Long-Term Changes from ERS

Regional Changes in Sea Level and Sea Surface Temperature

Ole B. Andersen and Per Knudsen

The ERS and Envisat satellites provide a unique opportunity for monitoring both changes in sea level and sea surface temperature as each is equipped with an altimeter to measure sea level height as well as an Along Track Scanning Radiometer to measure the sea surface temperature (SST). High quality observations are carried out with these satellites on both global and regional scales due to the combination of regular sampling and high spatial coverage compared with observations from either ship or tide gauges. Data from the two European Space Agency satellites ERS-1 and ERS-2 are used to evaluate regional changes in sea surface temperature and sea level of the oceans over an eight-year period ranging from September 1992 to September 2000.

Consistent increases in both sea level and sea surface temperatures are found in most parts of the Atlantic Ocean over this period. In the Indian Ocean and particularly the Pacific Ocean the trends in both sea level and temperature are still dominated by the large changes associated with the El Niño Southern Oscillation (ENSO). The regional changes detected by ERS sea level and sea surface temperature observations are highly correlated with independent finding from Topex/Poseidon sea level observations and the Reynolds AVHRR sea surface temperature observations.

Introduction

Long-term sea level change are important for a variety of environmental and socio-economic reasons, especially for the large portion of the world's population that lives in the coastal zones. Changes in sea level have traditionally been measured at a number of fixed tide gauge stations around the Earth, but with the increased accuracy of satellite altimetry, this now offers the best opportunity for improving our knowledge about global and regional sea level change. Long-term changes in sea level are attributed to a number of reasons such as deformation of the ocean basin or land uplift/subsidence. Another important factor is the melting of ice caps and thermal expansion/contraction of the oceans. Temperature changes of the ocean can conveniently be studied using the Along Track Scanning Radiometers (ATSR) on board ERS-1 and ERS-2 which have been designed specifically to provide new information urgently needed for the debate on climate change and global warming [*Mutlow et al.*].

Several studies have dealt with the question of climate or long-term sea level changes from the Topex/Poseidon (T/P) satellite mission. See [*Nerem & Mitchum*] for a review of the subject. However, only a few studies have included ERS data [*Harris & Candy; Knudsen et al.; Anzenhofer & Gruber; Cazenave et al.*]. The results obtained using ERS data are generally less accurate because the ERS altimeters are single frequency and because the orbits of the ERS satellites are less accurate than those of the T/P satellite. Furthermore, long-term changes are very sensitive to changes in the processing of the data, as well as to the stability over- time of the sensors. With ERS, this is furthermore complicated by the fact that the ERS data stem from two satellites having different types of altimeter and ATSR instrument on board.

Global estimates of sea level and sea surface temperature changes from ERS satellites will not be made in this paper; only estimates of regional changes in sea level and sea surface temperatures will be addressed using ERS-1 and ERS-2 observations from the altimeter and ATSR sensors. The ERS satellites are able to monitor detailed sea level changes, as these satellites have track spacings, which are about 3.6 times denser than that of the French-American T/P satellite. It will also be demonstrated that the results from ERS satellites on regional scales are highly correlated with results obtained from independent satellite missions like the T/P altimetry mission and the Reynolds sea surface temperature results based on AVHRR data from the NOAA satellites.

Data

The analysis was performed using as many observations as possible within the eight-year period ranging from September 1992 to September 2000. For details on the editing, pre-processing and selection of data for the present analysis please refer to *[Andersen & Knudsen].* It should be noted, that neither the ERS altimeter data set, nor the ERS ATSR sea surface temperature data sets provide complete coverage within the eight year period used, whereas the both the T/P and the Reynolds SST data set give virtually complete coverage. The 0.5° by 0.5° averaged sea surface temperatures data (ASST) are available via the UK-PAF *[Cardon et al.],* altimetry data (ERS-1, ERS-2 and T/P) are available via the NASA Pathfinder project:

<http://neptune.gsfc.nasa.gov/ocean.html>,

and the Reynolds SST data are available from the NOAA-CIRES Climate Diagnostics Center.

