25-Day Period Large-Scale Oscillations in the Argentine Basin Revealed by theTOPEX/POSEIDON Altimeter

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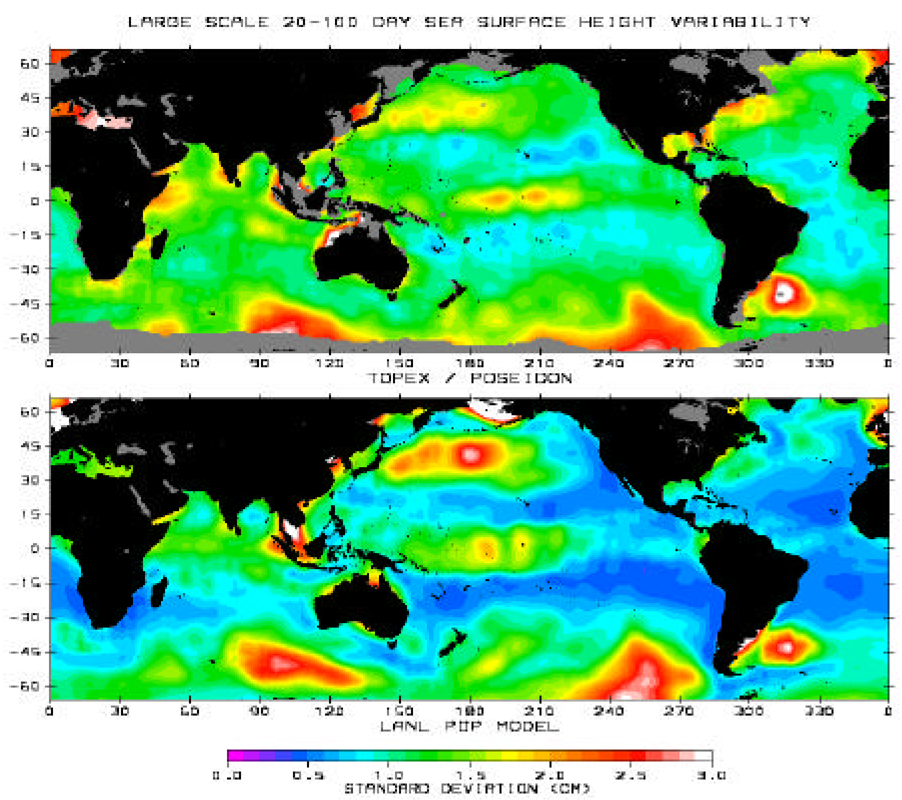
Abstract

The measurement of global sea surface height made by the TOPEX/POSEIDON (T/P) satellite has provided the first synoptic view of large-scale oceanic variability at the intraseasonal scales from weeks to months. Areas of significant intraseasonal variability were primarily found in the high-latitude oceans, the Southern Ocean in particular. The focus of the paper is the finding of large-scale oscillations at a period of 25 days in the Argentine Basin of the South Atlantic Ocean. These oscillations exhibit a pattern of counter-clockwise rotational propagation centered at 45º S and 317º E over the Zapiola Rise, with a half wavelength of about 1000 km. The peak-to-trough amplitude is about 10 cm. The amplitude of these waves has large seasonal-to-interannual variations. These oscillations are shown to be a free barotropic mode of the basin as a solution to a linearized barotropic vorticity equation. Closed f/H contours provide a mechanism for the confinement of the waves to the topographic feature of the Zapiola Rise. Results from a numerical model simulation reproduced the observed pattern of the waves. The barotropic nature of the variability yields an estimate of the amplitude of the mass transport variation to be about 50 Sv. Deep current meters in the Argentine Basin reveal signals that are consistent with the altimetry observations.

