.20
1951-1964	1.96	1.81
1965-1978	2.42	2.43
1979-1992	2.69	2.69
1993-2006	2.91	2.88

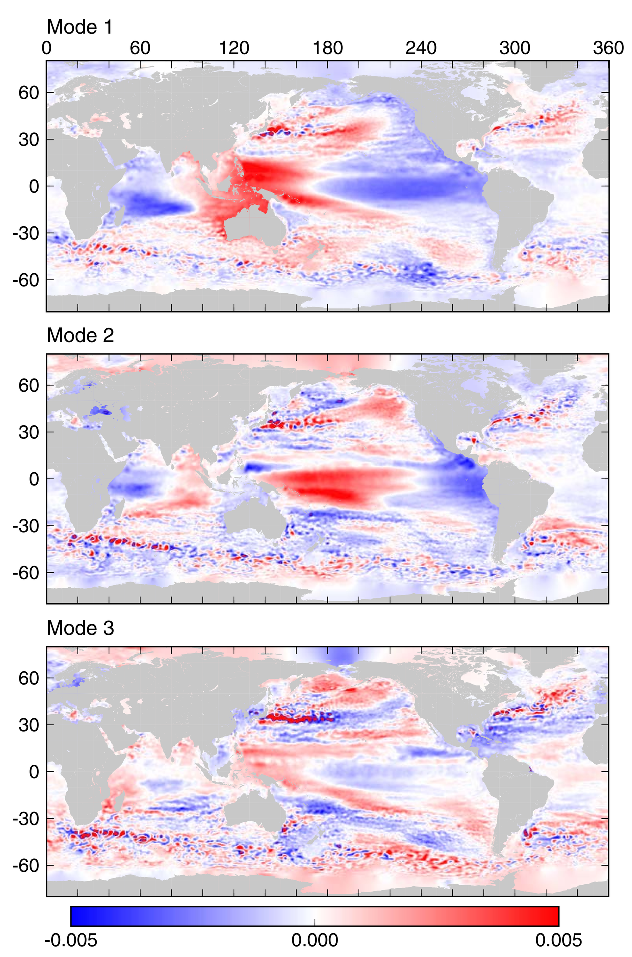
Trend of Estimated GSL, Synthetic Tide Gauge Data

An alternative method for estimating GSL change, following Church et al. (2004), is to estimate sea level at the GCOS stations in terms of the dominant EOF modes of SSH and a mean term (**Figure 8**),

$$\hat{H}(\vec{x}_G,t) = b_o(t) + \sum_{i=1}^{N} b_i(t)m_i(\vec{x}_G)$$

where the coefficients are obtained using the method of least squares. A time series of GSL is computed as the spatially weighted average of $\hat{H}$ over the entire SSH grid, and GSL trends are specified from this time series.

Fig 8



Using the synthetic GCOS data, we estimate a GSL trend of 2.35 mm/yr for the 1993-2006 period, lower than the 2.84 mm/yr from the full dataset (**Figure 9**). A similar value is obtained using 3, 5, and 10 EOF modes. Applying the analysis to the same 1993-2006 data but using different historical GCOS network configurations, we find that the estimated rate is biased low, with a tendency toward lower trend rates as the network coverage diminishes (Table 2).

Fig 9

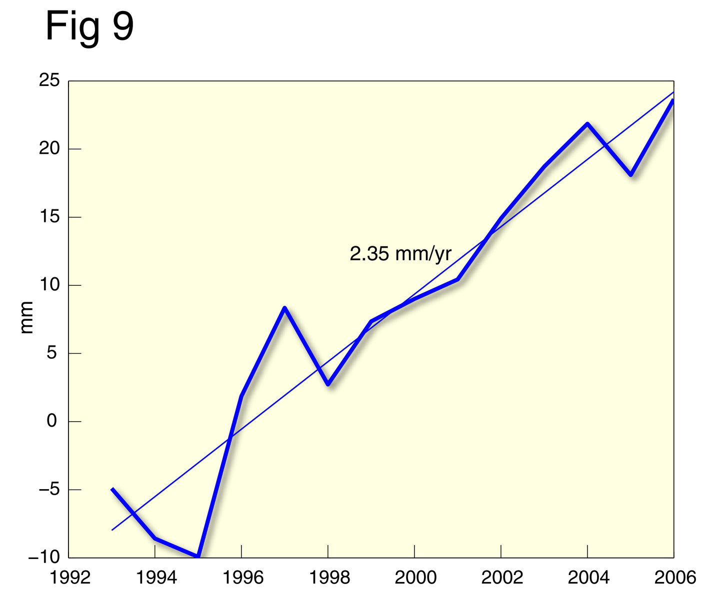


Table 2

gsl trend of mean		
period	5 modes	3 modes
1909-1922	1.86	1.87
1923-1936	1.33	1.13
1937-1950	1.60	1.26
1951-1964	1.66	1.61
1965-1978	1.92	1.95
1979-1992	2.03	2.11
1993-2006	2.48	2.47
All	2.37	2.35

