Chapter 4: 13-Day Period Oscillations in Spring 2004

Abstract

13-day period oscillations were observed in the first half of the year 2004 in equatorial ocean velocity records at 23°W and at 10°W. Two distinguishable 13-day period oscillations were identified; one was subsurface intensified and occurred from February to March and the other was surface intensified and occurred from April to May. A 13-day period oscillation in SST was also detected from March to May. The conspicuous SST 13-day period signal permitted to relate the velocity oscillations with SST variations and then to estimate the meridional structure and the zonal scale of the waves. The 13-day period oscillation in March-May was consistent with a second baroclinic mode standing mixed Rossby-gravity wave, forced by meridional winds presenting the same periodicity. Preliminary results indicate that waves with 13-day periodicities are well represented in high horizontal resolution model simulations (MICOM) where the waves could be inferred from velocity and sea surface height anomalies.

4.1 Introduction

Oscillations with biweekly periodicity have been observed in the three equatorial oceans (e.g., Zhu et al., 1998 in the Pacific; Miyama et al., 2006 in the Indian; and Houghton and Colin, 1987 in the Atlantic). In all the cases the oscillations have been associated with wind-forced mixed-Rossby gravity waves. In the Indian Ocean, these biweekly waves have a temperature signature as well; the wave is associated with intermittent off-equator upwelling and downwelling throughout the year (Sengupta et al. 2004). Since upwelling followed by mixing is an irreversible process, these authors suggest that the biweekly oscillations might have an impact on subsurface temperature and in biology, and eventually in climate.

Meridional velocity observations in 2000, (Chapter 1) and 2002, (Chapter 2) showed 11-15 day period fluctuations during boreal spring. Spring 2004 also showed 11-15 day period oscillations (hereafter 13-day period oscillations) in the meridional velocity component (Fig. 2) and in SST. The characteristics of the 13-day period oscillations in 2004 bore similarities and differences with the waves observed in other years. In this chapter we will not address those comparisons. Instead, we will focus on the 13-day period oscillation observed in 2004. This chapter is organized in four sections. Section two provides a brief description of the data and data processing. Section three studies some of the characteristics of the 13-day period oscillation in current velocities, SST and wind velocity data, and the fourth section discusses the results and compares them with the model results.

4.2. Data

To study the upper equatorial circulation in the equatorial Atlantic, the PIRATA (Pilot Research moored array in the Tropical Atlantic) program deployed moorings with ADCPs (Acoustic Doppler Current Profilers) on top, at 10ºW and 23ºW (see table below for the duration of the deployments). A mooring at 10ºW equipped with an upward looking ADCP NB150 sampling the upper 300 m was deployed on May 2003. The mooring was recovered and redeployed on February 2004, along with a second mooring at 23ºW equipped with an upward looking ADCP observing the upper 120 m. The two moorings were recovered in May and June 2005. The hourly data were averaged over 25 hours to remove tidal frequencies and re-sampled to provide daily resolution (Figure 1).

In this chapter, we also make use of satellite sea surface temperature and surface wind velocity data. Tropical Rainfall Measuring Mission (TRMM) – Microwave Imager (TMI) SST data were examined over the region between 9°S and 9ºN, and 35°W and 10ºE during the years 2000 to 2005. This SST product is the result of an optimal interpolation with temporal and a spatial resolutions of 1 day and 0.25º, respectively. SST data is available at http://www.remss.com/sst. QuikSCAT surface wind horizontal velocities were explored over the region bounded by 10°S and 10ºN, and by 50°W and 10ºE in the year 2004. These data is daily, has a horizontal resolution of 1/2º, and is available at www.ifremer.fr/cersat. SST and wind velocity time series were filtered using a digital Butterworth band pass filter to retain signals with periods in the band of 5 to 38 days.

The computational domain of the Miami Isopycnic Coordinate Ocean Model (MICOM) simulation used in this study is the North and Equatorial Atlantic Ocean basin from 28ºS to 70ºN, including the Caribbean Sea, the Gulf of Mexico, and the Mediterranean Sea. The horizontal grid is defined on a Mercator projection with resolution given by $1/12^{\circ}\times 1/12^{\circ}\cos(\Phi)$, where Φ is the latitude and is approximately 9 km at the equator. The vertical density structure is represented by 19 isopycnic layers topped by an active surface mixed layer that exchanges mass and properties with the isopycnic layers underneath. After a six-year spinup with monthly climatological forcing, the model was integrated using surface boundary conditions based on European Centre for Medium-Range Weather Forecasts (ECMWF) daily atmospheric data from 1979 to 1986. The high horizontal grid resolution drastically improved the model's behavior in comparison to that of previous coarse-resolution simulations (Paiva et al., 1999).

We analyzed the horizontal velocities, SST, and sea surface height (SSH) from the output model by computing a frequency dependent polarization analysis. This method is based on a singular value decomposition of a matrix of eigenspectra at a given frequency (Park et al. 1987). As a result, we were able to obtain the spatial structure and phase propagation associated with the 13-day periodicity.

Location	Depth	Starting date	End date	Days of good data
23ºW	ADCPs (10-120m)	13.Feb.04	28.May.05	471
10ºW	ADCP (26-286 m)	7.May.03	17.Jun.05	773

Table 1: Location, depth, and number of days of good data of the ADCPs from PIRATA moorings.

4.3. 13-Day Period Oscillations

From February to March, 13-day period oscillations were seen in the subsurface, at the depth of the Equatorial Undercurrent (EUC); from April to May, these fluctuations were surface-intensified. Subsurface 13-day period oscillations had maximum amplitudes of approximately 20 cm/s in both locations while surface-intensified oscillations reached amplitudes up to 50 cm/s at 10ºW, and did not exceed 10 cm/s at 23ºW. SST and surface wind velocity data also showed oscillations with periods in the 11-15 day band. In SST data, the 13-day period signal started to be observed in mid March, was confined to the equatorial region (Fig. 3, bottom panel), showed large zonal scales and had amplitudes of up to 2ºC. Sometimes, the spatial structure of the SST anomaly was anti-symmetrical about the equator and sometimes was symmetrical (e.g., fig. 4, snapshots of April 7 and May 10). There was no sign of zonal propagation.

In spring 2004, satellite surface wind data presented 13-day period fluctuations simultaneously in both horizontal velocity components. The 13-day period fluctuation in the zonal wind velocity component had the form of a strong zonal jet (amplitudes of up to 7 m/s) localized mainly between the equator and 5ºN, and between 20ºW and 0ºE (Fig. 5). The variance at periods between 11 and 15 days (Fig. 3) shows that there was also some energy in this period range off the coast of Gabon. Grodsky et al. (2001) reported strong quasi-biweekly fluctuations in surface winds and rainfall during boreal spring and summer of 2000. The disturbances they described are mostly zonal and are the result of a cycle of continental heating, convection, and cooling. The zonal wind observations in boreal spring of 2004 presented here are equivalent to the ones observed by Grodsky et al. (2001). In contrast, the meridional wind velocity component at this period had smaller amplitude (3 m/s) and a more complicated structure. The strongest meridional winds with this periodicity were found off the coast of Brazil (Fig. 3). However, the meridional winds relevant for the observed SST structures are the ones observed over the equatorial region. In spring 2004, meridional winds in the equatorial region with periods of ~13 days often presented different signs on each side of the equator (e.g., Fig 6, snapshots from March 24 and April 7) and sometimes there was even a three band structure like the one shown in the May 10 snapshot (Fig. 6).

