Interannual sea level variability in the Southern Ocean within the context of global climate change

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Two hydrographic time series stations near the Kerguelen Islands have been maintained since January 1999, by teams visiting the stations once every month the two stations located just south and east of the islands: CLIOKER 1 (50°46'S, 68°52'E) and CLIOKER 2 (49°28'S, 71°22'E). This multi-year project aims to document and understand seasonal-to-interannual water property variations and associated steric sea level variability in this part of the Southern Ocean, within the context of global climate change observed by TOPEX/POSEIDON (T/P).

Interannual sea level variability at Kerguelen

Observations at CLIOKER stations are not long enough alone to study the interannual variability of the region. (We used here the first 16 months of observations). Fortunately, we have hydrographic time series data from the previous KERFIX station, which had been occupied until the end of 1994 at nearly the same site as the CLIOKER 1 station. The mean steric sea level at KERFIX over the period 1992-1994 [Park et al., 1998] is used here to reference the CLIOKER 1 data. It is shown that between the KERFIX and CLIOKER 1 periods, the upper 500 metre water column of the site was warmed by 0.13°C and freshened in salinity by 0.03 psu to yield a mean sea level rise of 17 millimetres. Comparison with T/P data, however, indicates that the estimated rise accounts for only half of the real sea level change (+35 mm) between the two epochs, which has been verified also by tide gauge data at Port aux Français, Kerguelen. This may suggest that the other half of the sea level rise can be attributed to changes in the deeper water column below 500 metres. In other words, the changes in water properties are not limited to the surface layer but must have affected the whole 1,500 metre water column of the site, probably due to some meridional displacement of the regional current field or Polar Front. The steric heights at CLIOKER 1, after the adjustment done by taking the expected deeper layer changes into account, are shown in figure 1, together with the KERFIX data and low-pass-filtered T/P sea level curve. Recent short-term climatic change in the region is clearly seen. During the past decade, the sea level at Kerguelen was lowest in 1994 (-30 mm relative to the mean over the period 1993-2000), followed by an abrupt rise in 1997, reaching a peak of 50 mm above normal at the end of 1997, a period coinciding precisely with the strongest ENSO of the last century. From early 1998, the sea level gradually fell, coming close to the quasi-decennial mean level at the end of 2000.

Sea level trends: southern ocean versus global ocean

To situate the observed sea level variability at Kerguelen within the global context, T/P sea level trends of the world's oceans are shown in figure 2a. Two curves in figure 2b represent the overall sea level variations averaged within the Southern Ocean south of 40°S and global ocean, respectively. The most remarkable feature is a large regional difference in sea level trend. The North Pacific and equatorial Pacific exhibit the most spectacular E-W seesaw pattern, with strong positive trends in the western side and strong negative trends in the eastern side. The Atlantic Ocean shows the most homogeneous field and is associated with weak positive trends in general, while in the Indian Ocean negative trends are dominant, except for positive trends in the Indonesian throughflow region and west of Australia. The Southern Ocean south of 40°S shows noticeable positive trends in most places, with one notable exception in the Pacific Antarctic Basin, where there is a broad region of strong negative trends.

The Southern Ocean as a whole experienced sharp rise in sea level during the 1997-1998 ENSO period (see figure 2b), showing a very similar pattern to that at Kerguelen (cf. figure 1). A similar sea level rise is also observed for the global ocean, although the amplitude there is only half that of the Southern Ocean. Over the 1993-2000 period, the mean sea level trend of the Southern Ocean is estimated at 2.34 ± 0.34 mm/yr, compared to 1.21 ± 0.15 mm/yr for the global ocean. The latter value is close to the lower bound of the IPCC (Intergovernmental Panel on Climate Change) global trend range over the last century (1-2 mm/yr) and is also not significantly different from the estimate of Cazenave et al. [1998] over the period 1993-mid 1997 (1.3 ± 0.15 mm/yr). Globally, no dramatic sea level rising trend resembling the exponential concentration of CO_2 in the atmosphere is observed during the past century.

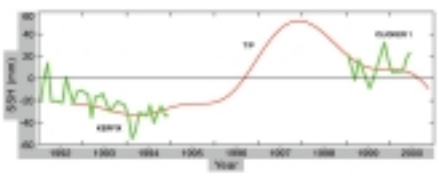

Figure 1: Sea surface height (SSH) anomaly time series (mm) at Kerguelen from hydrographic time series stations, KERFIX and CLIOKER 1, superimposed on the low-pass-filtered T/P sea level curve. Kerguelen is marked as "K" in figures 2 and 3.