Intraseasonal Variability

Root-mean-squares variability of sea surface height measured by T/P (top) and simulated by an ocean general circulation model (bottom) is shown in **Figure 1**. Both were filtered to retain energy at spatial scales larger than 1000 km and temporal scales from 20- 100 days. (from Fu and Smith, 1996). The details of the intraseasonal variability revealed in the T/P data have not been investigated previously. In this paper we present results from the investigation of a particular mode of variability in the Argentine Basin of the South Atlantic Ocean where the observed intraseasonal variability has the highest energy level.

Figure 1



Data Analysis

All the data from October 1992 through December 1997 within a box bounded by 30°S-50°S, 300°E-335°E were used in the analysis. A Gaussian- weighted smoothing scheme was applied to the data to create smoothed SSH anomaly maps on a uniform 1°x1° grid every 3 days. The half- weight scale was set to 1° in latitude, 2° in longitude, and 5 days in time. All the data with a search window (3° in latitude, 12° in longitude, and 20 days in time) were used to produce a smoothed estimate. Such a procedure is an efficient scheme for producing gridded maps of large-scale variabilities.

Figure 2

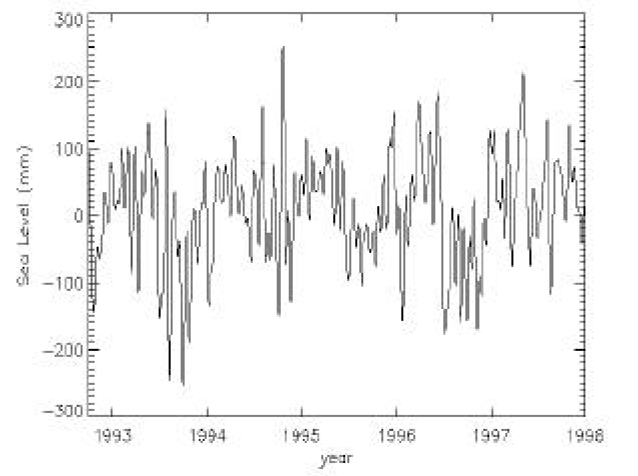
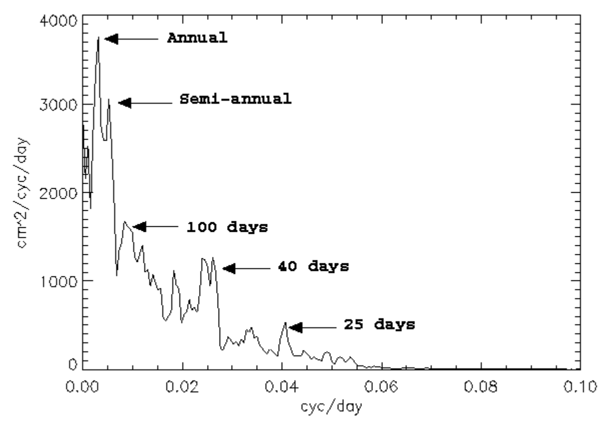


Figure 3



Variability of the Argentine Basin

Displayed in **Figure 2** is the time series of SSH at 42°S, 316°E, near the center of the study domain. An annual cycle superimposed with energetic high-frequency fluctuations is prominent. A spatially averaged (over a 4° latitude x 10° longitude box centered on 42°S, 316°E) frequency spectrum is shown in **Figure 3**. A high-passed version of Figure 2 with energy at periods longer than 30 days removed is shown in **Figure 4**. Fluctuations with peak-to-trough excursion of 20 cm are seen with seasonal and interannual modulations.

The spatial patterns of the high-passed SSH are displayed in **Figure 5** for a period of 21 days (March 30-April 20, 1993). The evolving patterns can be characterized by a spatially coherent, counter-clockwise rotating dipole wave. The peak-to-trough sea level amplitude is about 10 cm over a scale of 1000 km. The rms variability computed using the entire 5 years of data has a maximum value of 3 cm located around 42°S, 313°E (**Figure 6**). The contours of the energy level are somewhat aligned with the contours of f/H, suggesting the barotropic nature of the variability.

