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## Variability in horizontal current velocities in the central and eastern equatorial Atlantic in 2002

Lucia Bunge,<sup>1,2</sup> Christine Provost,<sup>1</sup> and Annie Kartavtseff<sup>1</sup>

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[1] Near-surface current velocity data from the Pilot Research Moored Array in the Tropical Atlantic at 23°W in the year 2002 were re-examined and compared to simultaneous unpublished velocity data at 10°W, near the surface. Strong 7-day-period fluctuations were observed in the zonal velocity component and in temperature records at 23°W. The large temperature fluctuations near the thermocline depth suggest a vertical velocity component at the same 7-day period. The 7-day-period signals occurred in June/July simultaneously with the seasonal upwelling. The meridional velocity component presented similar spectral contents at 23°W and at 10°W. Two distinguishable quasiperiodic signals were observed in the meridional component at both locations: The first signal occurred in the spring, had a periodicity of about 14 days, was subsurface intensified, and had the characteristics of a mixed Rossby-gravity wave. The second signal occurred three times in the year (once in winter 2001–2002, another in summer, and another during fall 2002), had a periodicity of about 20 days, was strongest close to the surface, and was the result of the passage of tropical instability waves (TIWs). Satellite sea surface temperature (SST) data show the same periodicities as the meridional velocity records, and present a spatial structure in accordance with the TIW-SST signature. The summer of 2002 showed different TIW-SST patterns depending upon location, suggesting the existence of different types of TIWs. Overall, variability in the current meter data for the year 2002 was mainly due to current instabilities, except around boreal spring, where intraseasonal variability in surface winds was strongest.

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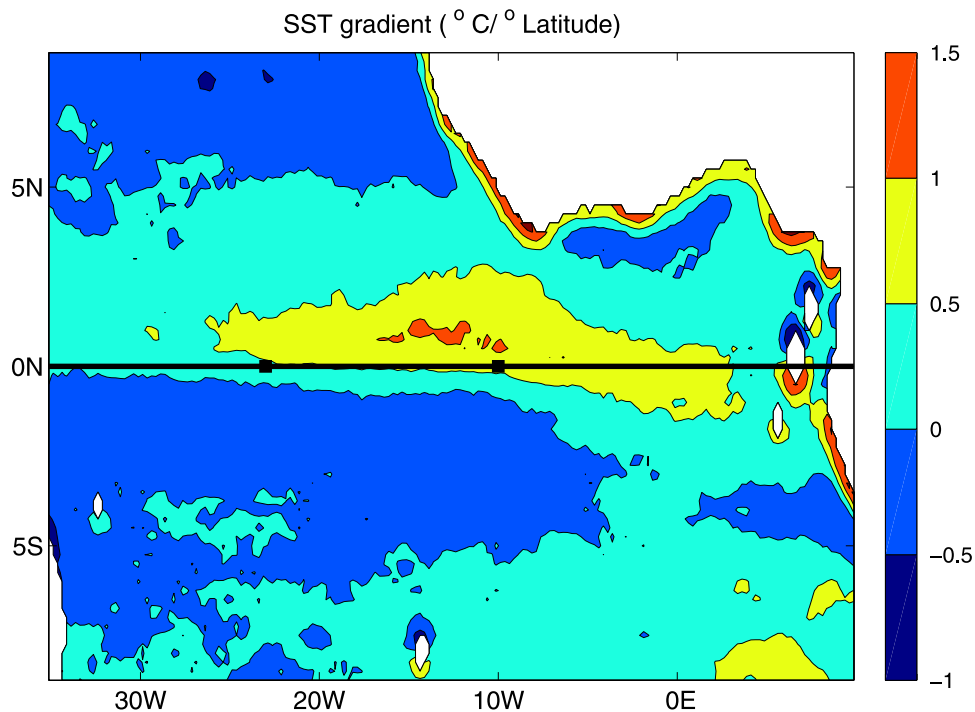
### 1. Introduction

[2] At intraseasonal timescales, velocity currents near the surface in the equatorial oceans are dominated by quasiperiodic fluctuations associated with the passage of equatorially trapped waves. During the FOCAL/SEQUAL experiment (1982–1984), ocean velocity time series were obtained at different locations in the equatorial Atlantic and allowed the documentation of propagating equatorially trapped waves, in particular of Tropical Instability Waves (TIWs) [Weisberg, 1984; Weisberg and Weingartner, 1988]. Since then, velocity observations at the equator in the Atlantic have been rather scarce and confined to single locations (e.g., 23°W in the work of Grodsky *et al.* [2005]; 23°W in the work of Brandt *et al.* [2006]; and 10°W in the work of Bunge *et al.* [2006]). In December 2001, within the Pilot Research Moored Array in the Tropical Atlantic (PIRATA) project (<http://www.brest.ird.fr/pirata/piratafr.html>), a mooring with an ADCP (Acoustic Doppler Current Profiler) was deployed near the surface at 23°W. Simultaneously, a Vector Averaging Current Meter (VACM) was deployed at 10°W by the French program PATOM (Programme Atmosphère et Océan Multi-échelles) at 154 m. The combined data set allows for comparisons of near-surface (upper 150 m) equatorial signals at two different locations, 10°W and 23°W during the year 2002.

[3] Most intraseasonal current velocity oscillations in the equatorial oceans are either wind forced or are the result of instabilities produced by the shear of zonal currents [Kessler, 2005]. In the eastern part of the basin, wind-forced oscillations having a 14-day period have been observed in near-surface oceanic records by Garzoli [1987], Houghton and Colin [1987], and Bunge *et al.* [2006]. In the last two papers, the structure of the oscillation was surmised to be a Rossby-gravity wave. In the atmosphere, the 14-day-period oscillation has been observed in both horizontal wind velocity components. The 14-day-period wind oscillations occurred during spring at the equator, when the Intertropical Convergence Zone (ITCZ) is at its most southern position. This is consistent with the work of Grodsky *et al.* [2003], who found a biweekly oscillation in the zonal wind component associated with a near-surface westerly jet close to

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**Figure 1.** Pilot Research Moored Array in the Tropical Atlantic (PIRATA)/Programme Atmosphère et Océan Multi-échelles (PATOM) mooring sites (solid squares) at 23°W and 10°W over a map of mean sea surface temperature (SST) gradient amplitude in 2002. The SST meridional gradient was estimated using satellite data described in section 2.

the African continent, which latitudinal position varied with the meridional migration of the ITCZ.