As observed in figures 5 and 6, the spatial structure of the 13-day period fluctuation in each wind velocity component does not bear much acquaintance. For that reason, the spatial structure of the 13-day period fluctuation is difficult to interpret in terms of the combination velocity components. However, both, zonal and meridional wind velocity fluctuations can potentially explain the SST anomalies observed in figure 4 separately. The zonal component is consistent with upwelling and downwelling at the equator due to Ekman pumping; the meridional component is consistent with convergent and divergent flows at the equator due to direct wind drag. The problem with the zonal wind velocity component is that there is a lag with respect to the SST signal, with the zonal wind leading by 7 days. This means that in the series at zero time-lag, a westward wind anomaly corresponds to a warm SST event at the equator and an eastward wind anomaly corresponds to a cold SST event, which is the opposite of what is expected. The meridional wind velocity component on the other hand, presents the right phase with respect to the SST signal; divergent velocities on the equator correspond with cold SST anomalies (e.g., figs. 4 and 6, snapshots corresponding to March 23 and April 13) and convergent velocities to warm SST anomalies (Figs. 4 and 6 snapshots corresponding to April 7 and May 4). There is even a case when the meridional component showed a three-band structure about the equator (fig. 6, snapshot of May 10) presenting northward wind anomalies at each sides of the equator and a southward wind anomaly right at the equator. The temperature snapshot for that same day shows an anti-symmetrical SST structure with a cold SST anomaly north of the equator and a warm SST anomaly south of the equator, which is consistent with the idea of converging and diverging flows due to direct wind drag. 9 days later, however, the SST anti-symmetrical structure changes sign; the warm anomaly is north of the equator and the cold anomaly is south of the equator, and there is no consistent change of sign in the meridional winds (figs. 4 and 6, snapshots corresponding to May 19).

Another possible explanation for the temperature 13-day period signal is that the SST anomalies are the signal of an oceanic equatorial wave. The wave could have been initially forced by the winds. The observed SST anomalies, especially those with antisymmetric structure about the equator, can be explained as the result of oceanic mixed Rossby-gravity waves in the ocean. In the following paragraphs we will explore that possibility.

A correlation analysis using SST data and the meridional current velocity component series at 26 m depth, at 10º W, shows that SST series precede the current meridional velocities by 3 days (Fig. 7). At the same time, the correlation map shows that the areas of good correlation between current and SST data agree with the SST structure attributed to the 13-day period oscillation and that the corresponding zonal scale is of over 30 degrees of longitude (~3300 km). The dominance of the meridional component over the zonal component in current measurements at the equator, the period of the wave and the anti-symmetrical SST structure about the equator, indicate that the 13-day oscillation in the ocean can be surmised to a mixed Rossby-gravity wave. The large zonal scale ($k \rightarrow 0$) and the lack of evidence of zonal propagation suggest a standing wave which surface moves up and down, but with opposite sign on each side of the equator (to the extent that velocity streamlines coincide with isotherms, this would explain the anti-symmetrical SST structure about the equator). All these characteristics are consistent with a second baroclinic mode mixed Rossby-gravity wave as shown in the dispersion relationship diagram of figure 8.

4.4. Conclusions and Comparisons with Model Outputs

In conclusion, there are two different signals presenting ~13-day periodicities in the meridional velocity component. The first one is subsurface intensified and appears to be related in someway to the EUC. The second is surface intensified and is well correlated with SST fluctuations. We do not know if these two signals are related. However, at 10°W where the EUC is close to the surface, the differences between the two 13-day period oscillations are almost imperceptible.

SST signals are well related to fluctuations in the meridional wind velocity component and in the current meridional velocity component. The SST signal could be the result of both, divergent and convergent meridional winds about the equator and a remotely wind-forced oceanic mixed Rossby-gravity wave. At times when the SST 13-day period signal is symmetrical about the equator, the meridional wind would be the main factor controlling the observed SST signal; when the SST 13-day period signal is antisymmetrical about the equator, the inherent dynamics of the mixed Rossby-gravity wave are responsible for the observed SST anomalies.

As mentioned before, other velocity observations have shown 11-15 day period oscillations in the meridional velocity component in boreal spring. However, the corresponding SST signal was not always present or did not last long enough to enable any significant correlation between velocity and SST fluctuations. For instance, in 2002, 2003 and 2005, no 13-day period signal was observed in SST at the equator, and in 2000 and 2001, only one or two full cycles of 13-day period fluctuations in SST could be detected. The presence or absence of the 13-day period signal in the SST may be related to the nature of the wave (surface or subsurface intensified) and to the pre-existing background SST field and the depth of the mixed layer. Further analysis is needed to understand the dynamics of the different types of 13-day period oscillations, examine whether they are related to each other or not, and investigate the main factors playing a role in the 13-day period SST signal.

Preliminary analysis of 8-years of model data (1979-1986, MICOM- forced with realistic daily winds) did not show similar SST structures at 13-day period. Nonetheless, the sea-surface height and the horizontal velocity components in the surface oceanic layer at 13-day period showed mixed-Rossby gravity waves characteristics; symmetric spatial structure in the meridional component and antisymmetric spatial structure in the zonal velocity component and in the pressure field (fig. 7). The analysis of the model outputs was done over the entire time series and one needs to repeat this analysis on a year by year basis to find out if the lack of SST 13-day period signature is over the whole time period or if some are present on a yearly basis as it is the case for the observations.

Velocity observations at intermediate depths at the equator have shown the presence of 13-day period oscillations at 1000 m depths during boreal spring (chapter 1). Further analyses are needed to know whether the 13-day period oscillations observed at 1000 m depth are the deep expression of the 13-day period oscillations observed at the surface or not. If they are related, then how 13-day period oscillations penetrate that far in the water column has to be understood.

The model outputs are interesting. They provide another way to continue studying this 13-day period oscillation near the surface and at depth. We shall compare the simulation products with data from other years in the Atlantic and to the biweekly oscillations found in the Indian (e.g., Miyama et al., 2006) and Pacific Oceans (e.g., Zhu et al., 1998).

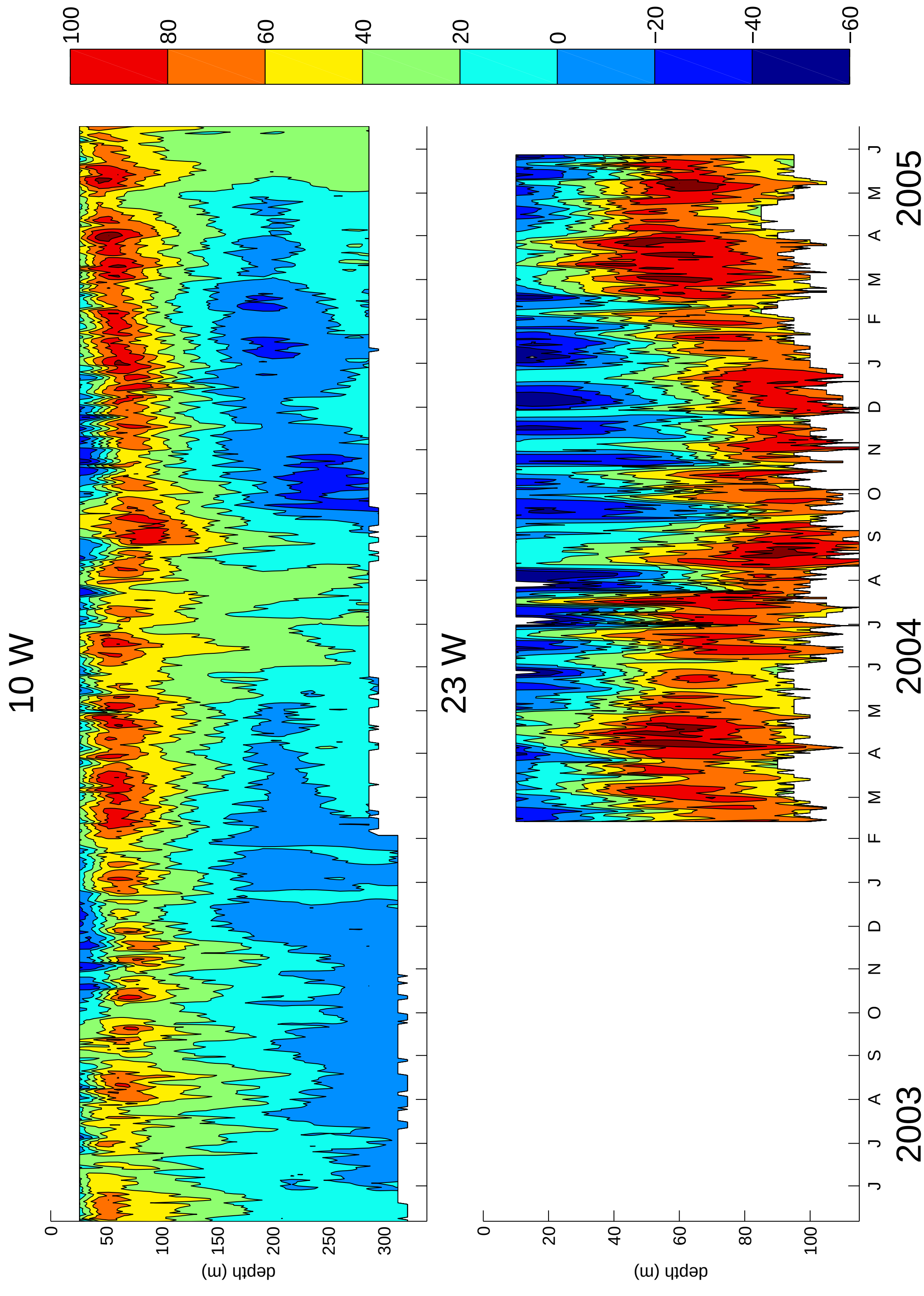

Figure 1: Zonal (first panel) and meridional (second panel) velocity components from the ADCP at 10ºW (top) and the ADCP at 23ºW (bottom).