Figure 4

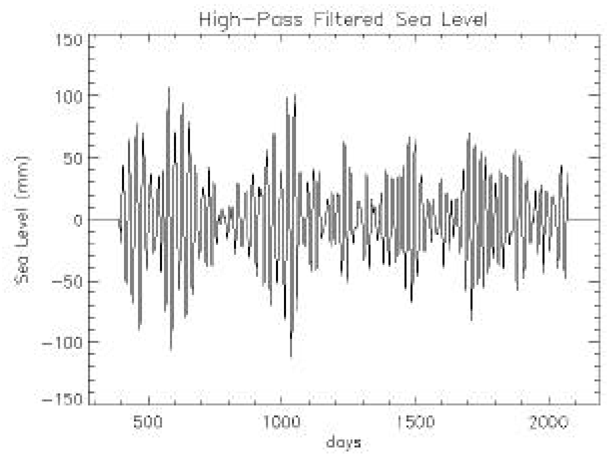


Figure 5

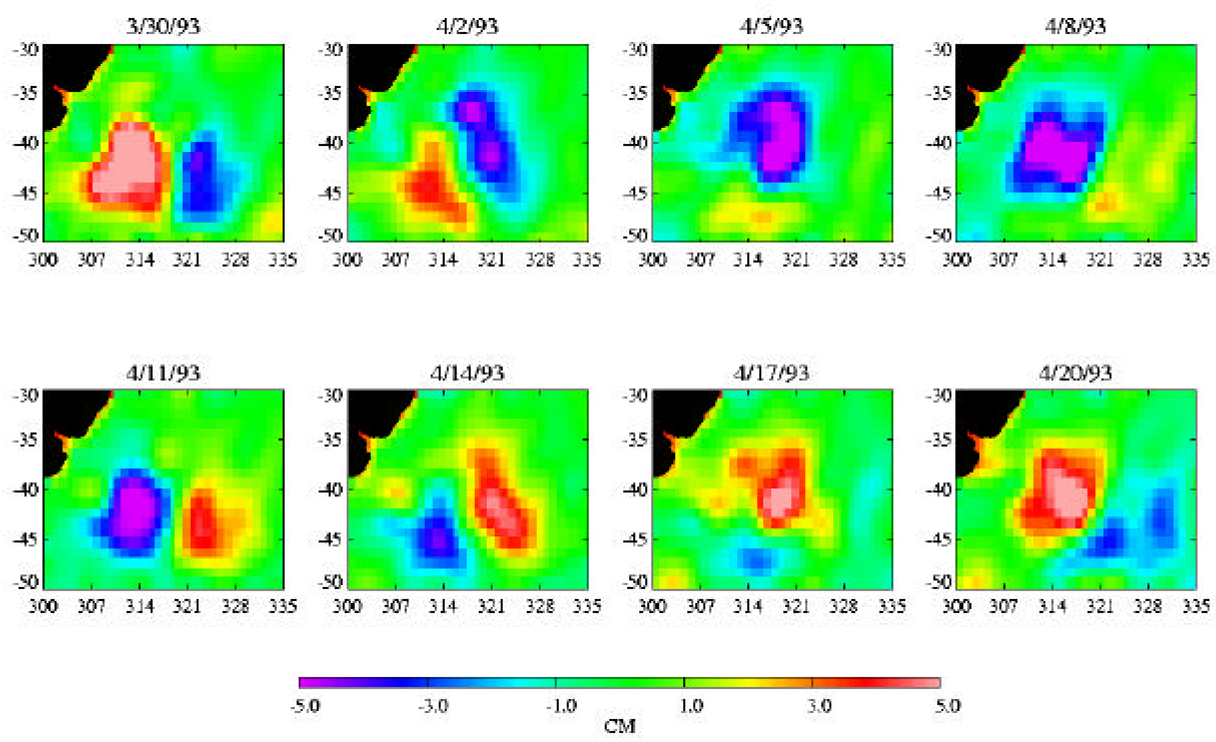
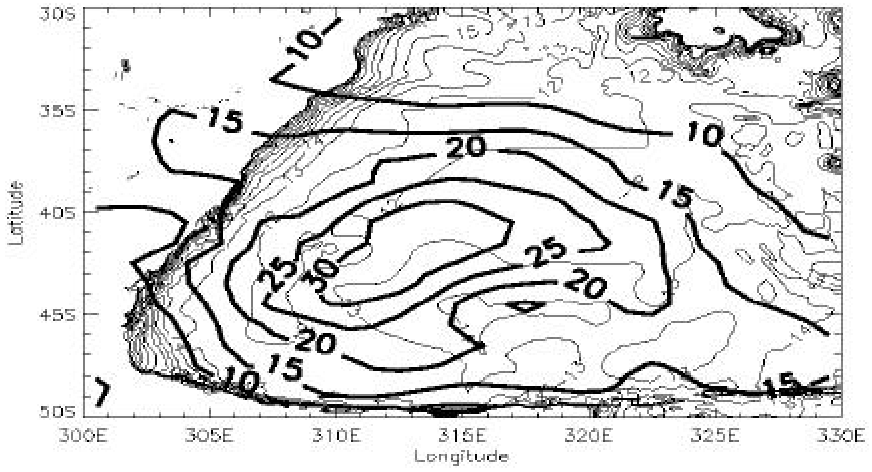