[4] The oscillations resulting from zonal current shears are the TIWs. In the Atlantic Ocean, these oscillations occur mainly in summer, along with the intensification of the South Equatorial Current (SEC), but they can also be seen in late fall [e.g., *Caltabiano et al.*, 2005]. They have central periodicities of 25 days, zonal scales of around 1100 km, phase speed of around 0.5 m/s and are strongest in the center of the Atlantic basin [*Weisberg and Weingartner*, 1988]. Their eastward limit is however not well established. Some observations suggest their presence as east as 4°W [*Weisberg et al.*, 1979], but east of 10°W, the waves have been observed to have shorter zonal scales (~600 km) and smaller meridional displacements, and to be more transient [*Legeckis and Reverdin*, 1987]. These differences in TIWs spatial-structure suggest the possibility of distinct TIWs depending on the region. In the Pacific Ocean, where TIWs have been most studied, different regions of TIW energy transfer have been detected [*Luther and Johnson*, 1990]. Furthermore, *Lyman et al.* [2007] found two distinct TIWs presenting different periods, cross-equatorial structure, and dynamics. The first wave is better represented on meridional velocity measurements near the equator, has a central periodicity of 17 days, and a mixed Rossby-gravity wave/surface trapped instability structure. The second wave has a strong signature on subsurface temperature data at 5°N, presents a central periodicity of 33 days, and has the structure of an unstable first meridional mode Rossby wave.

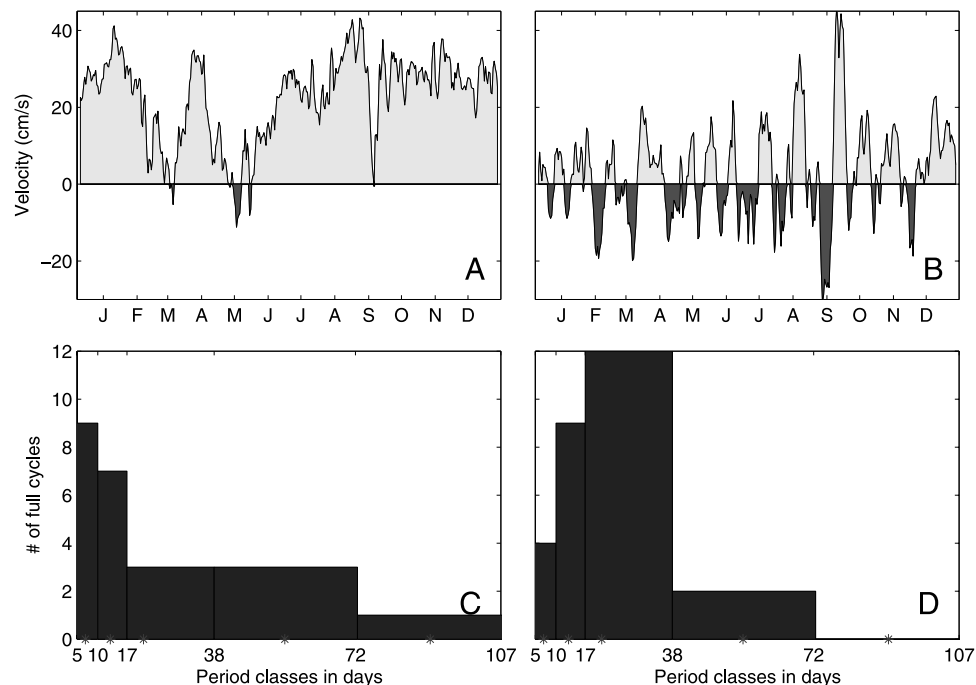
[5] The purpose of the present study is to further describe the intraseasonal variability (5 to 107-day period) in the

Atlantic of near-surface (upper 150 m) equatorial signals, by analyzing simultaneously velocity data from two different locations, 10°W and 23°W, together with satellite sea surface temperature (SST) and scatterometer surface wind velocity data. Since the FOCAL/SEQUAL years, satellite observations have improved with the development of microwave radiometry, which permits measurements of SST through clouds, and surface wind velocity measurements. Satellite data bring information about the spatial structures of some velocity oscillations, their eventual propagation, their origin and fate, and therefore were useful to support the analysis of the current-velocity observations. Because the data clearly contain quasiperiodic fluctuations that may be modulated in time or may occur only in certain portions of a time series, we used a wavelet-based technique to isolate and extract the signals of interest.

[6] The present paper is organized as follows: section 2 presents the data and data analysis; section 3 describes the near-surface velocity variability and compares it to signatures in SST; and the concluding section discusses and synthesizes the results.

## 2. Data and Data Analysis

[7] Horizontal current-velocity data were obtained between December 2001 and December 2002 from two moorings in the equatorial Atlantic, one at 0°N, 23°W, the other at 0°N, 10°W (Figure 1). At 23°W, a PIRATA acoustic Doppler current profiler (ADCP, Workhorse Sentinel 300 kHz; 4-m cell size and time step of 1 hour) sampled the upper 120 m of the water column [see *Grodsky et al.*,



**Figure 2.** Current-velocity data at  $10^{\circ}\text{W}$ . (a) Vector Averaging Current Meter (VACM) zonal velocity component. (b) VACM meridional velocity component; the depth of the VACM was 154 m. (c) Histogram showing the approximate number of full cycles in each period class for the zonal velocity components of the VACM at 154 m depth. (d) Histogram showing the approximate number of full cycles in each period class for the meridional velocity components of the VACM at 154 m depth.

2005, Figure 1], and at  $10^{\circ}\text{W}$ , a PATOM VACM sampled the horizontal velocity at around 154 m (Figure 2). Besides the velocity data, simultaneous temperature and salinity data from the upper 120 m of the water column were obtained from the PIRATA buoy at  $23^{\circ}\text{W}$  [see Grodsky *et al.*, 2005, Figure 1], but these data were not available at  $10^{\circ}\text{W}$  in 2002.

[8] The Vector Averaging Current Meter (VACM; Figure 2) was calibrated at the Institut Français de Recherche pour l'Exploitation de la Mer (Ifremer) for velocity and pressure; details of the data calibration and validation can be found in the work of Kartavtseff [2003]. The hourly data were averaged over 25 hours to remove tidal frequencies and resampled to provide daily resolution. Table 1 shows the location, depth, and duration of the time series.

[9] Data were analyzed using the wavelet-based technique described by Bunge *et al.* [2006]. This technique isolates significant “ridges” (regions in the wavelet transform with high amplitudes and relatively long duration), and thus the time-varying period of the main components. (Software tools for this analysis can be found at <http://www.jmlilly.net/jmlsoft.html>.)