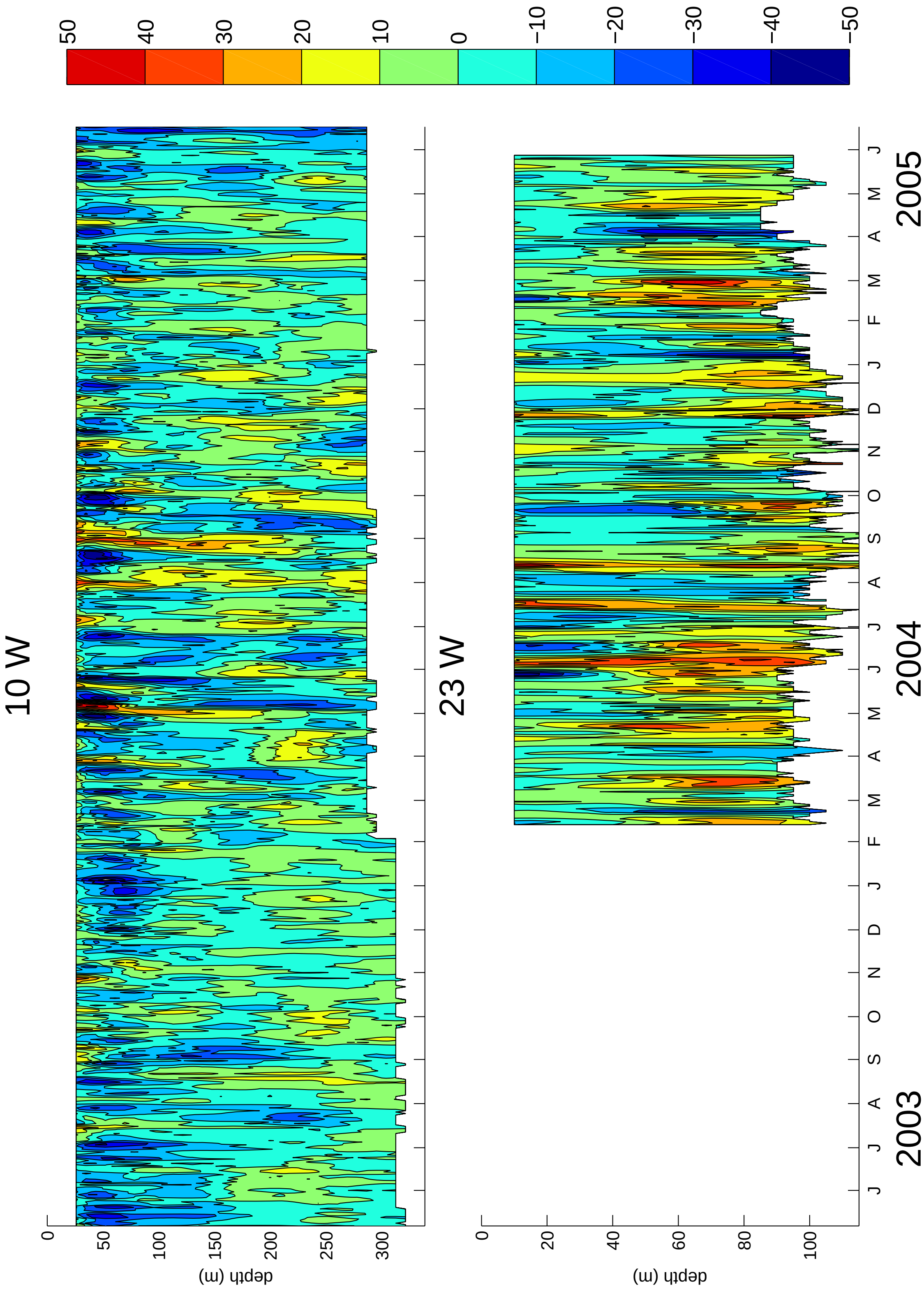

Figure 1: (continued).

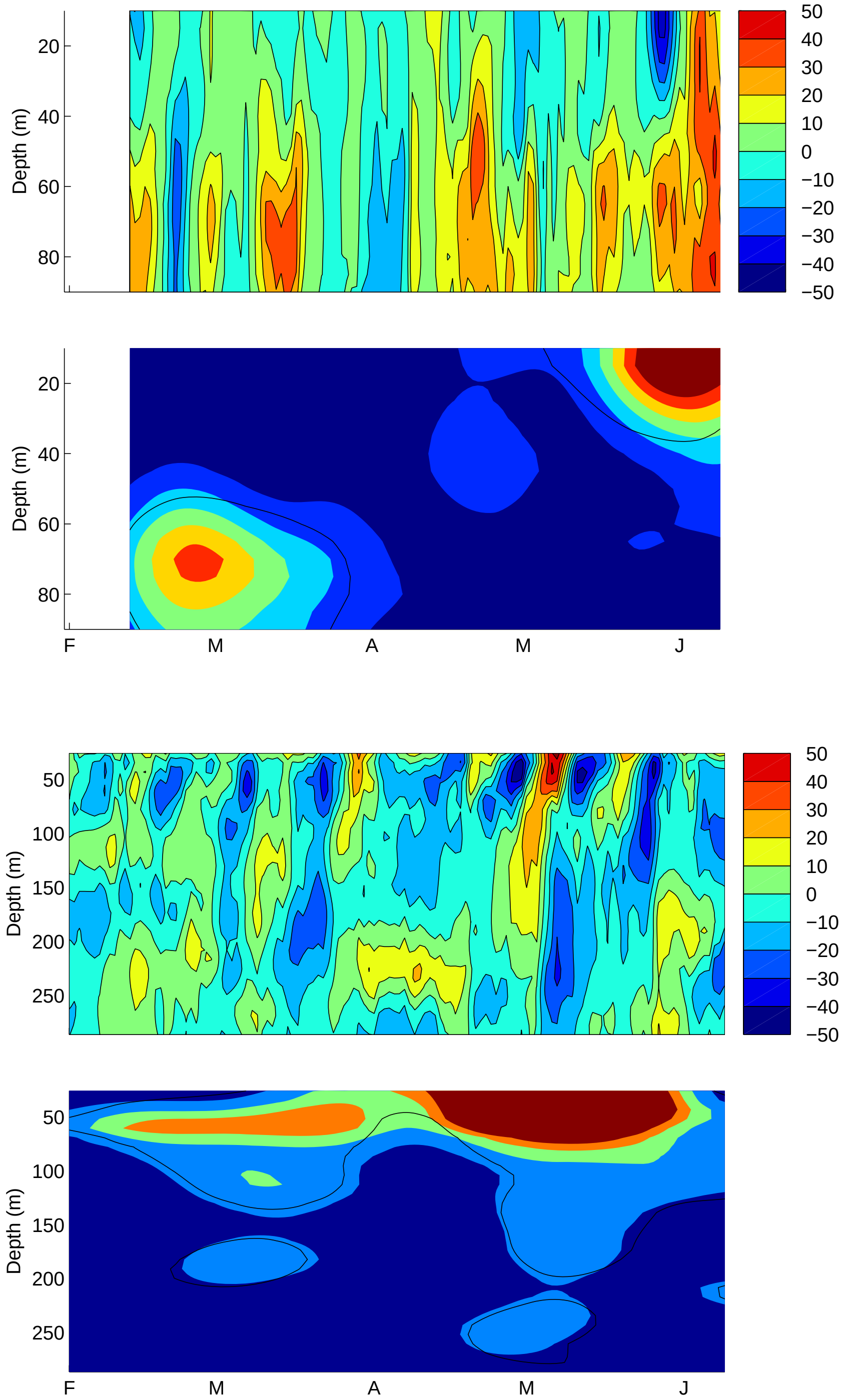

Figure 2: Meridional current-velocity component (in cm/s) during the 13-day-period fluctuations in the ADCP data at 23ºW (top panel) and 10ºW (middle-upper panel) and normalized wavelet energy of the meridional velocity component for the 12–15-day band for 23ºW (middle-lower panel) and 10ºW (bottom panel) ; the *black contour* indicates the 95% significance level. Roughly, from February to March the signal is subsurface intensified and from April to June the signal is surface intensified.