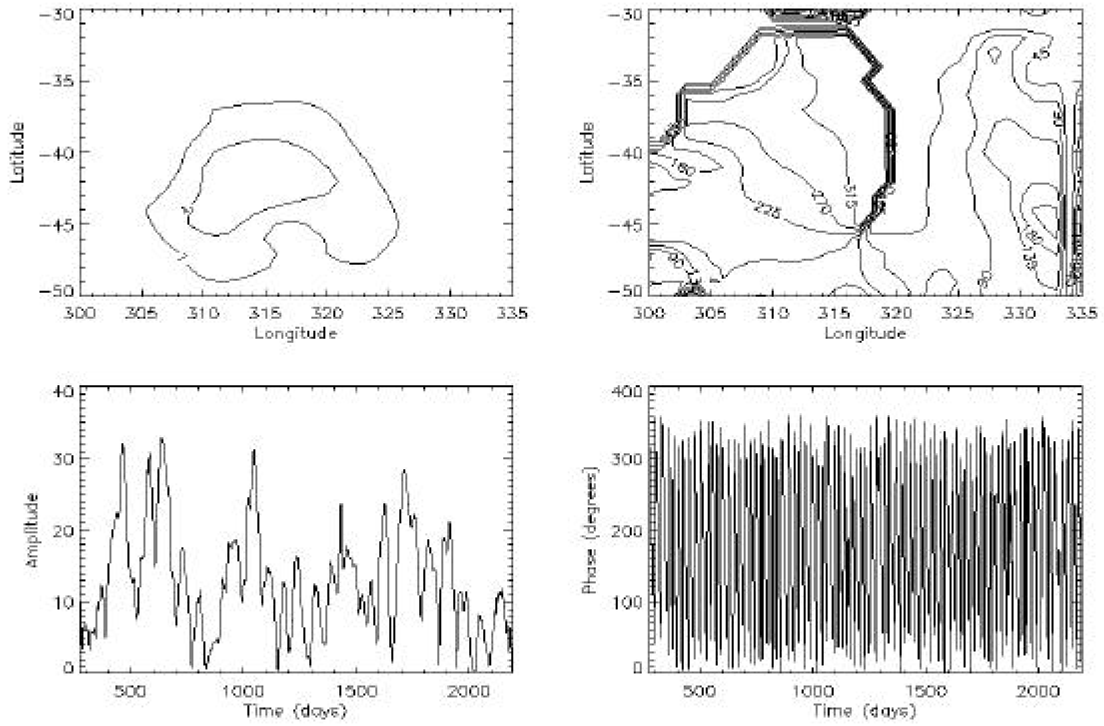
Figure 6



The technique of complex-valued empirical orthogonal function (CEOF) was applied to the entire array of high-passed SSH time series in the study domain to investigate the dominant spatial and temporal characteristics of the variability. The amplitude and phase of the leading CEOF are shown in **Figure 7**. This mode accounts for 38 % of the total variance. The spatial pattern of the amplitude is similar to the rms variability map (**Figure 6**). The spatial pattern of the phase indicates the rotational character of the variability, with the center of rotation located at 45°S, 318°E, over the Zapiola Rise. The definition of the phase in the CEOF computation indicates that the rotation is counter-clockwise as shown in **Figure 5**. The temporal evolution of the phase reveals a highly periodic fluctuation with a well-defined frequency of 1 cycle per 25 days. The temporal evolution of the amplitude shows a variety of scales. The low frequency components are visually consistent with the low-frequency modulation of the time series shown in **Figure 4**. The CEOF analysis indicates that the counter-clockwise rotating dipole wave shown in **Figure 5** is a persistent feature of the region with a highly variable amplitude.

