Estimation of Heat Transports in the Indian Ocean using Altimetry and MICOM

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We have developed a new technique to estimate the heat budget of the Indian Ocean using TOPEX/Poseidon (T/P) Sea Level Anomalies (SLA) and the Miami Isopycnal Coordinate Ocean Model (MICOM) in order to study the redistribution of heat in the Indian Ocean

Satellite altimetry with its abundant spatio-temporal coverage of the ocean provides an excellent opportunity to study the heat propagation in the ocean. These observations can be used for validating model results and also for improving models. Of particular interest to this study is the heat content redistribution over the Indian Ocean. The heat content anomalies of the ocean have been estimated from T/P Sea Level Anomalies (SLA), based on the assumption of a linear relation between sea-level change and the heat content of the water column. In regions of strong variability in the upper ocean heat content, such as the Indian Ocean, the derived heat content anomalies provide useful tools to study the spatial and temporal variability.

Heat Transports from altimetry

The sea level change due to heating can be approximated from the sea level anomaly measured by the altimeter (Manghnani et al., 2002) as:

$$\Delta\eta = \Delta\eta^{TOPEX} + \in \qquad (1)$$

where $\in$ is the error introduced by neglecting salinity and barotropic effects, as well as errors in altimetric measurement. Chambers *et al*. (1997) conclude that the size of $\in$ is at most 1 - 2 cm for the annual amplitude over most of the ocean. As we have seen, it may be ~ 6 cm in the Bay of Bengal.

Monthly surface flux data for net radiation (R_{sfc}) for 1993 - 1996 were obtained from the NCEP/NCAR) re-analysis. The latent heat flux (LHF) and sensible heat flux (SHF) were derived from the model simulations, as described in the model section. These data were used to calculate the net oceanic heat gain (Q_{sfc}) from the atmosphere, using the relation

$$Q_{sfc} = R_{sfc} - LHF - SHF \qquad (2)$$

The net oceanic heat gain used for application with the model and T/P derived fields is calculated using the same datasets.

The monthly heat storage anomalies were estimated using centered time differencing of the heat content anomalies. The value of heat storage thus obtained was subtracted from the net oceanic heat gain to yield an estimate of the oceanic heat flux divergence.

Heat transports from MICOM:

The Miami Isopycnic Coordinate Model (MICOM) is used in this study. MICOM is a three-dimensional primitive equation ocean general circulation model (OGCM) with 15-isopycnic layers and a mixed layer on top. The model is run in global configuration. A major modification is the implementation of a variable resolution horizontal grid, which is designed such that the resolution gradually increases while approaching the East African coast, the Indian subcontinent and the Indonesian Through flow (ITF) region (Fig. 1). The grid is generated by conformal mapping the North and South Poles to arbitrary locations on the Earth, in this case to one location near the coast of Africa (5°N, 38°E) and the other in one of the islands of Indonesia (0°N, 110°E).

The resulting grid has enhanced resolution in the Indian Ocean region and is inherently orthogonal. For this application we have chosen a grid which maintains relatively high (20-60 km) resolution in the northern Indian Ocean model domain to represent the transport by major current systems, equatorial phenomenon and the ITF.

The model was spun up from rest, using climatological forcing from the Climatology COADS for 6 years, by which time the top seven layers (*ie*. a depth of ~ 500m) of the model ocean had reached quasi-steady state. The model was then forced by monthly wind stress, radiation, wind speed, specific humidity and air temperature from the NCEP/NCAR reanalysis project for the 20-year period from January 1980 to December 1999. The model latent and sensible heat fluxes were calculated using wind speed dependent heat transfer coefficients. These fluxes are used along with the radiation fields to calculate the net oceanic heat gain using equation (2). Since most of the variability on seasonal to inter-annual scales is in the top 500 m of the Ocean, the model heat content is derived by integrating the top seven layers. The monthly heat storage was estimated as the rate of change of heat content using a 2nd order centered time difference scheme. Finally, the heat storage was subtracted from the model surface heat flux to yield the upper ocean heat flux divergence.

Fig. 2 shows the comparison between MICOM and altimetry of the annual march of the integrated variability in the region. The northern Indian Ocean experiences the most dramatic changes in its heat content over the annual cycle. Integrating the surface flux, the heat stored and the heat transport for the region north of the Equator, further condenses the variability in this region. During the winter, the north Indian Ocean gains heat, corresponding with northward transport of heat across the equator. During the summer, despite a net input of surface heat flux, there is a depletion of heat from the upper ocean. This is matched by an almost equal amount of heat transport south of the Equator. These patterns are clearly depicted even though the T/P derived estimates are weaker.

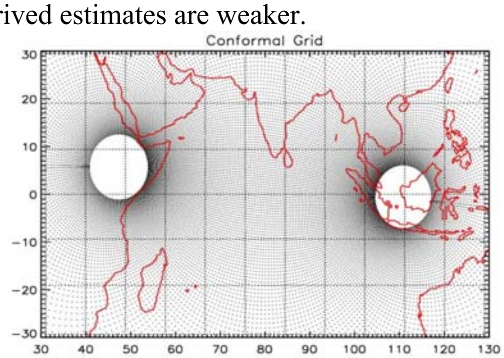
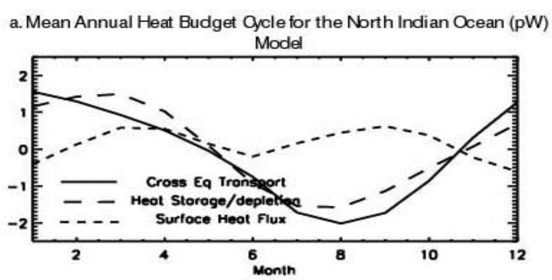


Figure 1. The global varying resolution grid used in the MICOM Indian Ocean Model. Only the Indian Ocean portion is shown. The poles are placed over land and thus avoiding the singularity problem. The resolution varies from 0.2° - 0.5° in the northern Indian Ocean and 0.5°-1° in nearby basins.



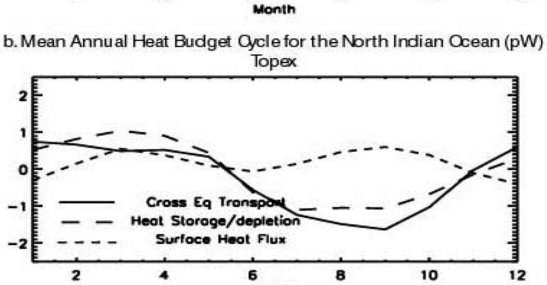


Figure 2. The mean annual cycle of the heat budget terms in the North Indian Ocean for (a) model derived fields and (b) the T/P SLA derived fields. The net oceanic heat gain, heat storage and heat transport are integrated over the northern Indian Ocean.

Reference: Maghanani, V., J. Morrison, L. Xie, and B. Subrahmanyam (2002). Heat transports in the Indian Ocean estimated from TOPEX/Poseidon altimetry and Model simulations. Deep-Sea Research Vol II, 49, 1459-1480.

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