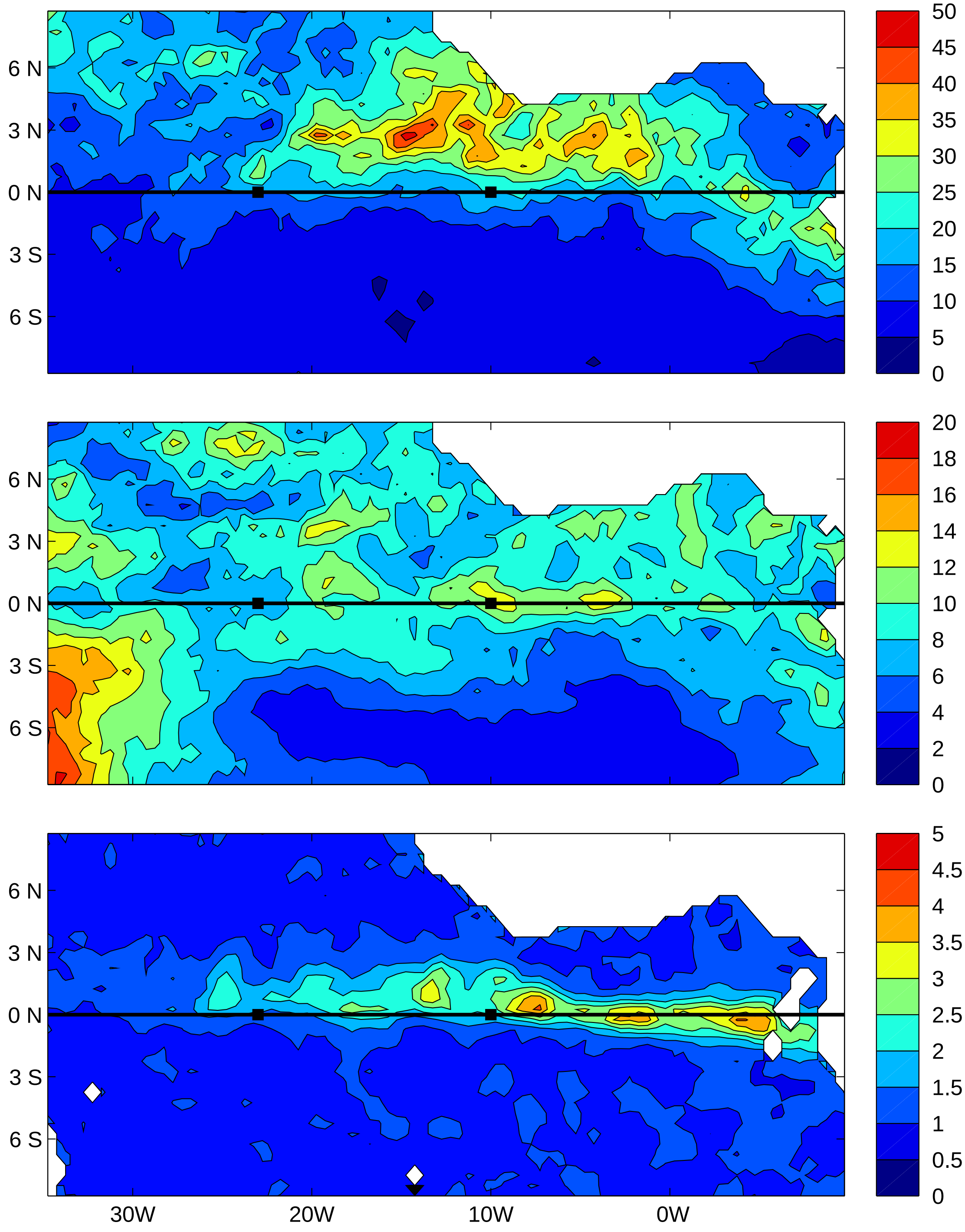

Figure 3: Variance over the year 2004, corresponding to the period band 11-15 days for the zonal and meridional wind velocity components (in m^2/s^2 - upper and middle panels respectively) and for the SST (in $ºC^2$ – lower panel).

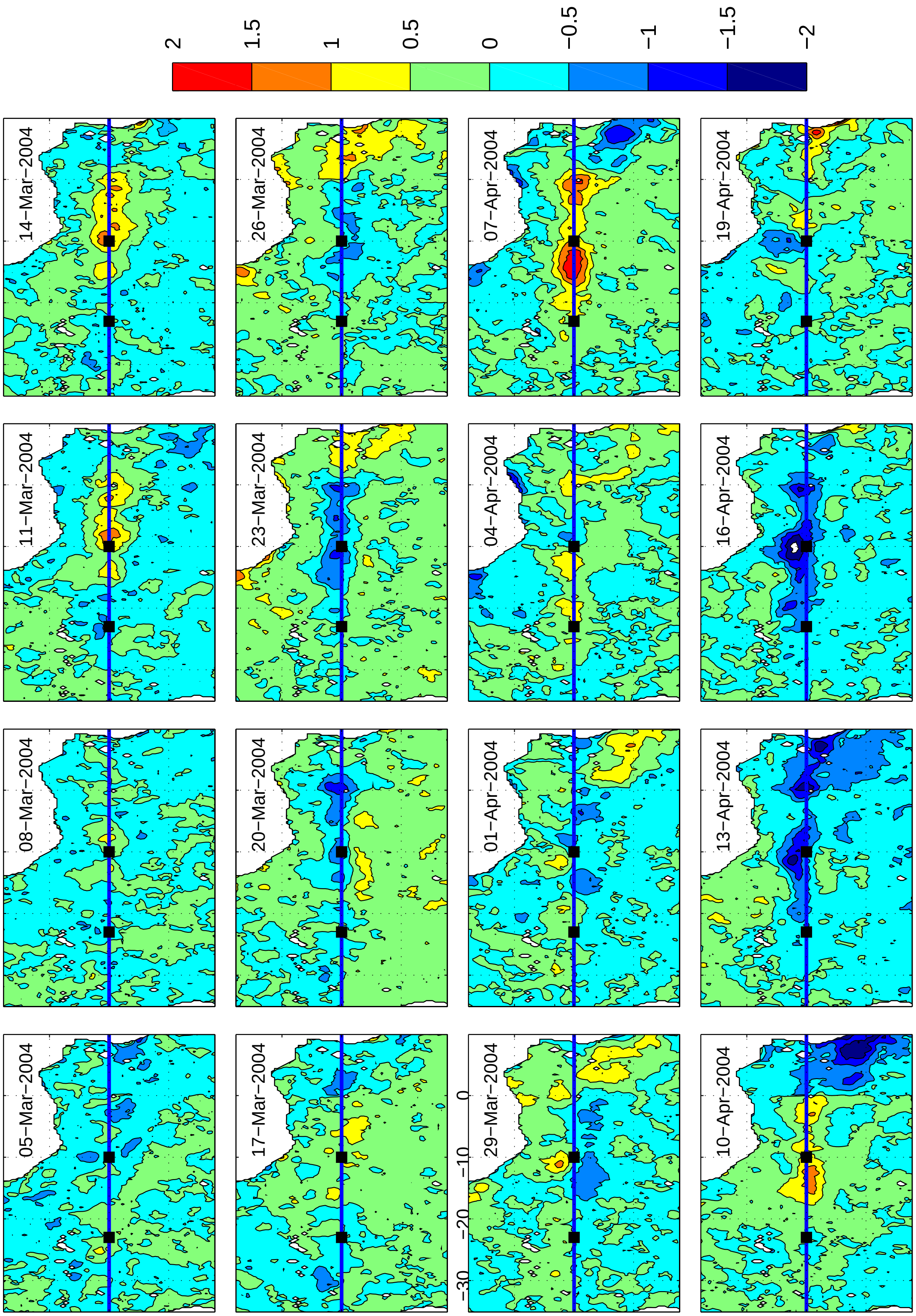

Figure 4: Snapshots of SST in spring 2004. Time series were filtered to retain variability in the 9 to 45 day period band.