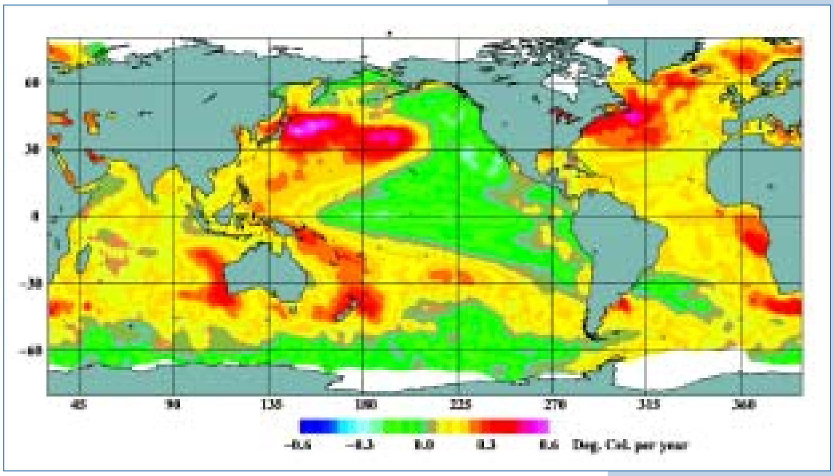


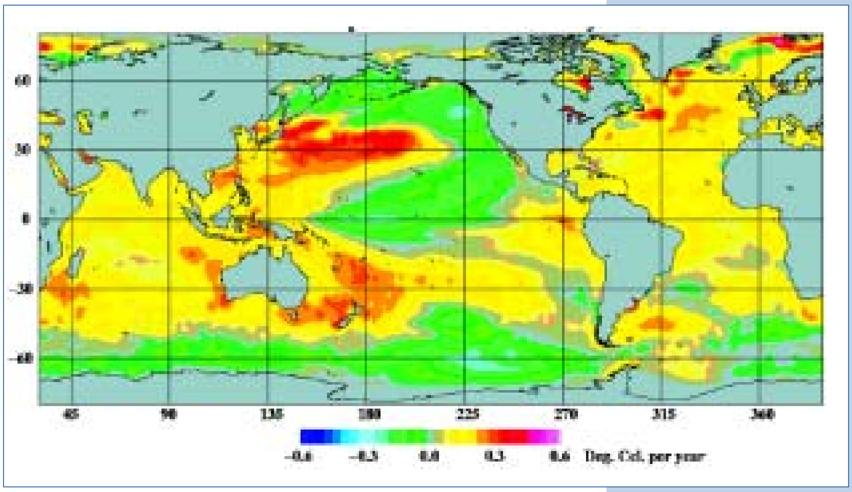
Fig. 1. Sea surface temperature trend from ATSR-1 and ATSR-2 observations in the period between September 1992 and July 2000. Values are in°C/year.

Merging observations from the ERS-1 and ERS-1 missions

Data from the ERS-1 and ERS-2 tandem mission (a 6 month period in 1995) were used to investigate possible systematic differences between the ATSR-1 and ATSR-2 instruments [*Andersen & Knudsen*]. Higher ATSR-2 surface temperatures were found in tropical regions and a slightly reversed situation with higher ATSR-1 temperatures at high latitudes. Consequently, different mean values for the ATSR-1 and ATSR-2 observations were estimated along with the sea surface temperature trends.

The NASA pathfinder team has calculated different radial offsets between the T/P satellite derived sea level observations and the missions of both ERS-1 and ERS-2, and applied these to missions of the ERS satellites.

Fig. 2. Sea surface temperature trend from Reynolds AVHRR observations. Values are in °C/year.



