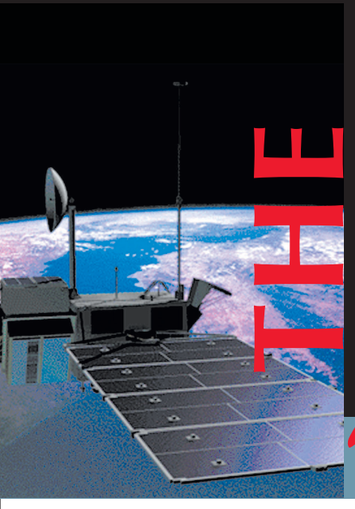

THE regional distribution of sea-level rise *from* 1950 to 2000

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Introduction

Estimates of 20th century sea-level rise cover a wide range, partly because of the poor distribution of tide gauges. We attempt to:

- narrow the broad range of sea-level rise estimates
- estimate the pattern of regional sea-level rise
- determine any variation in the rate of sea-level rise between 1950 and 2000

by combining nine years (1993 to 2001) of TOPEX/Poseidon satellite altimeter data with historical tide-gauge data.

Approach

The reconstructed sea surface height anomaly fields ($\mathbf{H}^{\mathbf{r}}$) are estimated by

$$\mathbf{H}^{\mathbf{r}}(x,y,t) = \mathbf{U}^{\mathbf{r}}(x,y)\boldsymbol{\alpha}(t),$$

where $\mathbf{U}^{\mathbf{r}}$ are the the leading empirical orthogonal functions (EOFs) of global sea-level variability determined from satellite altimeter data and $\boldsymbol{\alpha}(t)$ are their amplitudes. For each month, the amplitudes are found by minimizing the cost function

$$\mathbf{S}(\boldsymbol{\alpha}) = (\mathbf{K}\mathbf{U}^{\mathbf{r}}\boldsymbol{\alpha} - \mathbf{H}^{\mathrm{o}})^{\mathrm{T}} \boldsymbol{R}^{-1} (\mathbf{K}\mathbf{U}^{\mathbf{r}}\boldsymbol{\alpha} - \mathbf{H}^{\mathrm{o}}) + \boldsymbol{\alpha}^{\mathrm{T}}\boldsymbol{\Lambda}\boldsymbol{\alpha},$$

where $\mathbf{H}^{\mathrm{o}}$ are the tide gauge observed sea-surface heights, $\mathbf{K}$ is a sampling operator, and $\boldsymbol{\Lambda}$ is a diagonal matrix of the eigenvalues of the covariance matrix of the altimeter data. $\boldsymbol{R}$ is the error covariance matrix, given by

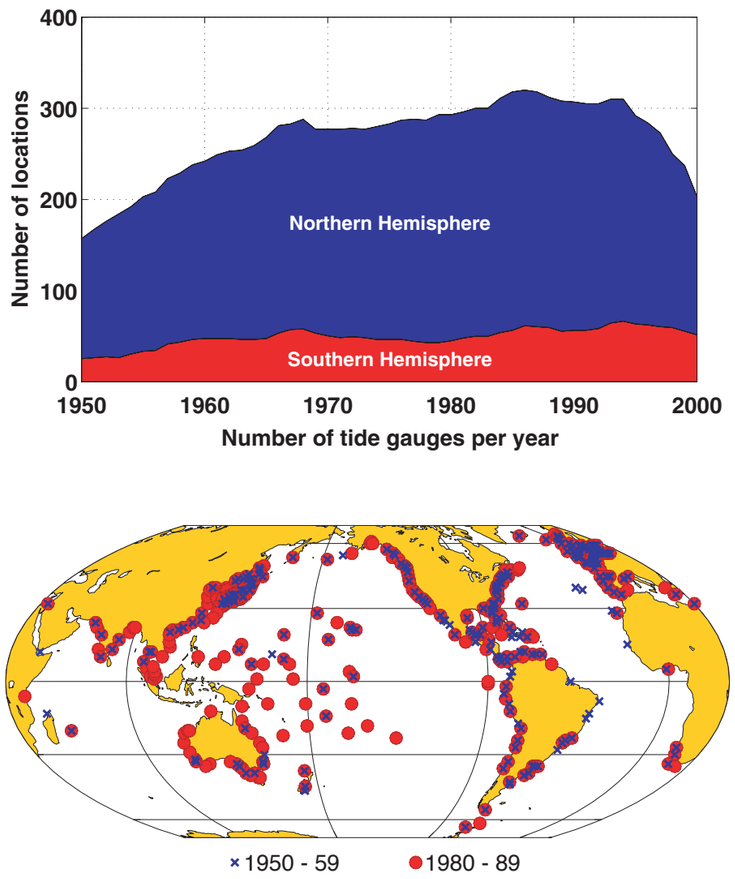
$$\boldsymbol{R} = \mathbf{R} + \mathbf{K}\mathbf{U}'\boldsymbol{\Lambda}'\mathbf{U}'^{\mathrm{T}}\mathbf{K}^{\mathrm{T}}.$$

$\mathbf{R}$ is the variance of the instrumental error, and the second term on the right hand side represents the error of omission introduced by deleting higher order EOFs. The prime indicates matrices of the omitted eigenvectors and eigenvalues.

