Low-frequency sea level variability in the Atlantic, Indian and Southern Oceans

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Our Jason proposal is concerned with understanding the ocean's dynamical response to climate variability, essentially on seasonal to interannual time scales and in three different ocean basins.
In the Indian Ocean, we are investigating how variations in the tropics are propagated into the mid-latitude band by coastal and Rossby waves; in the Southern Ocean we are examining the long-term variations in eddy energetics; in the North Atlantic and Southern Oceans we look at the role of eddy and mean advection on upper ocean property distribution; and finally in the North Atlantic we compare the upper ocean steric changes with altimetry in order to separate the baroclinic component from bottom pressure variability.

Seasonal and interannual variability in the southeast Indian Ocean

Starting in 1997, our group in Toulouse has been investigating the bands of high sea level variability in the southeast Indian Ocean. These energetic bands correspond to westward propagating Rossby wave signals [Morrow and Birol, 1998]. The northern band centered around 10°S is dominated by Rossby waves generated by the annual wind forcing in the region west of 110°E, although some semi-annual and interannual variability propagates into the region from the eastern boundary near Timor Passage, and from the northern boundary near Lombok Strait [Birol and Morrow, 2000]. In the southern band, higher variability between 20-35°S is dominated by semi-annual frequencies, which are not locally forced by the wind. Instead, a semi-annual signal originating in the Indonesian Sea region propagates from Timor Passage poleward along the West Australian coast, and then separates from the coast between 20-35°S where the coastal Leeuwin Current becomes intense [Birol and Morrow, 2001].

These propagating waves between 20-35°S are not well represented by the current generation of numerical models. As yet, we have no information on their vertical structure, nor their role in propagating heat and other tracers into the ocean interior. To rectify this, we undertook a series of in-situ hydrographic measurements crossing through a number of cyclonic and anticyclonic eddies in the Leeuwin Current region in September 2000 (TIP2000 campaign). We will use these measurements, in combination with some numerical model simulations, to help us interpret the dynamical response seen by the TOPEX/POSEIDON and Jason satellites. In addition, in 2002 we plan to launch some profiling floats between 20-55°S in the southern Indian Ocean as part of the ARGO program. These floats will also give us vital information on the ocean's vertical structure, and allow us to study the role of these high-variability bands in transferring heat and other tracers to the south-west Indian Ocean and in mixing and modifying the different water masses.

Seasonal and Interannual variability in the Southern Ocean

We have been monitoring the upper ocean variability between Australia and Antarctica since 1993, using a combination of altimetry and in-situ measurements. The in-situ data include six XBT sections per year (measuring temperature to 800 meters) and continuous surface temperature and salinity measurements between Hobart, Tasmania and the French Antarctic base, Dumont D'Urville.
These measurements span the main heating cycle in the Southern Ocean, from the end of winter conditions in October to the spring cooling in March. The combined altimetric and in-situ data allow us to investigate the dynamics of the Polar Fronts, monitor the variability of the Antarctic Circumpolar Current (ACC), and quantify the seasonal and interannual changes in the upper ocean heat content and salinity budget.

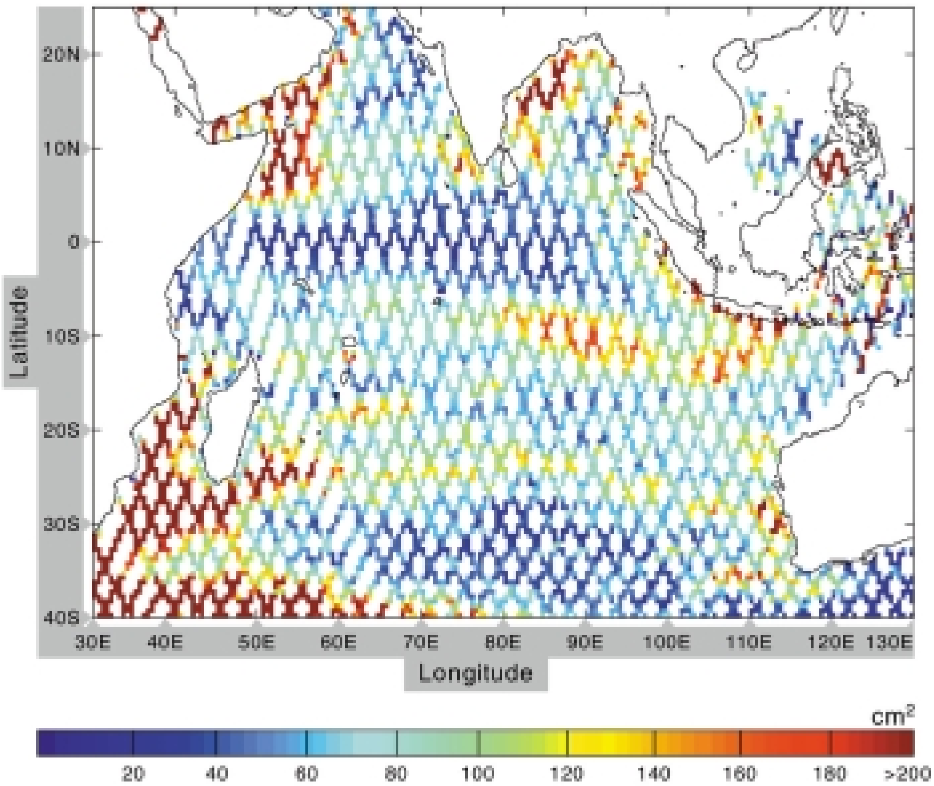

Figure 1: Sea level variance in the Indian Ocean measured along TOPEX/ POSEIDON tracks for the three-year period 1993-1995, showing the bands of high variability in the southeast Indian Ocean.