The spatial and temporal scales of the dipole wave indicate that the motion field is probably barotropic because the period of baroclinic Rossby waves with a wavelength of 1000 km is on the order of 4 years, much longer than the observed period of 25 days.

Figure 7



In-Situ Observations

Data from two current meters deployed at 10 m and 200 m above the ocean bottom in the region (42.5°S, 315°E) in 1987 revealed similar phenomenon (Courtesy of Georges Weatherly of the Florida State Univsersity). Shown in **Figure 8** are the rotary spectra computed from the data. The dominance of the counter-clockwise component at periods close to 25 days is clearly shown at both depths. The counter-clockwise component of velocities at the two depths are highly coherent at periods from 20-50 days (0.95, above the 95% confidence level with 5 degrees of freedom) with small phase difference (**Figure 9**). The spectral analysis suggests that a vertically coherent, counter-clockwise rotating current with a period of about 25 days does exist near the ocean bottom, consistent with the assertion that the T/P observed 25-day waves are barotropic and involve uniform motion of the entire water column.

Figure 8

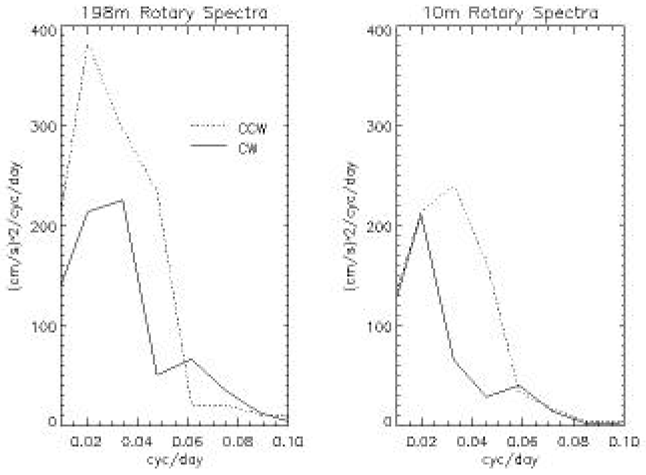
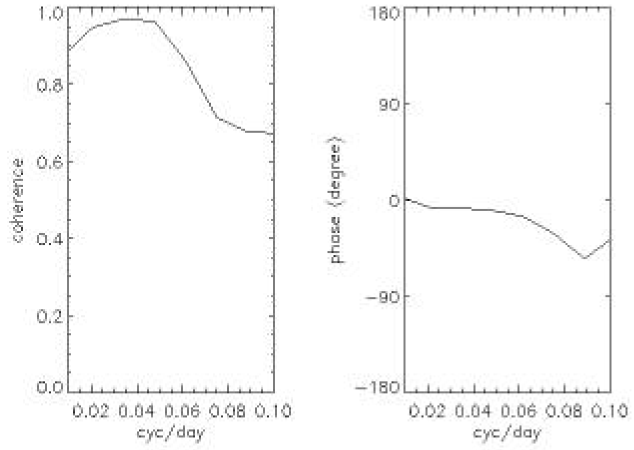