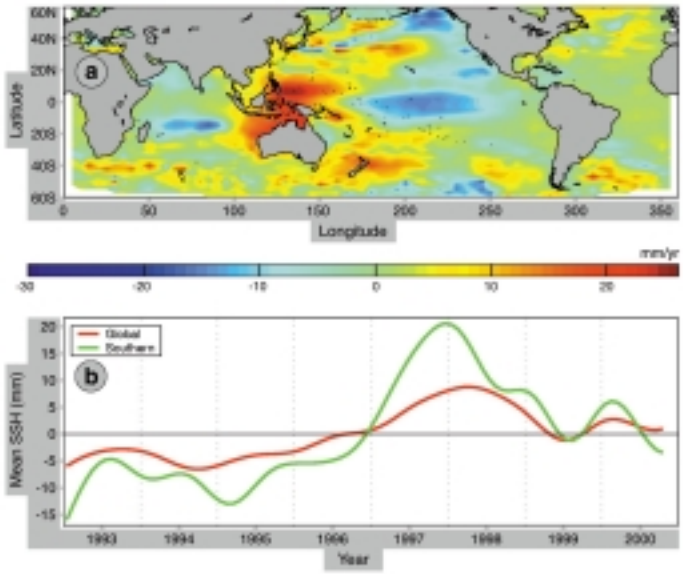

Figure 2: (a) Map showing sea level trends (mm/yr) calculated at each T/P crossover point over the period 1993-2000. Before the trend calculation, mean seasonal variations were eliminated from the monthly time series at each data point and then low-pass filtered using a Gaussian filter with a cut-off at six months. (b) Mean sea level variations (mm) averaged for the whole Southern Ocean south of 40°S (green) and for the entire global ocean (red). Area-dependent weights were applied during the averaging process.

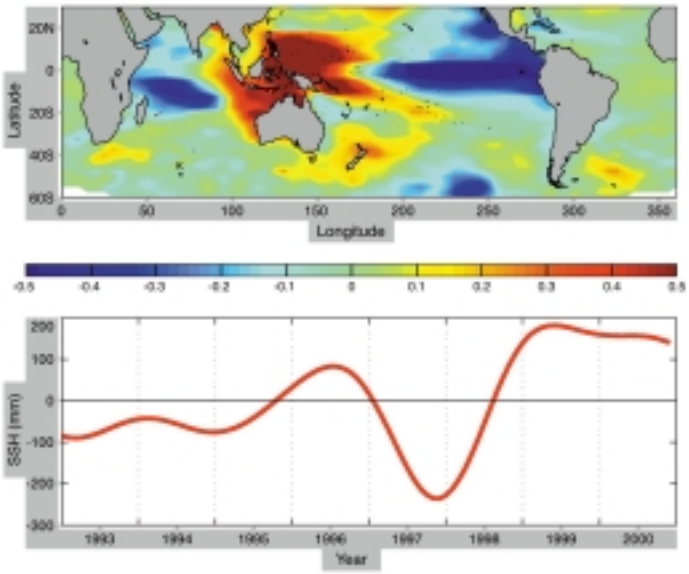

Figure 3: Spatial pattern and temporal coefficients (mm) of the first EOF of interannual SSH variations from T/P. This mode accounts for 44.6% of interannual SSH covariance.

Antarctic circumpolar wave: traveling or standing?

White and Peterson (1996) identified significant interannual variations in surface pressure, wind, temperature and sea-ice extent over the Southern Ocean. They suggest that these parameters are phase-locked and that the coherent anomalies propagate eastward with the circumpolar flow, with a period of four to five years and a wavelength of 180° in longitude, forming the so-called "Antarctic circumpolar wave". Contrary to those observations, we did not find in our 1993-2000 T/P data any clear visual evidence for such a traveling wave, although the subject deserves a further quantitative analysis.
On the other hand, the empirical orthogonal function (EOF) decomposition of T/P data shows that the first mode, which explains about 45% of the quasi-global (south of 30°N), coherent, interannual sea level variance, is related to the ENSO-like variability, especially in the Pacific and Indian Oceans (figure 3). The influence of ENSO in the Southern Ocean is most significant in the Pacific sector, with an out-of phase between the New Zealand region and the Pacific Antarctic Basin, a feature remarkably similar to the sea level trend map (see figure 2a). To a lesser extent, similar coherence is also observed in either side of the southern tip of South America, in the Agulhas Current system south of South Africa, and within the Enderby Basin west of the Kerguelen Plateau. At Kerguelen, the ENSO-like variability is less evident, despite the coincidence of the regional sea level peak in 1997-98 with the strongest ENSO event of the last century. Since the EOF mode of figure 3 represents a standing pattern, and considering its far greater contribution (45%), we are tempted to think that the dominant mode of interannual sea level variations should have standing-wave characteristics, in much greater proportion than traveling waves, as in the atmospheric forcing case of the Southern Oscillation.
Quantification of the relative contribution of standing versus traveling waves in the Southern Ocean is in progress.

Acknowledgments

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