[10] Once the main components of the signals were extracted, they were classified in period classes. The period range we observed was from 5 to 107 days. The period classes were chosen taking into account other equatorial Atlantic observations [e.g., Garzoli, 1987] but also emphasizing that the main components found in these data would be represented by one of these classes. Those classes are: 5 to 10, 10 to 17, 17 to 38, 38 to 72 and 72 to 107 days. Figures 2 and 3 display the number of oscillations for each period band in each time series. The zonal component

showed little quasiperiodic oscillations, except at  $23^{\circ}\text{W}$ , where 5- to 7-day-period oscillations were seen in the upper 120 m. The meridional velocity component was dominated by 10- to 17- and 17- to 38-day-period oscillations at both locations. Temperature time series showed similar variability as the zonal velocity component while the salinity time series was well correlated with the meridional motions (Figure 3). For all in situ data, there were no quasiperiodic fluctuations in the periods between 38 and 107 days.

[11] In order to document the spatial structures associated with the observed velocity fluctuations, Tropical Rainfall Measuring Mission (TRMM) – Microwave Imager (TMI) SST data were examined over the region between  $9^{\circ}\text{S}$  and  $9^{\circ}\text{N}$ , and  $35^{\circ}\text{W}$  and  $10^{\circ}\text{E}$  during 2002 (Figure 1). This SST product is the result of an optimal interpolation with a temporal and a spatial resolution of 1 day and of  $0.25^{\circ}$ , respectively (<http://www.remss.com/sst>). Surface wind horizontal velocities were also explored using a daily QuikSCAT product with horizontal resolution of  $1/2^{\circ}$  which is available at [www.ifremer.fr/cersat/en/data/overview/gridded/mwfsqcat.htm](http://www.ifremer.fr/cersat/en/data/overview/gridded/mwfsqcat.htm). SST and wind velocity time series were filtered using a digital Butterworth band-pass filter to retain signals with periods in the band of 5–38 days, which is the period band in which all quasiperiodic oscillations in the current-velocity time series were found.

### 3. Near-Surface (Upper 200 m) Variability

#### 3.1. In Situ Measurements

[12] The zonal velocity component had few quasiperiodic signals in the intraseasonal timescales when compared to the meridional component. At  $23^{\circ}\text{W}$ , the zonal velocity

**Table 1.** Location, Depth, and Number of Days of Data From the Current Meters on the PIRATA and PATOM Moorings<sup>a</sup>

Location	Depth	Date of Start	Date of End	Days of Worth Data
23°W	ADCP (12–120 m)	13 Dec 2001	21 Dec 2002	372
10°W	154 m	11 Dec 2001	29 Dec 2002	383

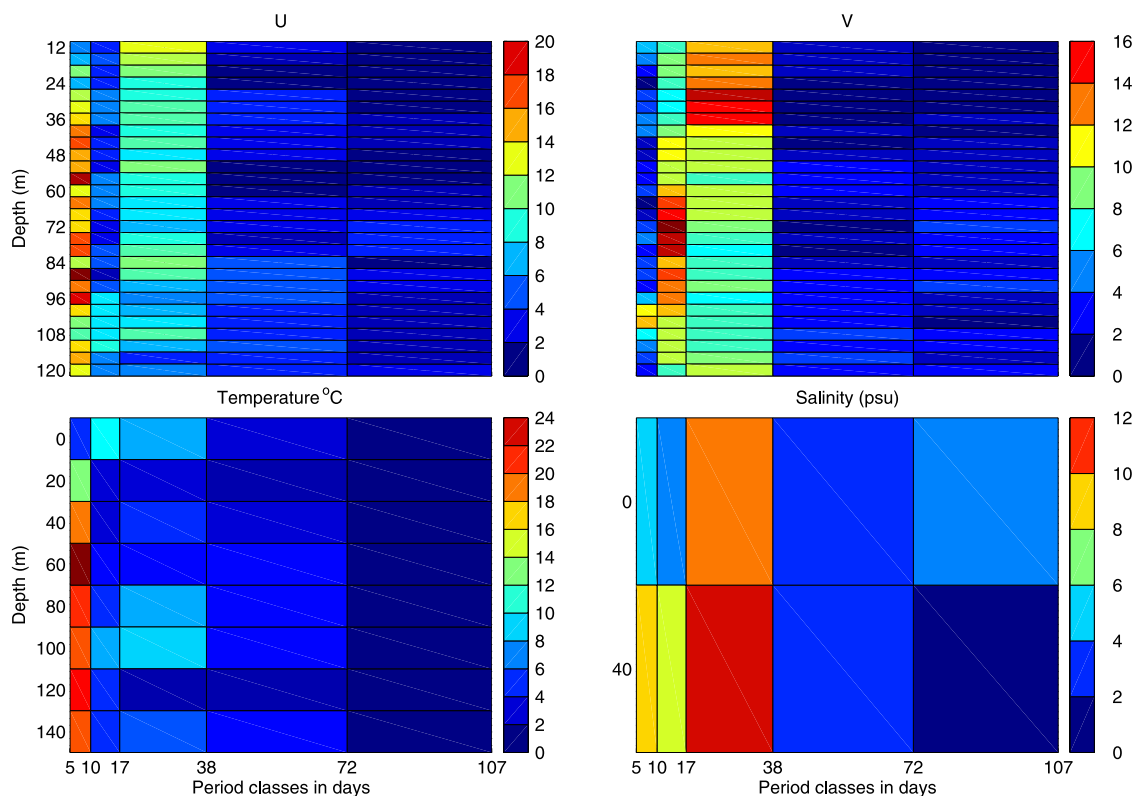
<sup>a</sup>PIRATA, Pilot Research Moored Array in the Tropical Atlantic; PATOM, Programme Atmosphère et Océan Multi-échelles; ADCP, Acoustic Doppler Current Profiler.

component exhibited 20- to 30-day-period oscillations in the mixed layer related to TIWs as described by *Grodsky et al.* [2005], and fluctuations with a periodicity of approximately 7 days (Figure 3, top left, period class of 5–10 days). The 7-day signal also had a signature in the temperature record (Figure 3, bottom left). During June and July and at around 60 m depth, close to the thermocline depth, the amplitudes of these 7-day fluctuations reached 25 cm/s in velocity and 2.5°C in temperature. An increase (decrease) in temperature was associated with a westward (eastward) velocity. Since the strong fluctuations in temperature cannot be surmised to the zonal displacements alone, and since the strongest temperature fluctuations are seen at the thermocline depth, a vertical velocity component at this period must exist. In the record at 10°W and at 154 m depth, no meaningful 7-day oscillations were observed. During year 2000, intermittent packets of 7-day-period oscillations were observed in the zonal velocity component at 10°W and at 30 m depth [*Bunge et al.*, 2006].

