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 Argo sea surface height (SSH) (1993-2006) and SODA-POP model sea level (1908-2001).

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).

Table 1

<table>
<thead>
<tr>
<th>Period</th>
<th>Trend from</th>
<th>Trend from</th>
<th>Mean from</th>
</tr>
</thead>
<tbody>
<tr>
<td>1909-22</td>
<td></td>
<td></td>
<td>1.18</td>
</tr>
<tr>
<td>1923-36</td>
<td></td>
<td></td>
<td>1.21</td>
</tr>
<tr>
<td>1937-50</td>
<td>3.12</td>
<td>3.32</td>
<td>3.22</td>
</tr>
<tr>
<td>1951-64</td>
<td>4.22</td>
<td>4.85</td>
<td>4.53</td>
</tr>
<tr>
<td>1965-78</td>
<td>6.42</td>
<td>7.28</td>
<td>6.85</td>
</tr>
<tr>
<td>1979-92</td>
<td>9.32</td>
<td>9.95</td>
<td>9.64</td>
</tr>
</tbody>
</table>

Trend of Estimated GSL, Synthetic Tide Gauge Data - An alternative method for estimating GSL rise is to estimate sea level at the GCOS stations in terms of the dominant EOF modes of SSH and a mean term (Figure 8), where the coefficients are obtained using the method of least squares. A time series of GSL is computed as the spatially weighted average of \( \bar{H} \) over the entire SSH grid, and GSL trends are specified from this time series.

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).

Table 2

<table>
<thead>
<tr>
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<th>3 modes</th>
</tr>
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<tr>
<td>1909-22</td>
<td>1.96</td>
<td>1.97</td>
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<tr>
<td>1923-36</td>
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<td>1937-50</td>
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<tr>
<td>1965-78</td>
<td>4.52</td>
<td>4.27</td>
</tr>
<tr>
<td>1979-92</td>
<td>6.84</td>
<td>6.42</td>
</tr>
</tbody>
</table>

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 (Table 1). 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).

Acknowledgments
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References


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

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 noiser 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.

Figures

Figure 1: Average SSH trend from GCOS with GCOS grid stations.
Figure 2: Global average SSH trend from GCOS with GCOS grid stations.
Figure 3: Average SSH trend from GCOS with GCOS grid stations.
Figure 4: Global average SSH trend from GCOS with GCOS grid stations.
Figure 5: Average SSH trend from GCOS with GCOS grid stations.
Figure 6: Global average SSH trend from GCOS with GCOS grid stations.
Figure 7: Average SSH trend from GCOS with GCOS grid stations.
Figure 8: Global average SSH trend from GCOS with GCOS grid stations.
Figure 9: Average SSH trend from GCOS with GCOS grid stations.
Figure 10: Average SSH trend from GCOS with GCOS grid stations.
Figure 11: Average SSH trend from GCOS with GCOS grid stations.
Figure 12: Average SSH trend from GCOS with GCOS grid stations.
Figure 13: Average SSH trend from GCOS with GCOS grid stations.