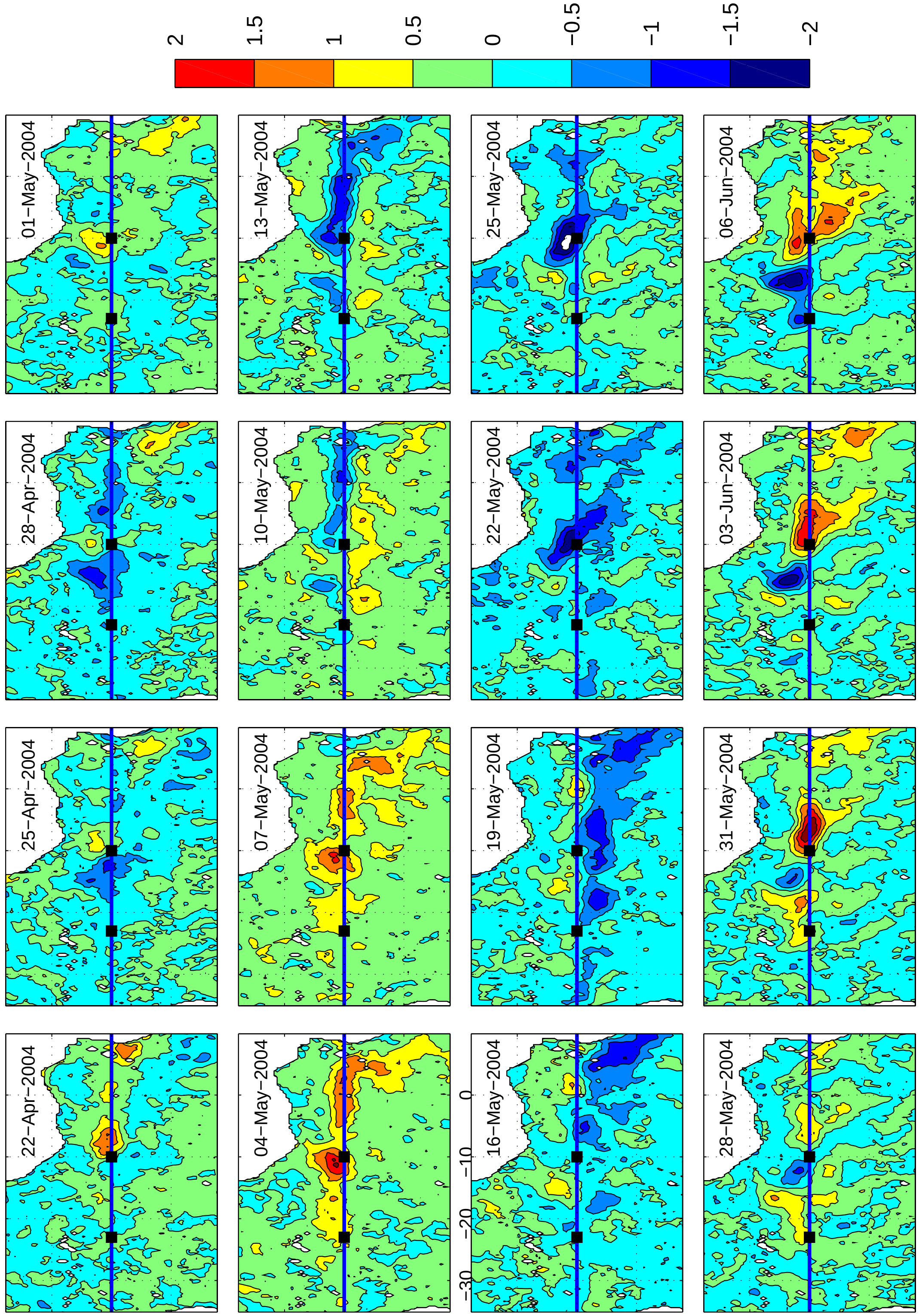

Figure 4: (continued).

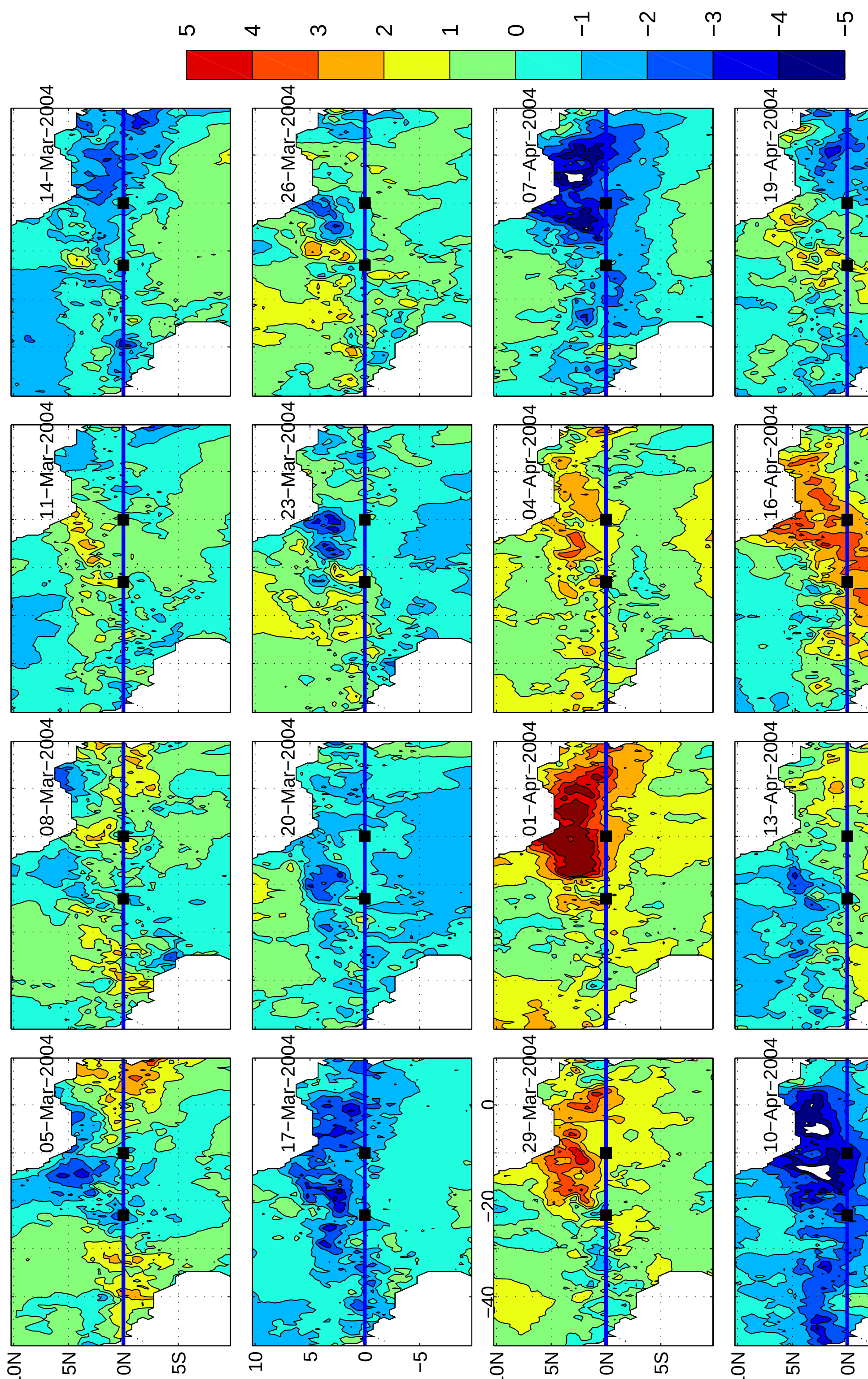

Figure 5: Snapshots of the zonal wind velocity component in spring 2004. Time series were filtered to retain variability in the 9 to 45 day period band.

