VARIABILITY OF THE NORTH PACIFIC SUBTROPICAL COUNTERCURRENT FROM THE TOPEX/POSEIDON ALTIMETRIC OBSERVATIONS

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The rms height variability map derived from the TOPEX/POSEIDON altimetric data over the past 4.7 years (October 1992ñJune 1997) reveals a regional maximum (> 10 cm) extending from 140°E to 170°W in the zonal band from 19°N to 25°N. This rms maximum corresponds to an area where multiple jets of the SubTropical CounterCurrent (STCC) system are located. Analysis of the eddy kinetic energy in this area indicates a distinct annual cycle with a maximum in May/June and a minimum in December/January. In contrast, no clear annual cycle is detected in the eddy kinetic energy levels of the neighboring Kuroshio / Kuroshio Extension and the North Equatorial Current systems. Seasonally-dependent baroclinic instability is hypothesized to be responsible for this eddy kinetic energy cycle in the STCC.

The discovery of the Subtropical Countercurrent (STCC) in the North Pacific Ocean by Japanese scientists dates back to the mid 1960's. By computing the Sverdrup transport from the springtime wind-stress data, Yoshida and Kidokoro [1967] predicted the existence of an eastward flow at 20°N to 25°N in the western North Pacific subtropical gyre, a region where one would otherwise expect a westward flow feeding the western boundary current based on the classical wind-driven circulation theory. The presence of this eastward current, which Yoshida and Kidokoro dubbed the STCC, was later confirmed by Uda and Hasunuma [1969] from direct current meter observations, by Hasunuma and Yoshida [1978] from geostrophic calculations using hydrographic data, and by White et al. [1978] using historical XBT data.

While early theories on the STCC have emphasized the Ekman convergence induced by westerlies to the north and trades to the south, more recent theories have stressed the importance of the geostrophic convergence causing the front and its associated zonal current [Cushman-Roisin, 1984; Takeuchi, 1984; Kubokawa, 1997]. Notice that these theories have focused on the mean state of the STCC. Because the STCC encompasses a geographical domain as large as 70 degrees in longitude (130°Eñ160°W) and 10 degrees in latitude (19°Nñ29°N), our knowledge of its spatial and temporal variability remains heretofore limited. The goal of this study is to characterize and understand the nature and causes of the STCC variability using available altimetry data from the TOPEX/POSEIDON (T/P) mission.

Figure 1 shows the rms sea surface height variability map derived from the T/P altimetric data over the past 4.7 years (October 1992ñJune 1997). In addition to the high variability regions of the Kuroshio/Kuroshio Extension, the North Equatorial Countercurrent, and the tropical convergence zone, a regional maximum extending from 140°E to 170°W in the zonal band from 19°N to 25°N stands out as well in the North Pacific. This region of high rms variability corresponds to where one finds the eastward-flowing STCC. To place the STCC in the context of the large-scale subtropical circulation, we show in Figure 2 a typical temperature cross-section observed in the western North Pacific.

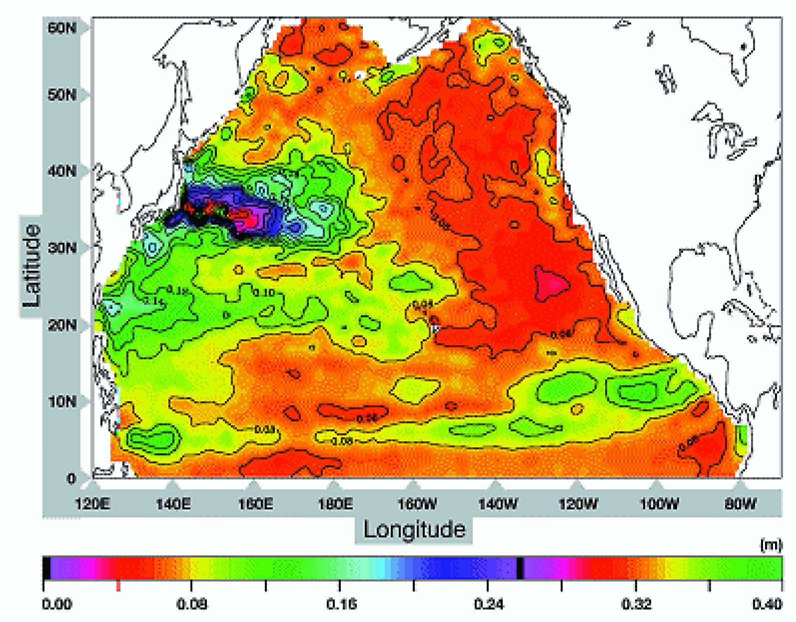

Figure 1
Rms sea surface height variability map (in m) derived from the T/P altimetric data over the past 4.7 years (October 1992-June 1997).