Figure 9



Theoretical Considerations

The fact that the dipole waves are essentially rotating around the Zapiola Rise suggests their origin as topographically-controlled Rossby waves dictated by the f/H contours. A linearized barotropic potential vorticity equation in polar coordinates centered on the Zapiola Rise can be written as

$$\frac{\partial}{\partial t}\left(\frac{\partial^2 h}{\partial r^2}+\frac{1}{r}\frac{\partial h}{\partial r}+\frac{1}{r^2}\frac{\partial^2 h}{\partial q^2}\right)-\frac{H}{r}\frac{\partial h}{\partial q}\frac{\partial}{\partial r}\left(\frac{f}{H}\right)=0 \qquad (1)$$

We seek azimuthally propagating wave solution, $h = p(r)\exp[i(sq - wt)]$, and define , $b_e \equiv H\frac{\partial}{\partial r}\left(\frac{f}{H}\right)$

which represents an equivalent beta effect. Eq. (1) then becomes

$$\frac{\partial^2 p}{\partial z^2}+\frac{1}{z}\frac{\partial p}{\partial z}-\frac{4s^2}{z^2}p+\frac{sb_e}{w}p=0 \qquad (2)$$

which can be transformed into a Bessel's equation with a general solution

$$h=\sum_{s=0}^{\infty}A_s\exp[i(sq-wt)]\,J_{2s}\left(2k\sqrt{r}\right) \qquad (3)$$

where $k^2 = sb_e/w$. Because the observed waves assume a dipole structure, we set s = 1. The fact that the observed waves are confined to the Argentine Basin leads us to require the solution to be confined to a circular region with a radius of L. This requirement gives rise to the following dispersion relation: $J_2(2k\sqrt{L})=0$, or 2 $k\sqrt{L}$ =5.15, leading to the following for the wave period :

$$T=\frac{2p}{w}=\frac{5.15^2 p}{2Lb_e} \qquad (4)$$

The value of b_e in the region is about 3.3 x10^{-11} sec^{-1} m^{-1}. L is on the order of 500 km. With these values for L and b_e , T ≈ 29 days (L=580 km would make T=25 days). **Figure 10** shows that T is not particularly sensitive to either L or b_e within a reasonable range of values. The observed wave period of 25 days can be readily explained by the theory. Shown in **Figure 11** is the wave function with the above parameters for s=1. The spatial patterns of the observed waves can also be qualitatively accounted for by the theory.