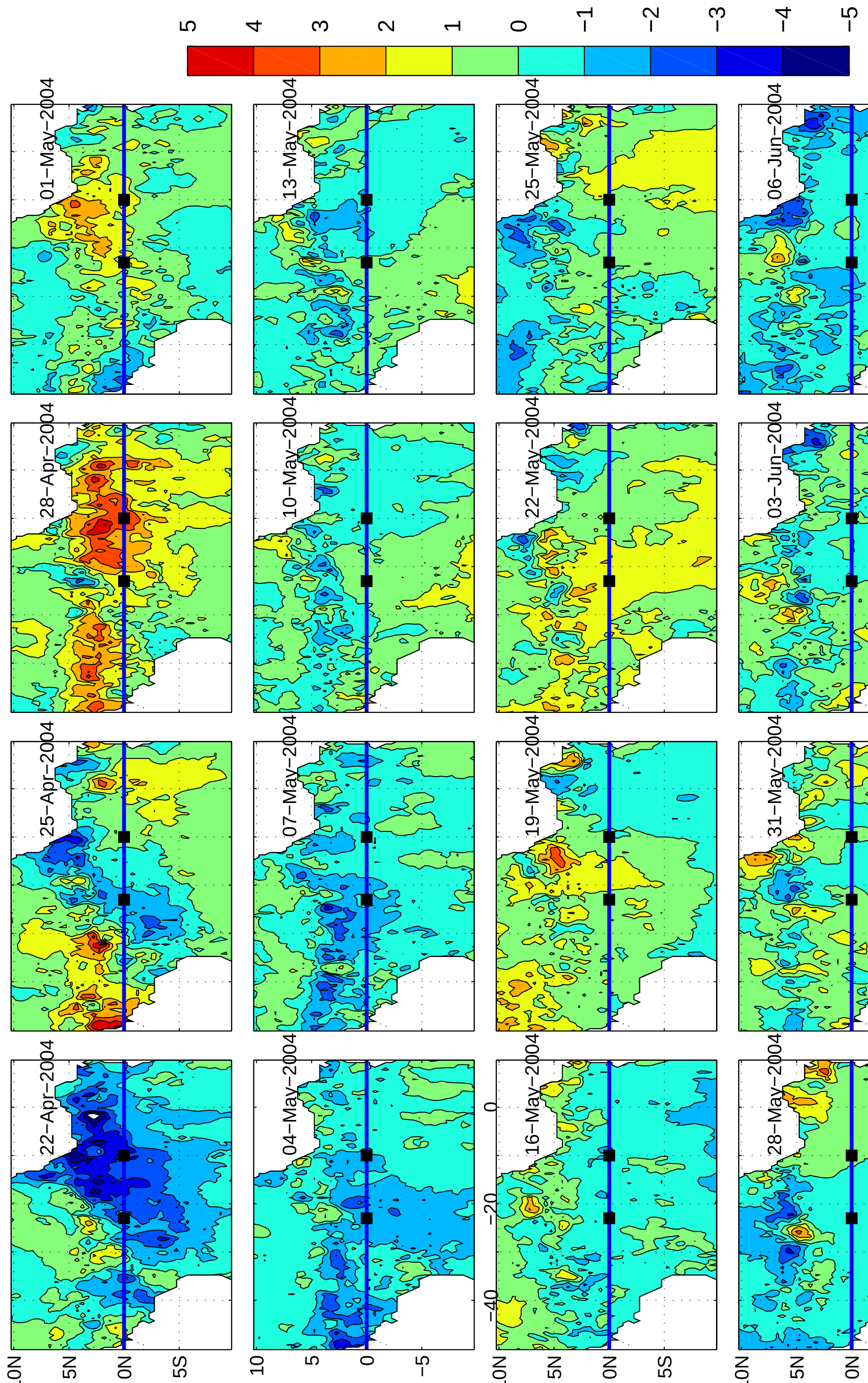

Figure 5: (continued).

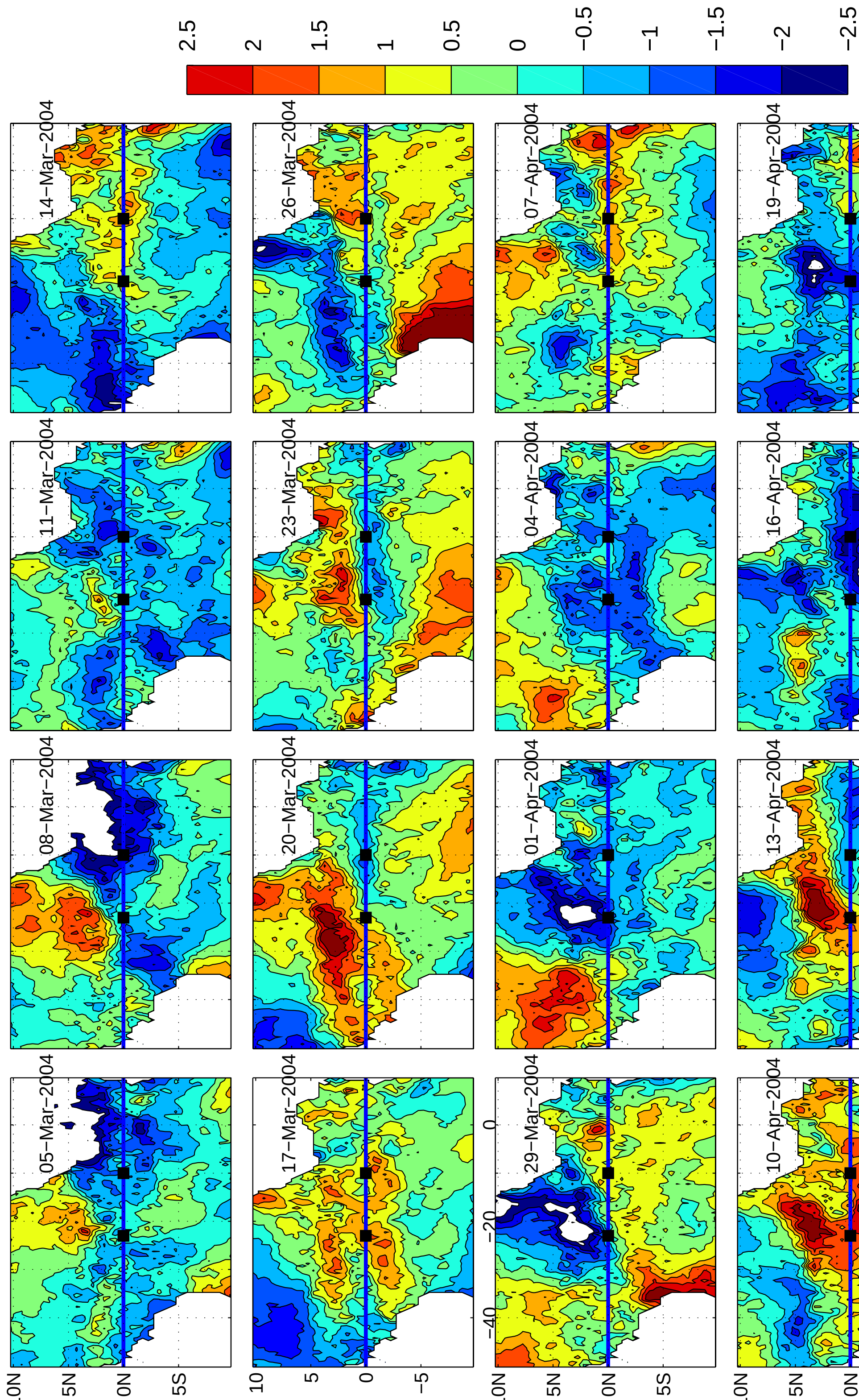

Figure 6: Snapshots of the meridional wind velocity component in spring 2004. Time series were filtered to retain variability in the 9 to 45 day period band.