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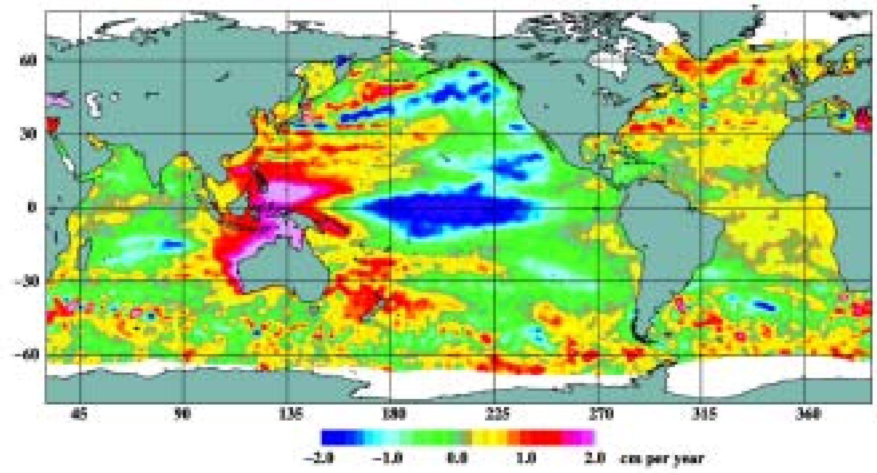

Fig. 3. Sea level trend from ERS-1 and ERS-2 observations in the period between September 1992 and March 2000. Values are in cm/year. A global second order polynomial was removed from the sea level trend differences between ERS and T/P.

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Regional changes in sea surface temperatures

The estimated sea surface temperature trends from ATSR-1 and ATSR-2 observations between September 1992 and July 2000 are shown in Fig. 1. The colour scale is tuned so that greyish colours correspond to no change in SST. Yellow and red correspond to an increase in SST, and blue-green corresponds to a decrease in SST. Regional trends of sea level and surface temperature computed in every 20° latitude band of the Atlantic, Pacific and Indian Oceans are shown in Table 1.

The SST is clearly increasing in both the Atlantic Ocean and Indian Ocean, with the most significant increase of roughly 0.1 degree/year as an average over most of the Atlantic Ocean. In the Pacific Ocean, the spatial pattern is dominated by the El Niño signal. The corresponding temperature trend from Reynolds AVHRR observations over the same period as the ERS data is shown in Fig. 2. The spatial pattern is similar to the result obtained from the ATSR-1 and ATSR-2 data and the spatial correlation within the 50° parallels is greater than 85%. The major differences are found in the Gulf Stream and the Kuroshio Extension (Pacific Ocean). These are highly dynamic regions, having a large gradient in mean sea surface temperature field. Differences are also found in the eastern part of the Pacific ocean and are most likely ascribable to a combination of the large variations associated with the El Niño event combined with the ERS-2 ATSR-2 sensor dropout in 1996. [*Vasquez & Sumargaysay*] also pointed out differences between the ATSR and AVHRR derived results in these regions.

Regional changes in sea level

In Figs. 3 and 4 the sea level trends derived from satellite altimetry are shown using the same colour scale as above, but displaying values in centimetres per year with a colour scale limited by ± 2 cm/year. A second order polynomial was fitted to the differences between the sea level trend from T/P and ERS, as the ERS-2 sea level observations in particular have a trend at high latitudes which is clearly too large when compared with those computed from the T/P satellite for the same period. The issue is currently under investigation, but in order to account for it the following was done: on global scales, a second order polynomial was fitted to the differences between sea level trend estimated from T/P and ERS data. Subsequently this polynomial was removed from the ERS trend estimates. In this way, the global scales of the trends from ERS are represented by the trends derived from T/P. In Fig. 3 this second order polynomial has been removed from the ERS derived trends, hereby fitting the large-scale trends of ERS to those derived from T/P.