[13] In the meridional component, fluctuations at 23°W near the surface showed strong similarities with fluctuations

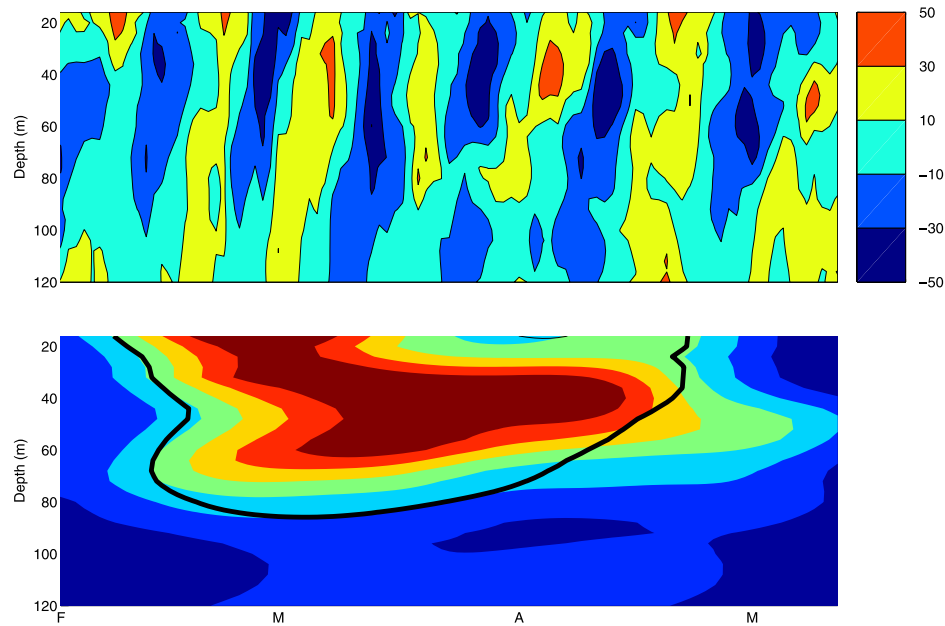
observed at 154 m depth at 10°W. There were two distinguishable signals; the first one had a period of approximately 14 days (period class 10–17 days), it started in mid-February and persisted till the end of April 2002, and was not described in the previous papers using these data [*Provost et al.*, 2004; *Grodsky et al.*, 2005; *Giarolla et al.*, 2005]. The second and strongest one had a periodicity of 20–30 days, occurred principally in summer, where it had been associated with the passage of TIWs [*Grodsky et al.*, 2005], but was also observed in December 2001–January 2002 and around November 2002.

[14] The 14-day-period signal was coherent in the meridional component throughout the upper 120 m and was also observed in the salinity records for the surface and for the mixed layer (Figure 3, right top and bottom). Maximum meridional velocity amplitudes associated with the 14-day-period fluctuations were found at around 40 m depth, with values of up to 0.45 m/s. There was a time lag of approximately 5 days between fluctuations at 120 m and at 16 m depths, with the former preceding the latter (Figure 4; top panel), implying upward phase propagation.



**Figure 3.** Histograms showing the approximate number of full cycles of each period class, for every measured depth for the different variables measured near the surface at 23°W. (top left) Zonal velocity component. (top right) Meridional velocity component. (bottom left) Temperature at levels 0, 20, 40, 60, 80, 100, 120, and 140 m. Series at 20, 60, and 120 had gaps. (bottom right) Salinity at levels 0 and 40 m.





**Figure 4.** (top) Meridional current-velocity component (in cm/s) during the 14-day-period fluctuations in the Acoustic Doppler Current Profiler (ADCP) data at 23°W; upward phase propagation is evident. (bottom) Normalized wavelet energy of the meridional velocity component for the 12 to 15-day band. The black contour indicates the 95% significance level; downward energy radiation is observed.

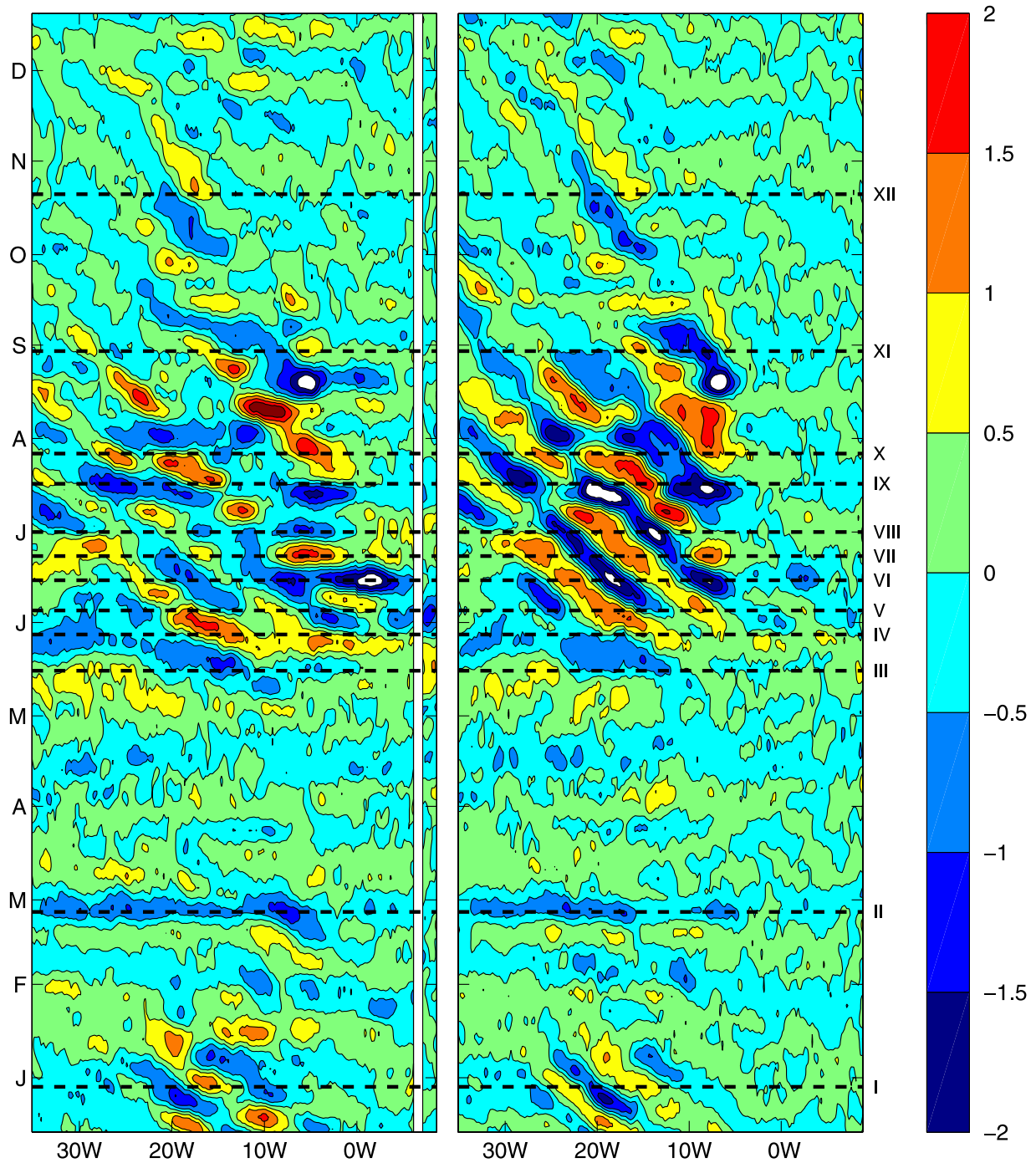
The energy of the signal in the upper 50 m of the water column showed downward radiation (Figure 4; bottom panel). At 10°W, 14-day-period fluctuations were roughly in phase with those at 23°W and 120 m. However, one has to be cautious when comparing phases since the two time series were at different depths and on different isopycnal surfaces. The 14-day signal was consistent with a surface-forced mixed Rossby-gravity wave of vertical mode one or two because of (1) its 14-day period, (2) lack of variability at that period in the zonal component, (3) upward phase propagation and downward energy radiation, and (4) an apparent long zonal scale.