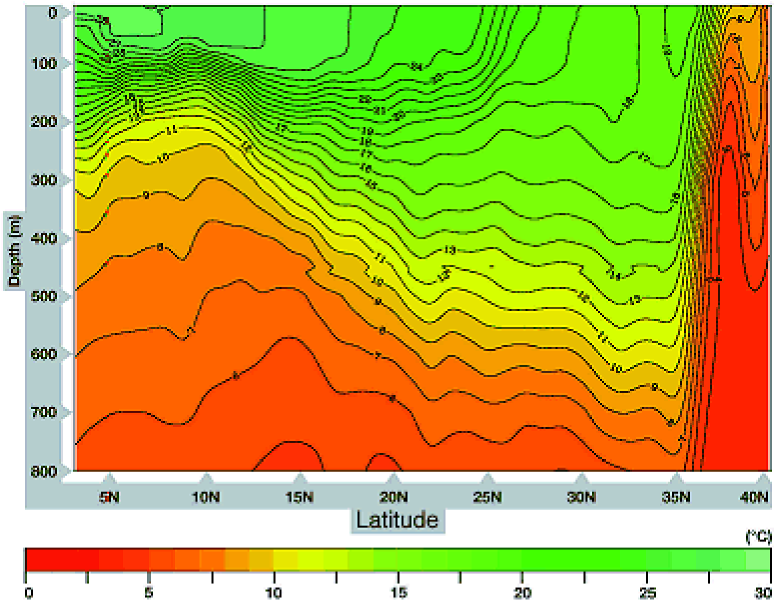

Figure 2
Temperature cross-section (in °C) observed in the western North Pacific along 144°E in spring 1987. Based on XBT and CTD measurements from R/V Takuyo of Japan Marine Safety Agency and R/V Kaiyo-Maru of Tohoku Regional Fisheries Research Laboratory.

The thermal front at 36°N corresponds to the Kuroshio Extension and the wind-driven main thermocline there is deep, reaching 600 to 700 m. The thermocline in between 19°N and 27°N has an upper and a lower branch. The surfacing upper branch corresponds to the eastward-flowing STCC and the lower branch corresponds to the wind-driven, westward-flowing North Equatorial Current. The high rms values detected by the T/P altimeters are associated with the variability of this upper branch of the thermocline.

Figure 3a shows the time series of eddy kinetic energy averaged in the region of 140°E-170°W and 19°N-25°N from the 4.7-year T/P data. A distinct annual cycle with a maximum in May/June and a minimum in November/December is clear in the eddy kinetic energy level of the STCC. Notice that despite its higher level of variability, no clear annual cycle is detected in the eddy kinetic energy field of the neighboring Kuroshio/Kuroshio Extension

(Figure 3b). A likely cause for this difference is that while the Kuroshio and the Kuroshio Extension are connected to the deep main thermocline of the subtropical gyre, the STCC is associated with the surfacing of the upper portion of the thermocline, which is more likely subject to the seasonal changes in the surface wind and buoyancy forcings.