Average of Trends, GCOS Tide Gauge Data

Applying the average of trends method to the actual GCOS annual mean time series for the 1993-2006 period yields an estimate of the GSL trend of 3.30 mm/yr, higher than the full SSH estimate (**Figure 10**). One possibility is that vertical land motion at the GCOS stations causes an over-estimate of the GSL trend. To test the effect of land motion corrections, we use direct land motion estimates from GPS (courtesy of G. Woppelmann) near a small subset of the GCOS stations (**Figure 11**). Where GPS rates are not available, we use rates from a Global Isostatic Adjustment model (Peltier, 2001). The GPS/GIA corrections have a small effect on the average trends versus latitude (**Figure 10**) and on the overall trend (3.34 mm/yr compared to 3.30 mm/yr uncorrected).

Fig 10

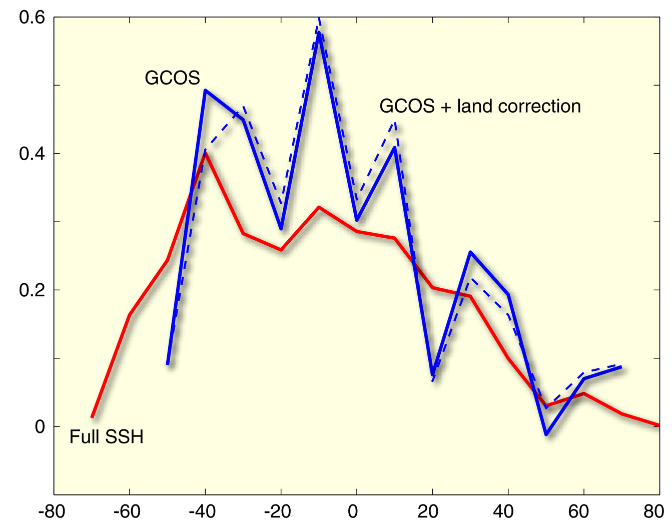
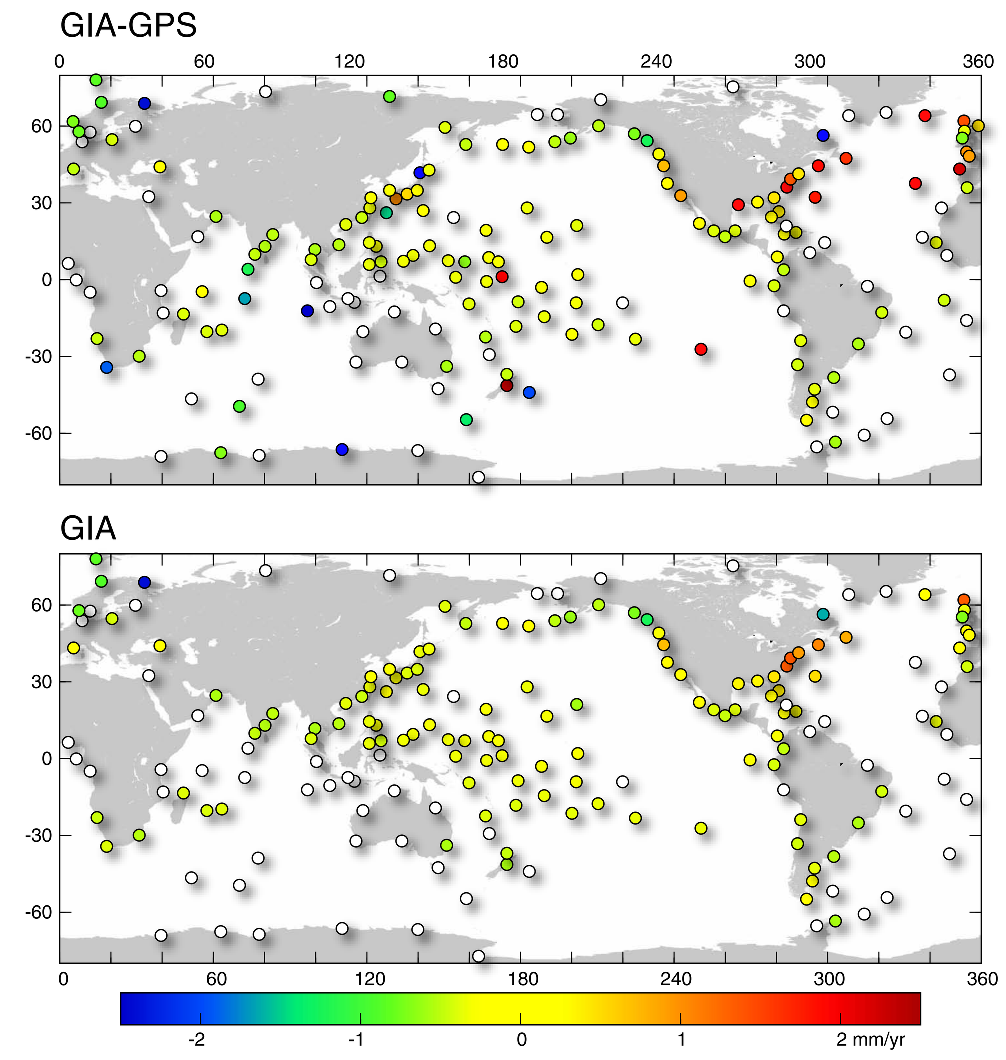