[15] TIWs signatures were observed at both locations during the summer. As for the 14-day-period oscillations, the vertical structure of the TIWs presented a phase shift of approximately 5 days between fluctuations at 120 m and at 16 m depths showing upward phase propagation. Zonally, one cannot relate individual TIW-induced fluctuations at 10°W to fluctuations at 23°W with in situ velocity measurements at only these two locations. The reason is that TIWs are generated around 17°W [Jochum *et al.*, 2004], and akin westward propagating mixed Rossby-gravity waves, the phase velocity propagates westward while the group velocity propagates eastward. TIW-induced fluctuations can thus be observed at 10°W only if the energy has propagated enough to the east. Such propagation can, however, easily be documented and tracked with SST data, as shown in section 3.2.

### 3.2. Comparison to Satellite SST

[16] TIWs have a strong SST signature and can be easily detected with satellite data. The large spatial and temporal coverage of satellite SST data sets permits to follow the time

evolution of SST anomalies and examine their spatial structure. Figure 5 shows two Hovmöller diagrams of filtered SST data at latitude 0.125°N and 1.125°N which describe the time evolution of the SST anomalies. The spatial distribution of the maximum SST gradient is such that, west of 10°W, it is zonal at ~1°N and that, east of 10°W, it is tilted across the equator toward the southeast (Figure 1). This implies that variability due to the TIWs in the center of the basin is highly visible in the Hovmöller diagram at 1.125°N while variability taking place in the east of the basin is better illustrated in the Hovmöller diagram at 0.125°N. Both Hovmöller diagrams show TIW-like westward propagating anomalies during December 2001 and January 2002, with a periodicity of 20–30 days and phase propagation of about 0.5 m/s. Between February and beginning of May 2002, basin-scale anomalies showing no propagation and relatively small SST amplitudes were observed. Then, in May, just before the TIW season, eastward propagating anomalies were seen in the west of the basin (Figure 5). The time period between June and August presented the strongest SST signals. West of 10°W, there was the unmistakable signature of TIWs. The Hovmöller diagram at 1.125°N shows the westward phase velocity of TIWs and their eastward energy radiation. TIW events are seen to have originated around 18°W in early June, and as the energy radiated eastward, their signatures reached 10°W in mid-June. East of 10°W, however, the SST anomalies showed no zonal propagation (Figure 5, left panel). These eastern features could also be the result of instabilities; however, since they present no zonal propagation, they are different from the well-known westward propagating TIWs. Both Hovmöller diagrams show westward propagating anomalies from June to mid-

