TOPEX/POSEIDON Altimetry Captures Cycles of the Indian Ocean

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Measurements of 1993–1996 sea-level variability in the Indian Ocean from the orbiting TOPEX/POSEIDON (TP) altimeter (Fu et al., 1994) reveal patterns of semiannual, annual and interannual cycles. These patterns are composed of both propagating and non-propagating features. Most off-equatorial sea level anomalies propagate westward as Rossby waves and equatorial anomalies propagate eastward as Kelvin waves. The seasonal cycle is found to be regular over the years examined, but the semi-annual (6 month) cycle is disrupted during 1994 for unknown reasons.

Gridded (1 degree by 1 degree) TP sea-level anomalies for 1993-1996 relative to the 4-year mean field were obtained from the Center for Space Research, the University of Texas at Austin (Tapley et al., 1994) from 10°S to 23°N and 40°E to 119°E. Subtraction of the 4-year mean effectively removes both the geoid and the mean currents, yielding a time-varying field dominated by the seasonal cycle. The average seasonal cycle is examined. Variability is also explored using Complex Empirical Orthogonal Functions (CEOFs, see Shriver et al., 1991), which breaks the data into a finite series of paired complex temporal and spatial functions. Here, the temporal functions are scalar functions in time and the spatial functions are scalar functions depending upon latitude and longitude only. The product of each pair is referred to as a mode.

The seasonal cycle

The largest manifestation of the seasonal cycle in the Indian Ocean is the reversal of the monsoonal winds and the underlying ocean currents off Somalia. This TP dataset does not capture the Somali Current very well, probably due to the 1-degree gridding of the data. The average monthly sea level deviation indicates seasonal variability throughout the Indian basin. The average January sea-level from TP has positive and negative deviations from the mean state (Fig. 1) with spatial scales of several hundred to a few thousand kilometres. The south-west tip of India has a strong positive signal, corresponding to the Laccadive High (Bruce et al., 1994). West of India, the sea-level gradient indicates a northward current forming the eastern branch of an overall cyclonic circulation in the Arabian Sea. The winter circulation in the Bay of Bengal appears less coherent, though the eastern boundary appears to possess a coherent southward current. This current exits the Bay of Bengal with a strong westward component, loops around the Laccadive High and moves northward into the Arabian Sea. This is a dramatic demonstration of the linkage between the two northern basins of the Indian Ocean.

Other features in January are the strong cyclonic circulations centred around 8°N just east of Somalia, and along the coast of Sumatra. Open isolines associated with the former feature are probably due to lack of coastal currents in the TP dataset. The Sumatra feature results from an eastward travelling upwelling Kelvin wave identified in longitude-time diagrams (not shown). A final feature is a weak anticyclonic circulation located round 10°S and 50°E.

The average July state is a rough opposite of the winter state. A relatively weak cyclonic circulation is found south of India. The eastern boundary current west of India has reversed direction and the overall circulation in the Arabian Sea now appears to be anticyclonic. The ocean off Somalia is also developing an anticyclonic motion. The central (65°E) equatorial region has a positive feature. This is the manifestation of the seasonally occurring downwelling Kelvin wave. The zonal structure along 10°S has been replaced by cross-meridional isolines in the westernmost part of the basin. The feature at

Figure 1. Monthly climatological average sea height from TOPEX. Deviations from a 4-year mean (a) January, (b) July. The grey scale bar indicates sea level in cm.
The phase rate of change is fairly constant with little high-frequency fluctuation. The second mode has a semiannual frequency in the first and last year of the period of study. In the intervening time the dominant mode of variation is roughly a 1-year mode. To test whether this is phenomenon is real or an artefact of the dataset, we used a 1.5-layer reduced gravity model of the Indian Ocean forced with the FSU winds. This type of model is known to faithfully represent the large-scale ocean currents and waves. The model sea level variations are also analysed with CEOF techniques. The first and second mode again display the annual and semiannual cycle, respectively. The second mode possesses a nearly identical shift in the frequency of the temporal phase function. This implies the shift observed in TP data is real and is a wind-driven phenomena.

Orbiting altimeters continue to be powerful tools for studying the ocean circulation. New discoveries can be anticipated as multi-year records from existing instruments and their successor accumulate.

References


The Along Track Scanning Radiometer Programme

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Following on from Victor Zlotnicki’s interesting and useful article “Satellite Datasets for Ocean Research” in issue No. 30 of the WOCE Newsletter (1998), the purpose of this note is to inform the WOCE community of the new sea surface temperature (SST) and other data sets that are available to them from the Along Track Scanning Radiometer (ATSR) Programme.

The ATSR programme

The ATSR instruments are designed to provide: (1) a SST time series which will help establish if climate change is taking place, (2) high spatial and temporal resolution SSTs for model validation, and (3) data for comparison with in situ observations of bulk SST, both for validation purposes and to understand the processes at the atmosphere-ocean interface.

The primary objective of the ATSR programme is to provide a long-term data-set of consistent and accurate observations of global SST to meet the needs of WCRP and the climate research community. To meet this goal the instruments were designed and built to meet the following objectives: (1) the measurement of SST averaged over 50 km by 50 km areas to an absolute accuracy of better than