Fig 11



Trend of Estimated GSL, GCOS Tide Gauge Data - The regression analysis approach of determining GSL yields good agreement with integrated SSH during the 1993-2006 period (**Figure 12**). The global GSL trend from the tide gauges is 3.10 mm/yr using this method. The GPS/GIA corrections due not significantly change the result. The ability to predict trends using historical subsets of the GCOS network is evaluated using fixed station configurations for the entire record length (i.e., stations available in 1923-1936 are used to estimate GSL for the entire 1923-2006 period, and so on). The resulting GSL trends are consistently less than the 1993-2006 (**Figure 13**). The simulations with synthetic data suggest that some of this reduction may be due to the tendency for the analysis to underestimate the actual trend as the number of stations decreases (**Table 2**). We note that even with these possible bias errors, the different reconstructions do not show a systematic acceleration in rise rates.

Fig 12

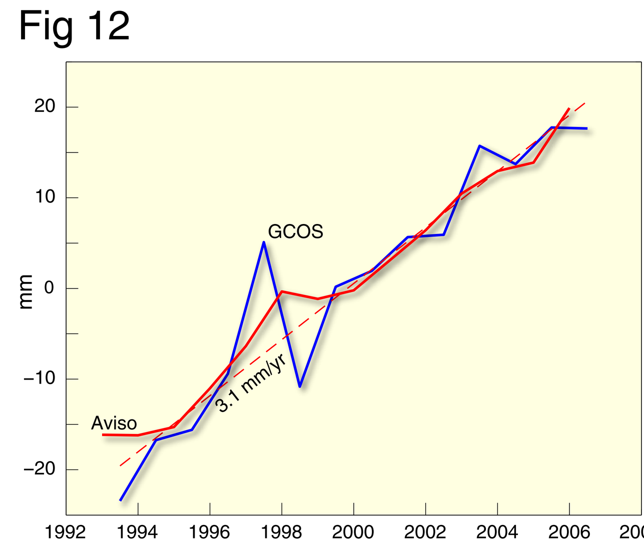
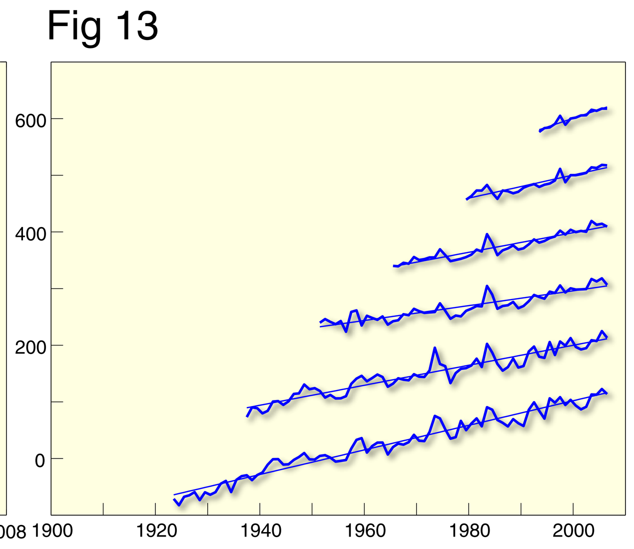


Fig 13



Summary

1) The GCOS network of tide gauges can provide estimates of GSL change consistent with altimeter datasets.

2) Historical reconstructions based on subsets of GCOS stations are subject to bias errors.

3) Using the same subset of stations to predict GSL change over time does not indicate substantial trend increase since the 1920s.

4) Ground motion remains a source of error in the trend estimates. GPS rates are needed at more of the GCOS stations to assess this error.

Acknowledgements

Support for this project was provided by JPL-NASA (#1278112) and the Office of Climate Observation, NOAA (NA17RJ1230).

References

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