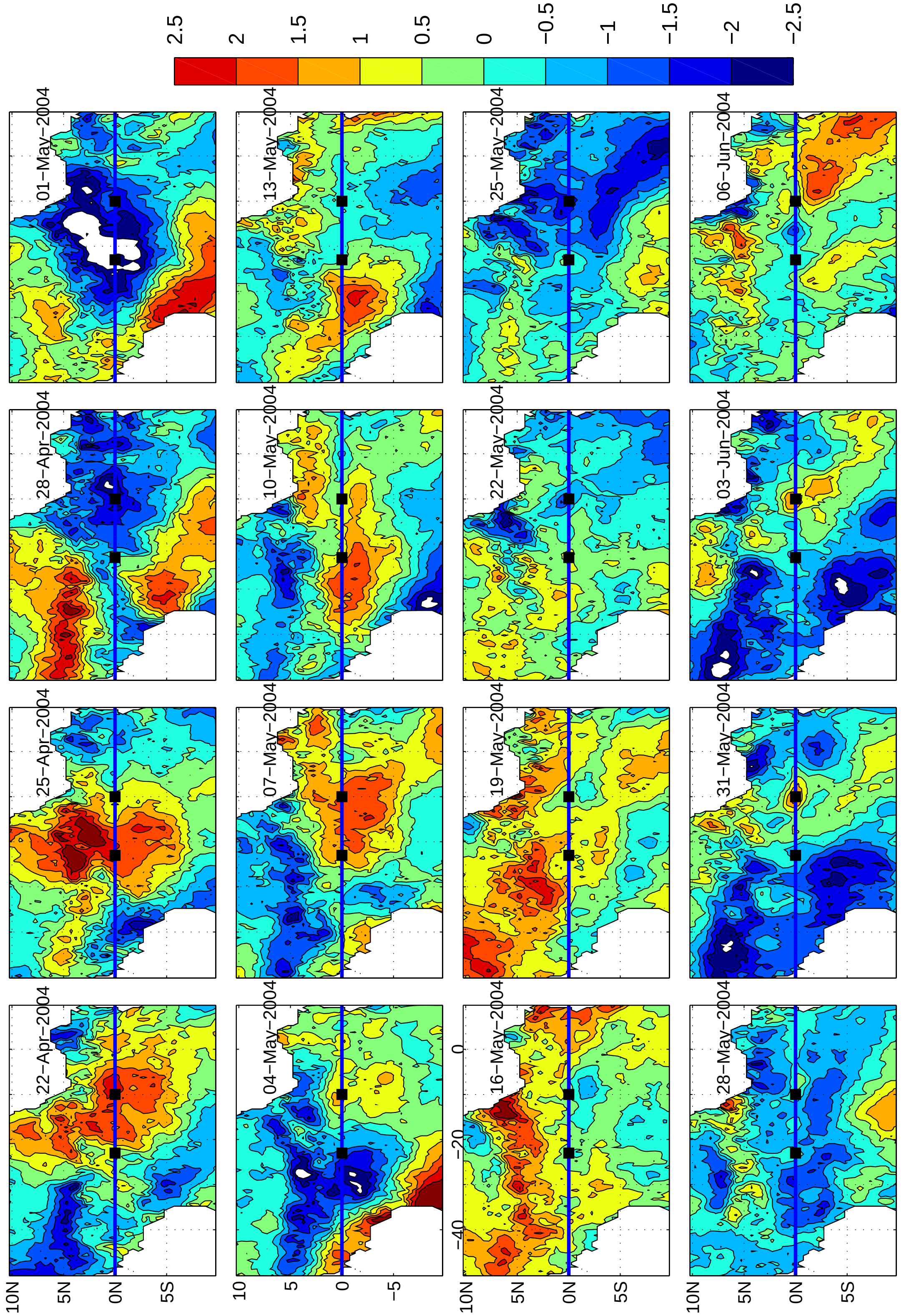

Figure 6: (continue).

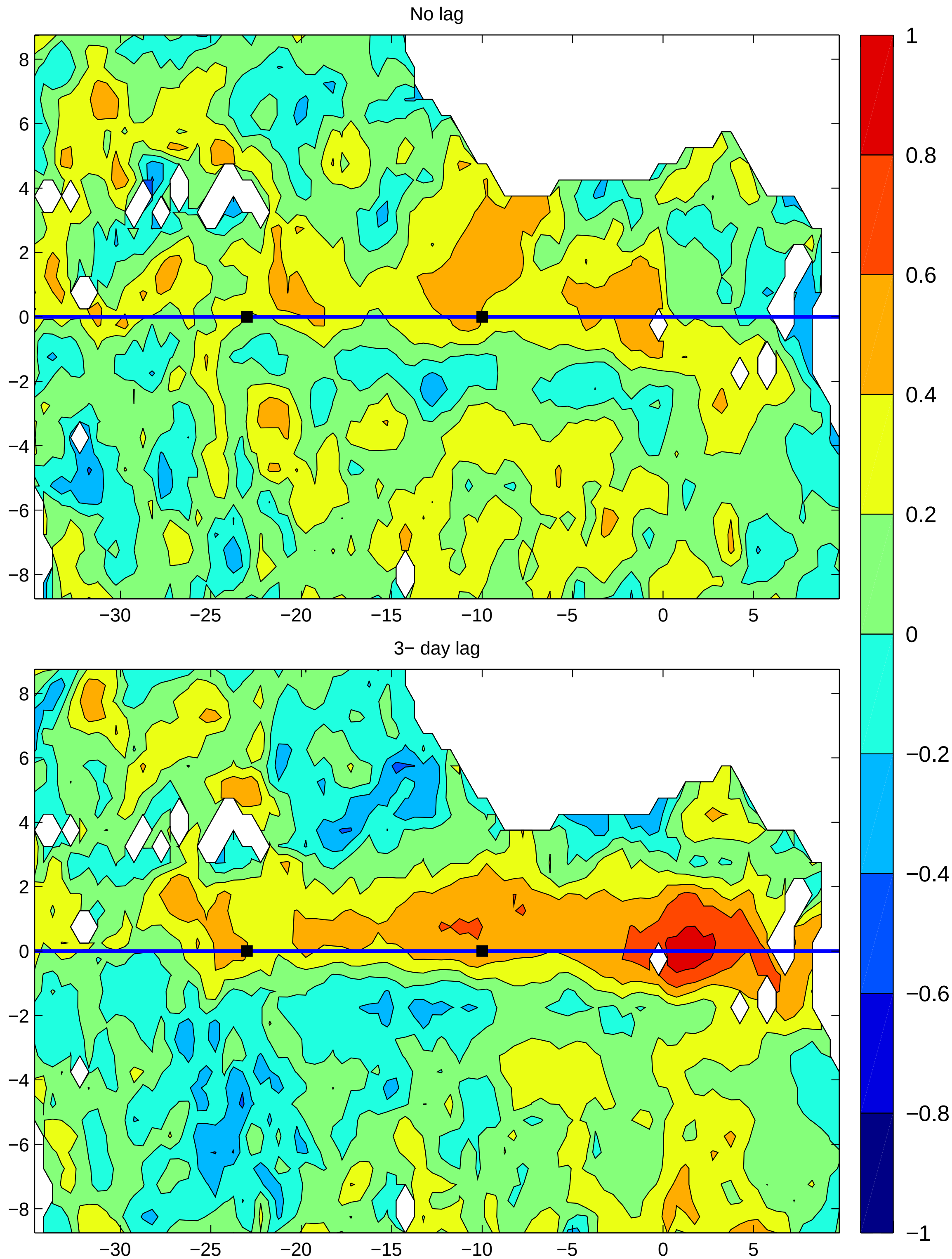

Figure 7: Correlation between 5-38 day band pass filtered SST time series and meridional current velocity at 26 m and 10ºW. The correlation was performed over 101-day time series around boreal spring 2004.