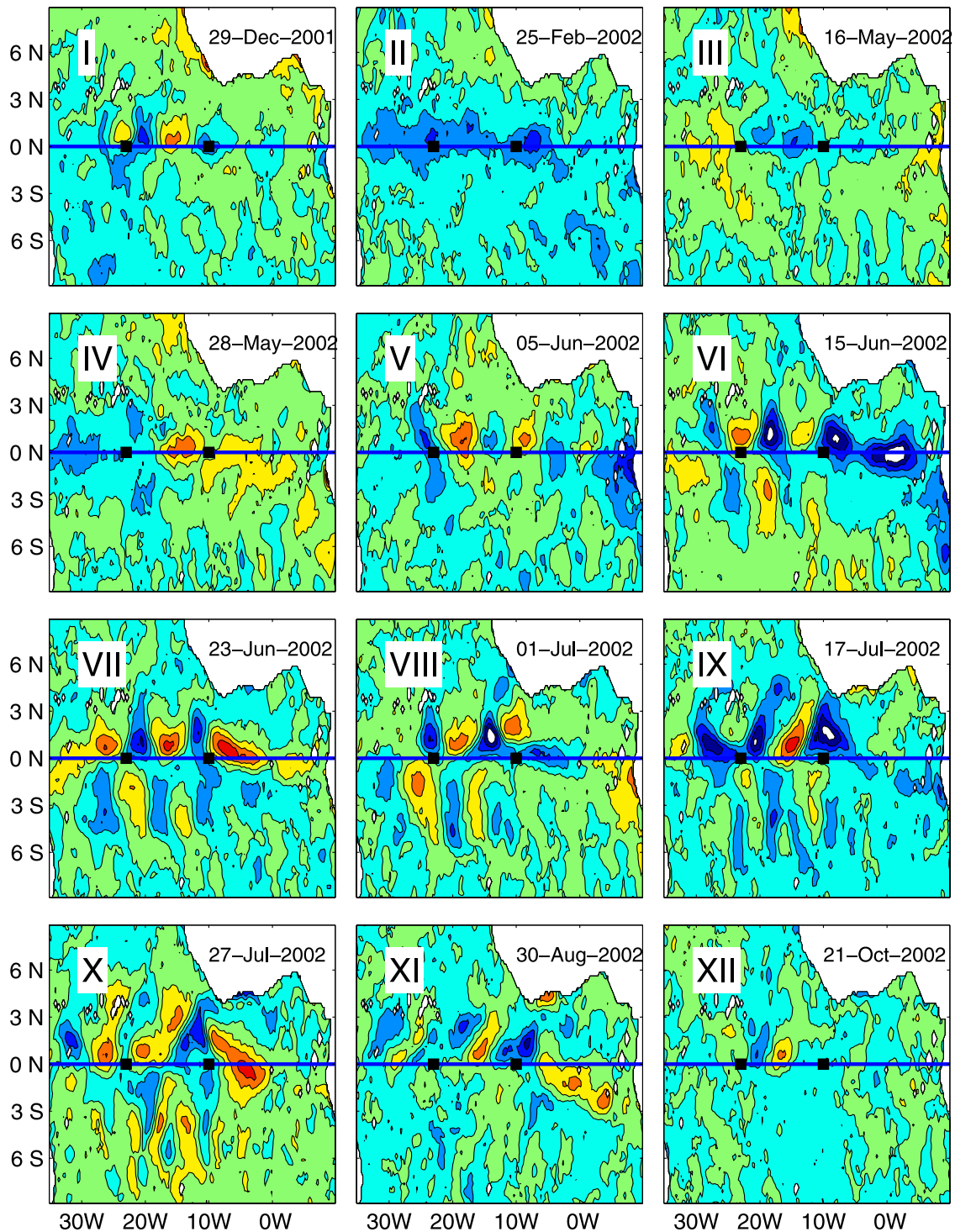


**Figure 5.** Two SST Hovmöller diagrams at latitudes (left)  $0.125^{\circ}\text{N}$  and (right)  $1.125^{\circ}\text{N}$ . SST data have been band-pass filtered to retain variability in the 5- to 38-day-period band. The temperature scale is in degrees Celsius, the months on the y axis correspond to the first day of each month, and the roman numbers on the right indicate the time for the snapshots in Figure 6.

July in the center of the basin. Afterward, the  $1.125^{\circ}\text{N}$  diagram shows a discontinuity in the propagation pattern of the SST anomalies and the  $0.125^{\circ}\text{N}$  diagram shows anomalies which propagated much slower than they initially did. A possible explanation for such changes in the TIW propagating patterns is the coexistence of two different signals at the same time, as it will be discussed in section 4. Later, during October and November, westward propagating TIW-like anomalies were observed again.

[17] In summary, the SST Hovmöller diagrams show westward propagating anomalies with TIWs characteristics at  $23^{\circ}\text{W}$  during most of the year, except from February to May when the SST anomalies showed no propagation and large zonal scales. In the eastern part of the basin, the SST anomalies did not propagate.

[18] The spatial structures of the SST anomalies detected in the Hovmöller diagrams are shown in the 12 panels of Figure 6. Panel I illustrates the TIW-like features that occur



**Figure 6.** Filtered SST snapshots visualizing the spatial structure of some of the SST anomalies detected in the Hovmoller diagrams presented in Figure 5. The roman numbers correspond to the marks on the time line in Figure 5. For the color code, see the color bar in Figure 5.



at the end of December 2001 and beginning of January 2002. During that period, a train of at least three alternate-sign SST anomalies centered at about  $1^{\circ}\text{N}$  and presenting zonal scales comparable to those of TIWs was observed. The panels II and III (corresponding to February 25 and May 16, 2002) show an example of the nonpropagating large-scale features detected in Figure 5. The transition from basin-scale anomalies to TIWs is illustrated by the panels IV and V: on May 28, two opposite-sign anomalies were situated at the equator and by 5 June, the SST anomalies from the Northern Hemisphere began to show smaller zonal scales. The SST snapshot of 15 June (panel VI) shows well-developed TIWs. West of  $10^{\circ}\text{W}$ , the SST anomalies exhibit zonal wavelengths of approximately 1100 km and an antisymmetric phase structure about the equator, both characteristic of TIWs [e.g., *Weisberg and Weingartner*, 1988; *Chelton et al.*, 2000]. The TIW-SST signal was strongest by 23 June (panel VII). East of  $10^{\circ}\text{W}$ , however, the temperature anomalies are very different, presenting similar periodicities but at larger zonal scales than the SST anomalies west of  $10^{\circ}\text{W}$  (panels VI, VII, and VIII). Around 17 July (panel IX), the antisymmetric structure about the equator of the TIWs became disorganized: in the southern SST anomalies, at about  $4^{\circ}\text{S}$ , there was a partition of the zonal scale leading to a new zonal scale of roughly 500 km (panels IX and X). In the Northern Hemisphere, the SST anomalies are no longer round-shaped, as it is the case on the 27 July snapshot (panel X). By the end of August (panel XI), the TIW season, as represented in the SST snapshots, was over. Later, in October and November 2002, SST anomalies with the characteristics of TIW were, however, again observed around  $18^{\circ}\text{W}$  (panel XII).

[19] The variability in the satellite SST series at  $10^{\circ}\text{W}$  and  $23^{\circ}\text{W}$  (Figure 7) does show similarities to that of the meridional velocity data fluctuations. This is especially true for TIW events at  $23^{\circ}\text{W}$  (Figure 7b). At  $23^{\circ}\text{W}$ , there is a time lag between the SST and the meridional velocity records at 16 m depth, with the SST leading by 5–10 days, depending on the particular TIW event (Figure 7b). There is, however, no phase lag between the SST and the meridional velocity at 120 m (not illustrated). This is not surprising considering that the phase propagation of the meridional velocity component is upward with the TIW signal in the meridional velocity component at 120 m depth happening to be in phase with the TIW-SST signal. Similarly, at  $10^{\circ}\text{W}$ , there is also no time lag between SST-TIW events and the 154 m depth velocity time series (Figure 7a).