The tide gauge data

Monthly mean sea levels obtained from the Permanent Service for Mean Sea Level are corrected for glacial isostatic adjustment (GIA) using three different earth models.

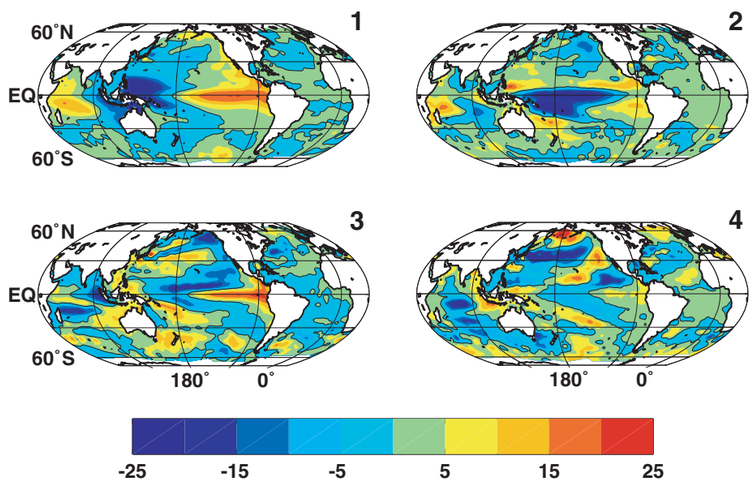
The poor distribution of tide gauges and the inadequate information on vertical tide gauge movement are major sources of uncertainty.



Tide gauge records available in 1950-59 and 1980-89.

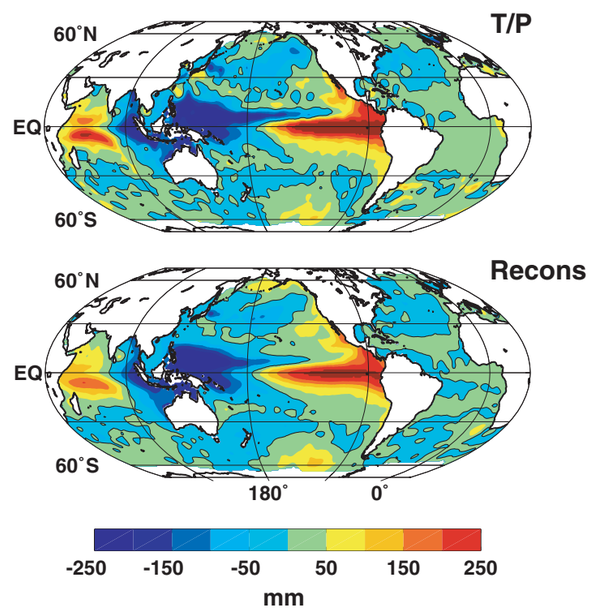
The Empirical Orthogonal Functions

After removal of the seasonal signal, the first four EOFs of the altimeter data account for 39%, 11%, 7% and 4% of the variance and show the influence of the dominant ENSO signal.



Reconstructed and observed sea levels for 1993-2000

The reconstructed sea level anomalies correlate well with observed fields (as high as 0.95) when there are strong anomalies. Lower correlations (as low as 0.50) occur when the anomalies are weak.

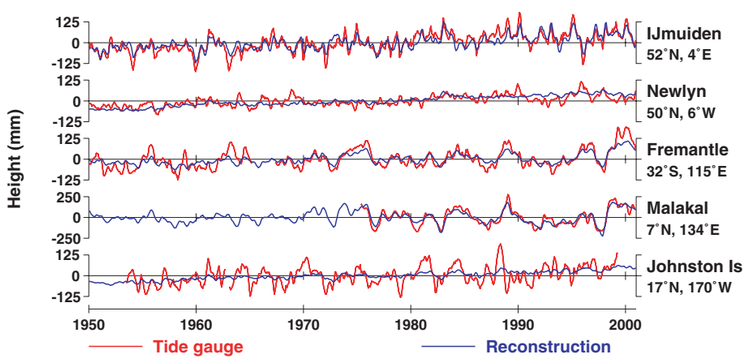


The observed and reconstructed sea level fields for November 1997.