On regional scales the sea level trends are in remarkably good agreement and correlate within the 50° parallels to better than 85%. Both the ERS and the T/P estimates are clearly dominated by the El Niño signal which was also found by [*Nerem & Mitchum*]. The El Niño build up causes an increased sea level in the western part of the Pacific Ocean and a decreased level in the eastern part. This is very similar to the ATSR results for sea surface temperature.

Interesting regional features associated with the Gulf Stream and the Kurushio Extension are also visible in both ERS and T/P data. However, the ERS features have more details. There is some difference between the sea level trends in the Indian Ocean and in the eastern Atlantic Ocean where the T/P data show larger values than ERS. Such differences are most likely associated with the differences in data coverage and the fact that ERS derived trends are based on observations from two satellites, which means that any unresolved global or regional bias between the ERS-1 and ERS-2 observations will map into the trends.

Conclusion

ERS satellites data have been used to study regional changes in sea surface temperature and sea level of the oceans. The regional changes detected by ERS sea level and sea surface temperature observations are highly correlated with independent findings from T/P sea level observations and the Reynolds AVHRR sea surface temperature observations, with spatial correlation larger than 85% within the 50° parallels.

Interesting features were revealed related to the higher spatial resolution of ERS data especially in the Gulf Stream and Kuroshio Extension, which demonstrate the value of merging the observations from T/P and ERS. On the larger spatial scales the sea level trends are represented by the T/P results because of the global fit of ERS to T/P. In the current investigation we do not take into account the TMR drift in the T/P dataset, because the Pathfinder dataset does not have this drift applied. Secondly, there is the SPTR drift near the end of ALT A, and the bias between two different altimeters on board T/P - ALT A and ALT B. These are also not corrected for because they are still an area of research. Upon studying the regional changes in sea level, these effects might be important (see also [*Nerem & Mitchum*]) and should be investigated further.

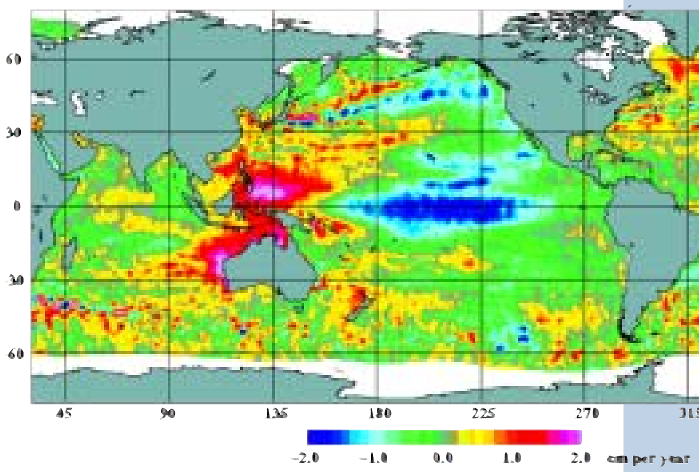

Fig. 4. Sea level trend from T/P altimetry. Values are in cm/year.

Acknowledgments

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	Atlantic Ocean	Pacific Ocean	Indian Ocean
70°S - 50°S	0.15, 0.08	-0.04, -0.02	0.09, 0.00
50°S - 30°S	0.03, 0.11	0.03, 0.11	0.09, 0.14
30°S - 10°S	-0.02, 0.13	-0.06, 0.09	-0.19, 0.12
10°S - 10°N	0.13, 0.18	-0.51, -0.02	0.01, 0.11
10°N - 30°N	0.04, 0.12	-0.10, 0.08	-0.18, 0.12
30°N - 50°N	0.10, 0.21	-0.31, 0.14	-
50°N - 70°N	0.41, 0.20	-0.39, 0.02	-

Table 1. Regional trends of sea level and sea surface computed in 20° latitude bands for each of the world's oceans. Sea level trends are given in cm/year and sea surface temperature trends are given in °C/year.