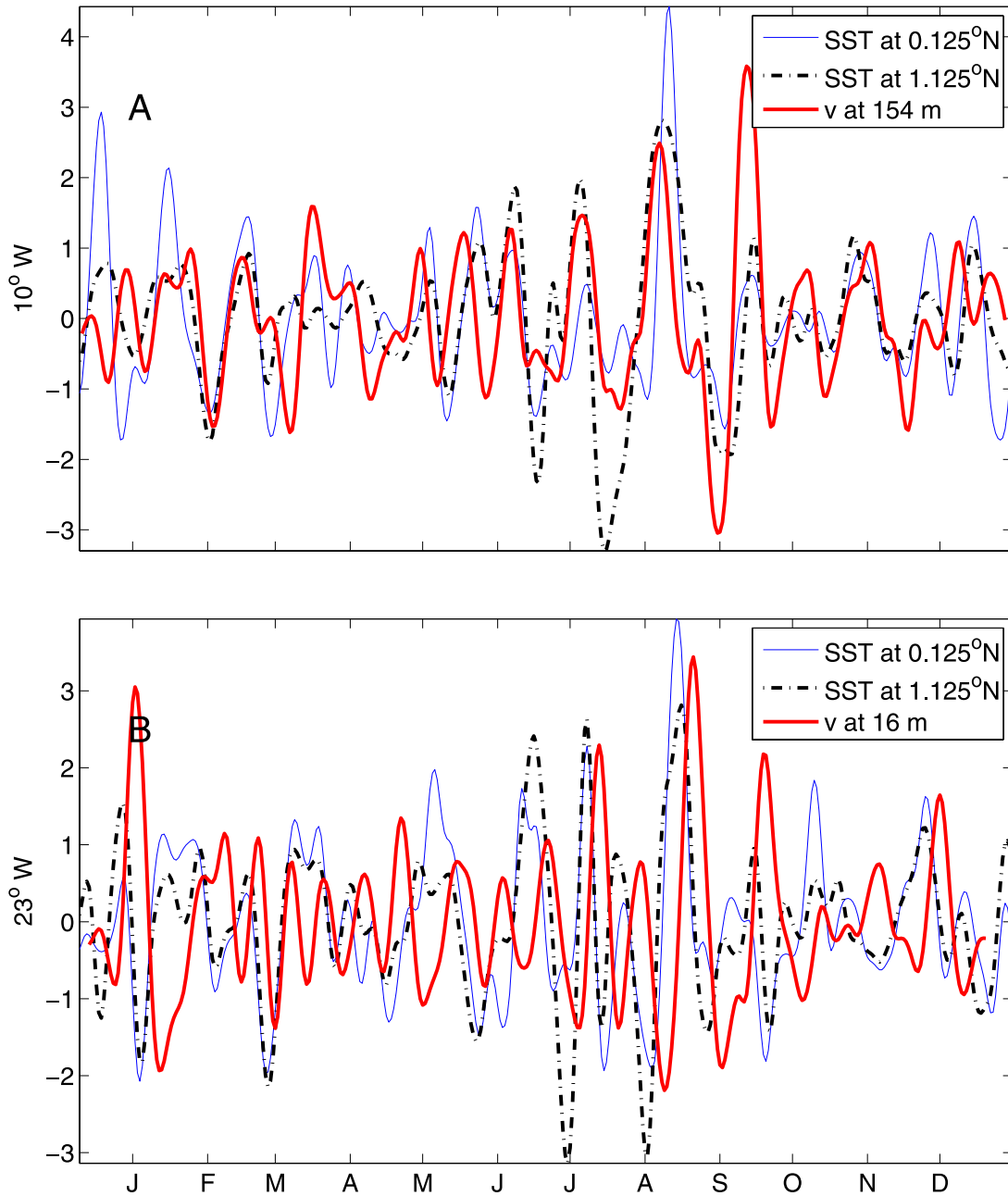
#### 4. Discussion and Conclusions

[20] In the near-surface velocity data set at  $10^{\circ}\text{W}$  and  $23^{\circ}\text{W}$ , signals at subseasonal timescales are less conspicuous in the zonal component than in the meridional component. There is, however, one exception at  $23^{\circ}\text{W}$ : fluctuations with periodicities of 5–7 days that showed a near-surface temperature signature as well. The relation between temperature and zonal velocity component cannot be surmised to the zonal displacements since zonal temperature gradients are unlikely to be important on a 7-day timescale. Since the largest amplitudes in temperature ( $2.5^{\circ}\text{C}$ ) are seen at the thermocline depth ( $\sim 60$  m), it is most likely that these near-surface temperature fluctuations

are linked to vertical water movements. The temperature fluctuations in the 5- to 10-day range are especially interesting since they mostly occur during June and July simultaneously with the seasonal upwelling and therefore could contribute to the heat exchange at the base of the mixed layer.

[21] An important part of the variability observed at both locations in the near-surface meridional velocity component is due to oscillations with an approximately 14-day periodicity (Figure 4). These 14-day-period oscillations are present exclusively in the meridional component and show a clear upward phase propagation and downward energy radiation, reminiscent of a first mode mixed Rossby-gravity wave of similar characteristics to what was observed in the western Pacific Ocean by *Zhu et al.* [1998]. In the work of *Zhu et al.* [1998], the wave resulted from a northerly wind burst crossing the equator. Examination of QuikSCAT surface wind velocity data for the year 2002 in the Atlantic shows great activity at intraseasonal timescales in both horizontal velocity components at large zonal scales (Figure 8). When comparing the QuikSCAT wind velocity data to the current velocity data, however, we could not find a perfect correspondence for all individual events with either wind velocity component. When there is no correspondence, this does not mean that the 14-day-period oscillation in the meridional velocity is not due to wind fluctuations: it could indeed be set in motion by the wind initially and then persists as a free wave by its inherent dynamics. The SST data between February and May 2002 showed nonpropagating large-scale anomalies and, even though these anomalies occurred simultaneously with the 14-day-period oscillation in the meridional velocity component, they could not be directly related to the first baroclinic mode mixed Rossby-gravity wave observed in the velocity measurements. This is because (1) the SST time series has larger periods than the meridional current-velocity time series and (2) the SST signature of a mixed Rossby-gravity wave should show an antisymmetric temperature structure about the equator and the SST anomalies of boreal spring 2002 have a symmetric structure about the equator.

[22] TIWs can easily be detected in SST snapshots by their equatorially antisymmetric phase structure and by their zonal scale of  $\sim 1100$  km [e.g., *Chelton et al.*, 2000]. This situation is observed three times in the year, one at the beginning of 2002, one in summer 2002, and another one in fall 2002. The formation of TIWs depends on the intensification of zonal equatorial currents [e.g., *Kessler*, 2005] and, since there is a second intensification of the winds and currents in the Atlantic during the November–December period [e.g., *Provost et al.*, 2004; *Okumura and Xie*, 2007], it was not surprising to observe TIW-like events during November 2002. The TIW events in early January, however, can only be explained in terms of interannual variability. Indeed, an analysis of interannual variability in the equatorial Atlantic by *Provost et al.* [2006] showed that the winter 2001–2002 had the coldest SSTs, the strongest westward winds, and the steepest zonal slope anomaly, when compared with other winters from 1993 to 2003. These anomalous conditions could have also led to anomalously stronger equatorial currents, which in turn could have favored the generation of TIWs in winter 2001–2002. Overall, variability in both the SST and the meridional