Salinity plays a major role in Southern Ocean dynamics south of the Polar Front, since the temperature stratification is relatively weak and the seasonal sea-ice signal introduces large fluctuations in the surface freshwater signature.
We have compared our seven-year surface temperature and salinity measurements with some climatological data sets; the seasonal temperature changes are well represented in the climatology, but the surface salinity compares poorly south of the Polar Front [Morrow and Chaigneau, 2001]. This in turn modifies the surface density field, which is critical in this region of active water mass formation.
The seasonal and interannual upper ocean density changes are also captured by altimetry, and in the future we will investigate the sea level response to surface salinity and temperature changes. We will also monitor the upper ocean thermal and freshwater response to local fluctuations in the atmospheric forcing, and estimate the role of advection using both geostrophic currents from altimetry and wind-driven Ekman currents from scatterometry.

We are further interested in the role of eddies in transferring momentum, heat and other tracers along and across the ACC. With altimetry, we can monitor the seasonal and interannual changes in the eddy kinetic energy levels, and investigate their relation to the changing thermal structure using the XBT line across the ACC [Morrow and Brut, 2001]. We can also estimate the eddy heat and momentum fluxes precisely along the XBT line, and intend to extend these investigations to other hydrographic lines in the region (WOCE SR3 south of Tasmania, and the OISO lines near Kerguelen in the Indian sector).

Oceanographic variability in the North Atlantic subpolar gyre

We have been monitoring the upper ocean variability in the southern part of the North Atlantic subpolar gyre since 1993. This includes an in-situ component, primarily from ships of opportunity (VOS) between Iceland and Newfoundland and between Denmark and southwest Greenland, to investigate the variability of upper ocean temperature and salinity (using thermosalinographs and launched XBTs). We will continue this monitoring until at least early 2003 to obtain a reasonably long time series, and be able to analyze the performance of the observing network in more detail. These data will complement the ongoing sampling by profiling floats within ARGO (some floats whose data are not yet available were deployed in 1996-1997, and new floats with public available data will be deployed this year). The data are used to construct fields of upper ocean properties [Reverdin et al., 2001, in preparation].

Altimetric data from Jason and other satellite-borne platforms will be used in two ways:
1) To derive geostrophic currents, which are used with property maps and wind stress to estimate upper ocean advective transports. This is important to understand to what extent the observed anomalies in the subpolar gyre develop locally or

are advected from remote regions, and how this eventually feeds back on the atmosphere, on ice cover and on the thermohaline circulation. The data have been used up to now only for temperature [Verbrugge and Reverdin, 2001]. A similar effort needs to be undertaken for salinity, and density fluctuations need to be reconstructed over long-enough periods. Further comparison with model simulations needs to be carried out (in particular, the advection from cold and fresh boundary currents originating from the Arctic has been poorly monitored up to now, and its effect on the subpolar gyre needs to be assessed by dedicated model and data comparisons).

2) To compare the upper ocean steric changes with altimetric sea level, in order to separate the baroclinic component from the bottom pressure variability. The sea level geostrophic current changes are known to be strongly influenced by bottom topography and therefore the observed variability likely includes a significant bottom component as well in the North Atlantic subpolar gyre [Reverdin et al., 1999]. The steric changes were estimated up to now mostly from temperature data, with some correction for surface salinity. The work needs to be expanded to take into account subsurface salinity changes through the water column as these become better known (in particular, for the period from 1996 to now, during which profiling floats have been transmitting data from this area).

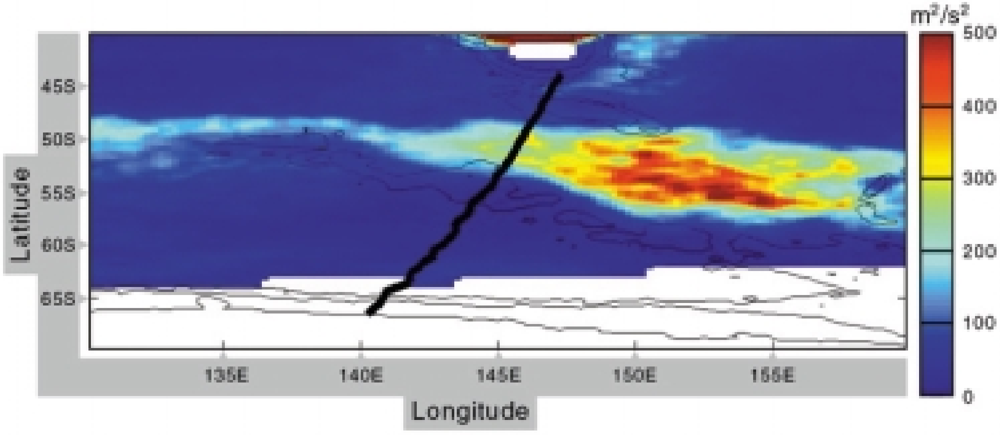

Figure 2: Eddy kinetic energy (m^2s^{-2}) across the Antarctic Circumpolar Current south of Australia for the "eddy" band with periods less than 90 days. The location of the XBT line between Australia and Antarctica used to estimate upper ocean heat and surface salt transports and eddy fluxes is marked. Bathymetry contours are shown.

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