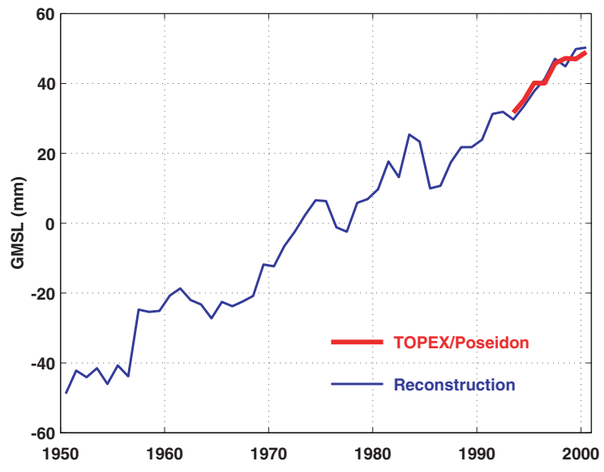
The eustatic rate of global mean sea-level rise for 1993-2000 from the reconstruction is 2.9 ± 0.7 mm yr^{-1}. TOPEX/Poseidon gives a rate (relative to the Earth's centre of mass) of 2.6 ± 0.7 mm yr^{-1}. The difference is consistent with the 0.2-0.5 mm yr^{-1} difference we would expect from GIA (Tamisea *et al.* pers comm).

Reconstructed sea level for 1950-2000

The monthly tide-gauge data contains contributions from many regional and coastal phenomena as well as large-scale climate-related phenomena. The residual variance is about 50% of the observed variance.

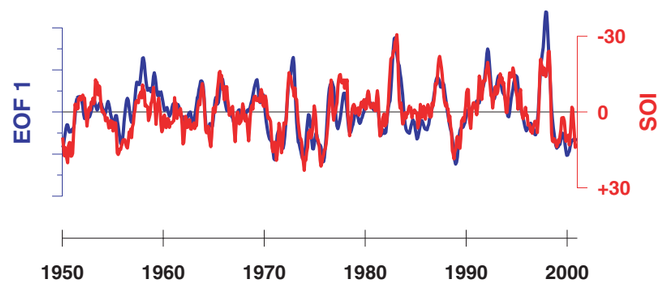


Globally-averaged sea-level rise from the reconstructed monthly time series is 1.8 ± 0.3 mm yr^{-1}. There is no detectable increase in the rate of sea-level rise over the period 1950 to 2000. Note the decadal variability.



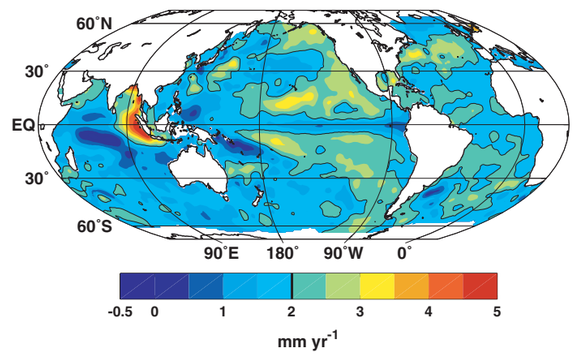
Regional distribution of sea-level rise

The regional distribution of sea-level rise is determined by trends in the EOF amplitudes. There is a good (negative) correlation (r = -0.78) of the Southern Oscillation Index (SOI) with EOF 1 but only a weak correlation with global mean sea level. The variances of EOFs 1 and 2 increase with time, consistent with a shift to ENSO events being more frequent, persistent and intense since the mid-1970s.



Time series of EOF 1 and the SOI index.

The maximum sea-level rise is off the west coast of Indonesia and in the eastern off-equatorial Pacific. There is a minimum along the Equator, in the western Pacific and eastern Indian Ocean. Sea-level rise off the eastern North American coast is greater than off the United Kingdom and the Scandinavian Peninsula.



The regional distribution of sea-level rise between January 1950 and December 2000

Key conclusions

The rate of increase of globally-averaged mean sea-level rise from 1950 to 2000 is 1.8 ± 0.3 mm yr^{-1}.

The rate of rise over the TOPEX/Poseidon period is greater than the 1950 to 2000 average. There is no detectable increase in the rate of rise over this period.

The minima in global mean sea levels in about 1965, 1977, 1987 and 1994 occur a few years after volcanic eruptions and their negative forcing of global climate.

The spatial pattern of sea-level rise is consistent with other known changes in the climate system and with previously observed local estimates.

Acknowledgements

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Tide gauge data was obtained from the Permanent Service for Mean Sea Level, Bidston, UK.

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