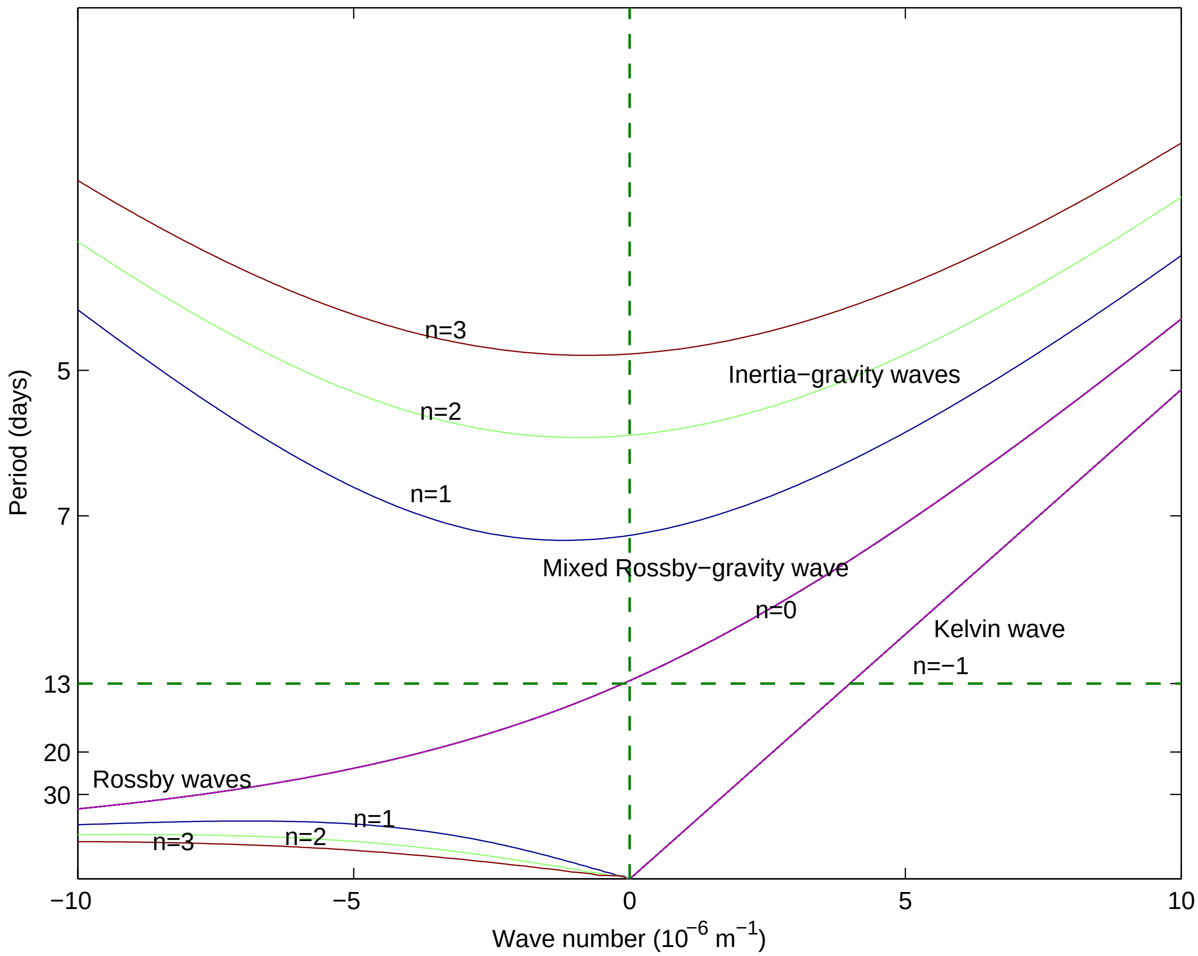

Figure 8: Dispersion relation for the second baroclinic mode with c_2=1.4 m/s (Philander 1990). The horizontal dotted line indicates the period at 13 days.

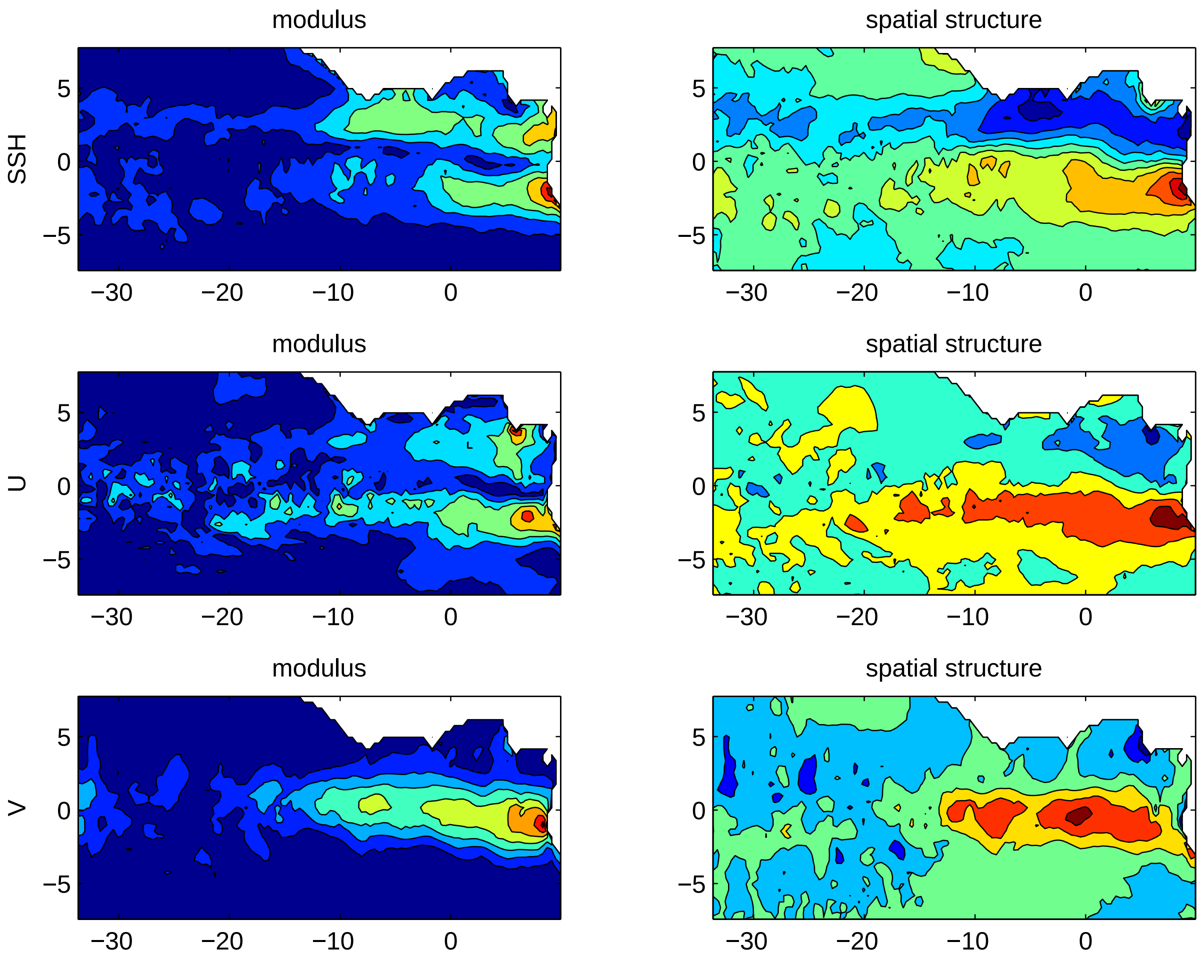

Figure 9: Modulus and spatial structure of the 13-day period oscillation in sea surface height (top pannels), zonal velocity component (middle panels) and meridional velocity component (bottom pannels). In the modulus panels yellow-red colors indicate regions of strong 13-day period activity. In the spatial structure panels, positive values are in red and negative values in blue. These results were obtained performing a polarization analysis over 8-years of MICOM data (see Park et al. 1987 for details on this method). Scales of the variables are missing but will be added in another version.