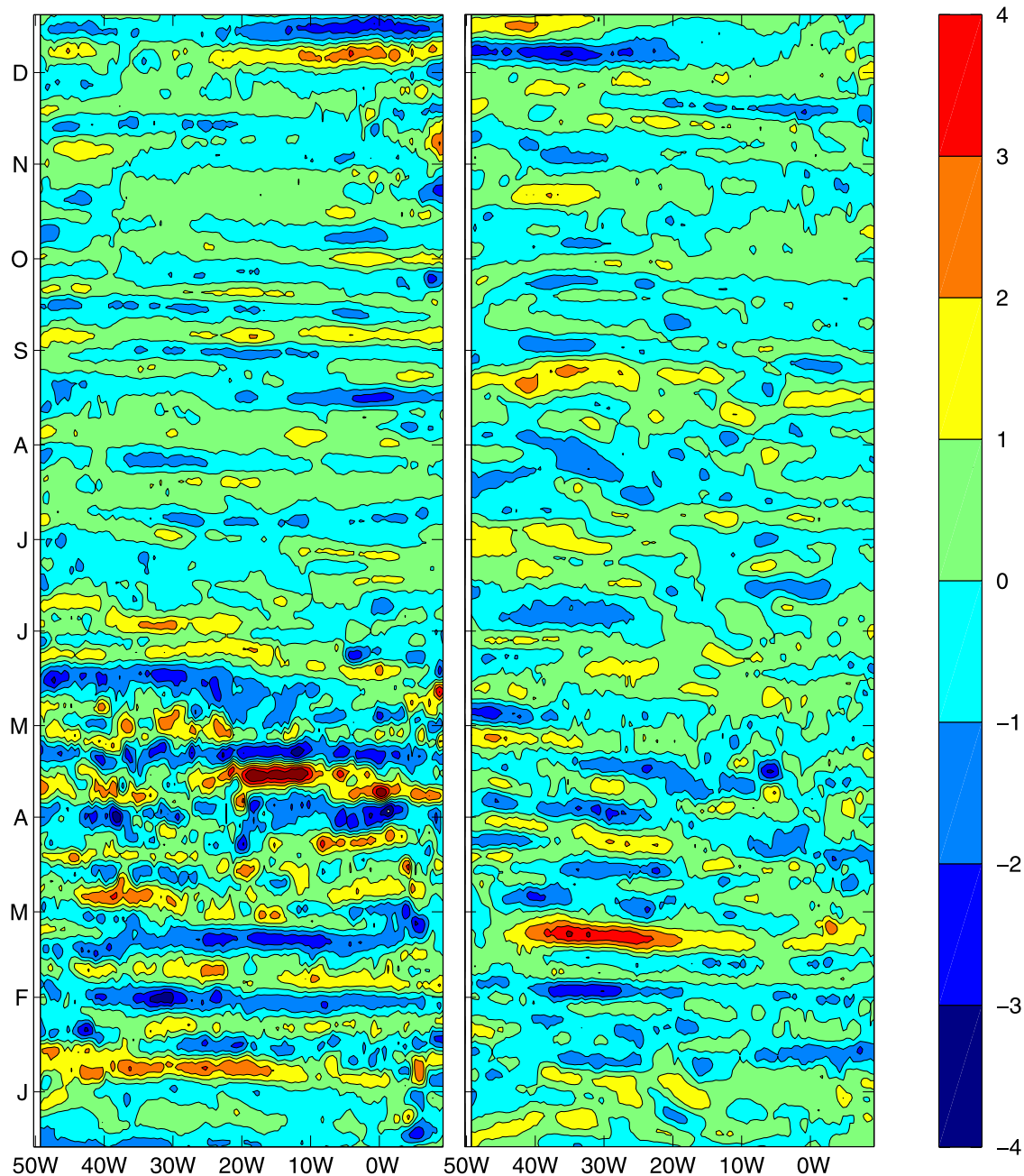


**Figure 7.** (a) Normalized and filtered satellite-SST time series from grid points 0.125°N (thin line), and 1.125°N (dashed line) at 10.125°W, compared to normalized and filtered meridional velocity component data (thick line) at 10°W and 154-m depth. (b) Same as Figure 7a but for SST time series at 23.125°W and meridional velocity component at 23°W and 16-m depth.

velocity component was dominated by TIWs-like events throughout most of the year, except from February to mid-May. During the latter, the agreement between the zonal scales of the SST and wind velocity anomalies as well as between the 14-day period in wind and current meridional velocity suggests that the variability was wind forced.

[23] The antisymmetric phase structure of the TIW events during the summer of 2002 was only observed from early June to mid-July. Afterward, the anomalies north of the equator became disorganized and the anomalies to the south reduced their zonal scale by half and disappeared soon after.

These changes are accompanied by a reduction of the phase velocity of SST anomalies at the equator (see Hovmöller diagrams in Figure 6). Despite the fact that the SST anomalies no longer had the antisymmetric shape of TIWs, the SST time series and the meridional velocity component at 23°W went on showing perturbations with the same periodicity, therefore implying that the TIWs had not died off. Indeed, SST signatures of TIWs in the Pacific Ocean have been shown to persist after the velocity perturbations have died off with the propagation of the anomalies resulting from advection by the background flow [Contreras,



**Figure 8.** Hovmoller diagrams of (left) zonal wind velocity components at latitudes  $0.25^{\circ}\text{N}$  and (right) meridional wind velocity components at latitudes  $0.25^{\circ}\text{N}$ . The wind velocity data have been band-pass filtered to retain variability in the 5- to 38-day-period band. The velocity scale is in m/s, and the months on the y axis correspond to the first day of each month.

2002]. In the Pacific Ocean, there is an apparent difference in the periodicity of TIWs, depending on the quantity under consideration: SST, altimetric sea surface height, or current velocity [Kessler, 2005]. This is not the case in the Atlantic; time series of SST at  $10^{\circ}\text{W}$  and  $23^{\circ}\text{W}$  have oscillations induced by TIWs with the same periodicity as the TIW-induced signatures in the near-surface velocity records (Figure 7). This fact made the comparison between the velocity and SST data sets straightforward. Lyman *et al.* [2007] found that the differences in the periodicity of TIWs

in the Pacific detected in off-equatorial temperature records and in meridional velocities at the equator, were the result of two types of TIWs coexisting at the same time with distinct periods, dynamical structures, and latitudinal extent. During the deformation of TIWs in mid-July, the reduction of the phase velocity of the SST anomalies at the equator suggests the development of a different TIW. However, there is no change in the period.

[24] Finally, another intriguing set of SST anomalies were the ones found east of  $10^{\circ}\text{W}$  in the Gulf of Guinea.

Although they presented the same periodicities as in the west, their temperature structure had different characteristics: the zonal scale was larger than that of TIWs observed in the west and they did not propagate (Figures 5 and 6). Whether all these different SST-TIW anomalies expressions share the same dynamics or not, whether they are all part of a single instability process or of different types and/or regions of TIW generation, are questions that remain to be explored.

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