Figure 10

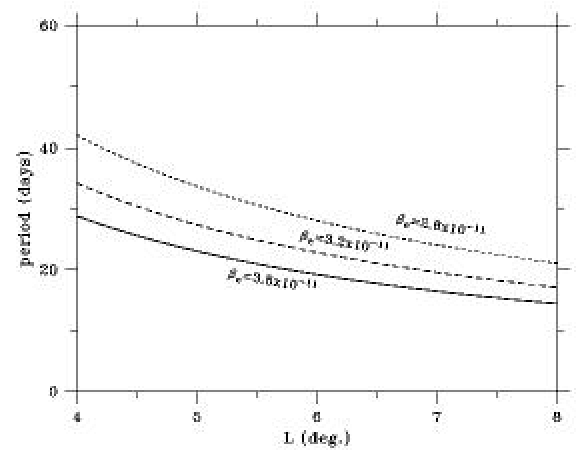


Figure 11

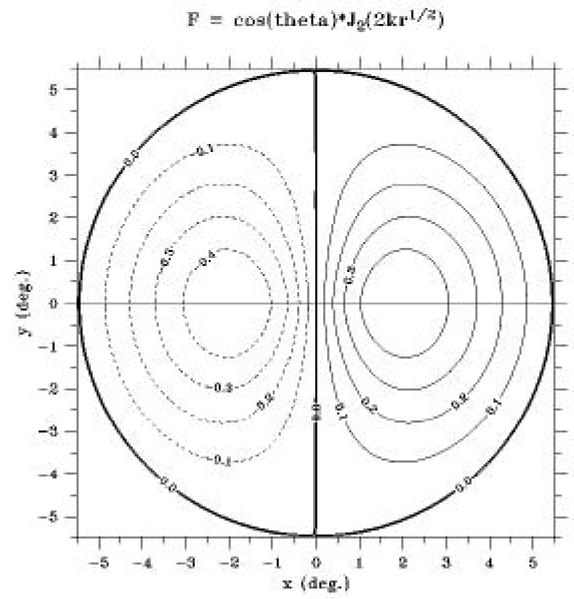
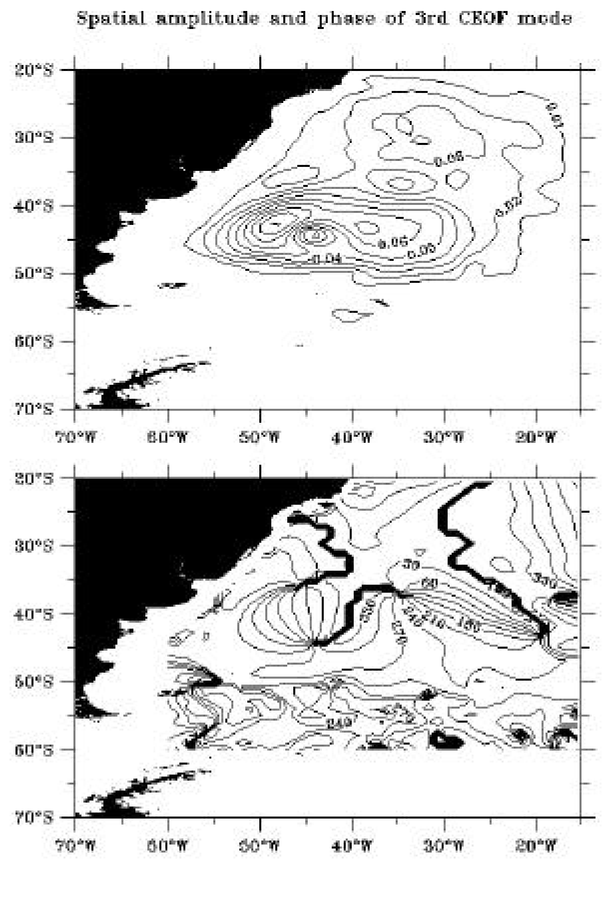


Figure 12



Numerical Model Simulation

The theoretical analysis discussed above suggests that the observed waves are signatures of a normal mode associated with the local topography. To verify the existence of such a mode in a more realistic setting, a numerical model was run to simulate the variability of the Argentine Basin. This is a barotropic model with a spatial resolution of 0.5° x 0.5°, covering the domain of 75° W-15° W and 20° S-60° S. All the model boundaries are closed. The NCEP daily wind was used to drive the model from January 1, 1990 to December 31, 1997. The 8-year mean wind was removed because the mean circulation is not of interests to the study. CEOF analysis was applied to the resulting barotropic stream function. While the first two modes are not related to the observed wave, the third mode, accounting for 10% of the variance, has a distinct period of 22 days with spatial patterns similar to the observed 25-day waves (**Figure 12**). The degree of resemblance in both the spatial phase and amplitude distribution between Figure 7 and Figure 12 is fairly convincing. The peak-to-trough sea level amplitude associated with the mode is about 8 cm, comparable to the observation.