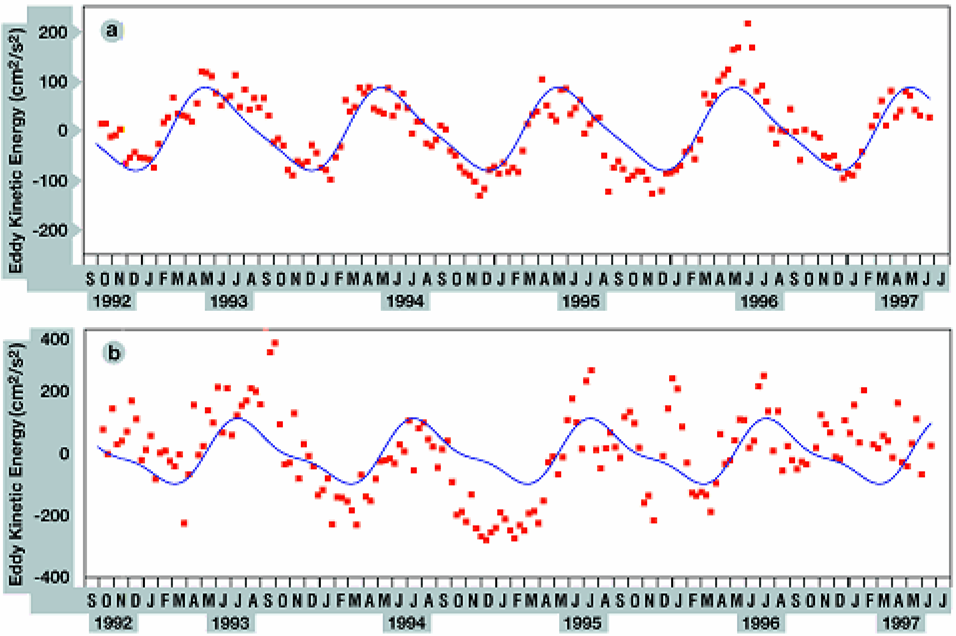

Figure 3

(a) Eddy kinetic energy (in cm^2/s^2) from the 4.7-year T/P data in the STCC region of 140°E-170°W and 19°N-25°N. Squares are estimates from individual T/P cycles (after removing the linear trend) and solid lines indicate the best fit of the annual changes. (b) Same as (a), except for the Kuroshio Extension region (140°E-170°W and 32°N-38°N).

To further clarify the physical processes controlling the eddy kinetic energy cycle of the STCC, we looked into the seasonal evolution of the STCC from available historical XBT data. Figure 4 shows the monthly averaged thermal structures associated with the STCC in March, June, September, and December. Due to the strong latitudinally-dependent surface cooling from late October to early spring, the well-stratified upper thermocline of the STCC of summer/fall (Figure 4c) is destroyed over the winter season (Figure 4d). The convectively-enhanced tilt of the upper thermocline reaches the maximum in early spring (Figure 4a), and it is subsequently replaced by a flatter seasonal thermocline when the surface buoyancy forcing changes from cooling to heating (Figure 4b).

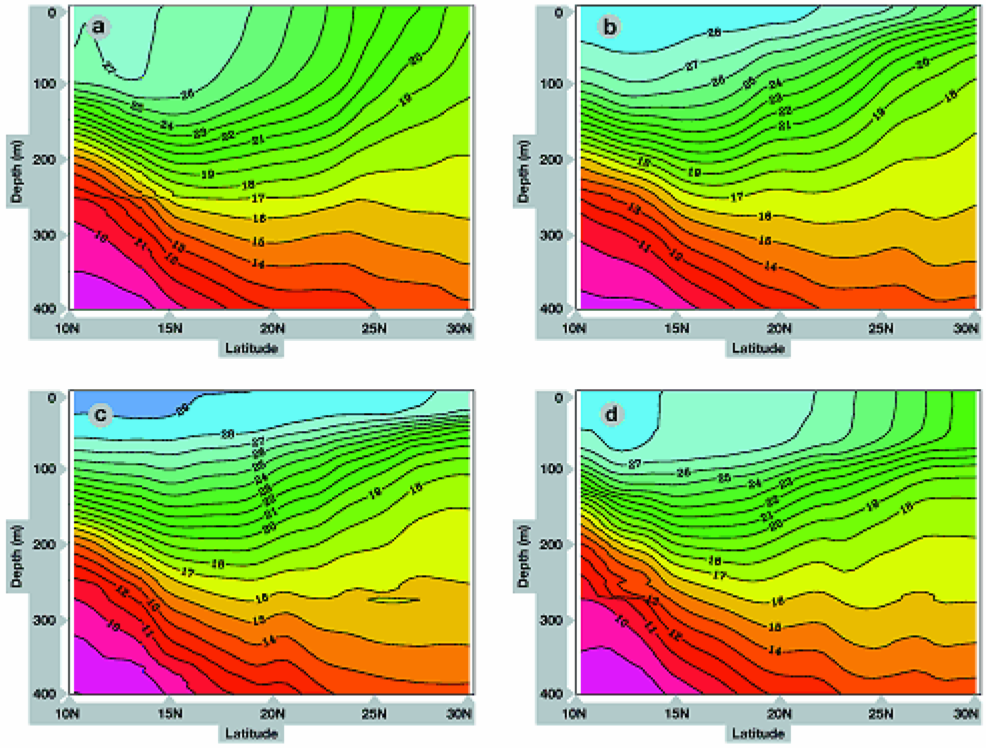

Figure 4

Seasonal evolution of the thermal structures (in °C) associated with the STCC and the North Pacific Current in the western North Pacific. (a) March, (b) June, (c) September, (d) December. Based on historical XBT data between 150°E and 160°E.

The dynamical consequence of this upper thermocline's seasonal evolution is that the regional current system, namely, the STCC and the underlying North Equatorial Current, undergoes a regular seasonal change. In particular, the vertical shear between the STCC and the NEC becomes strongest (weakest) in March (November) when the upper thermocline tilt reaches a maximum (minimum). As shown in Figure 5, this annual cycle of the vertical shear between the STCC and the NEC (green line) leads the eddy kinetic energy cycle of the STCC (blue line) by about 1.5 months.

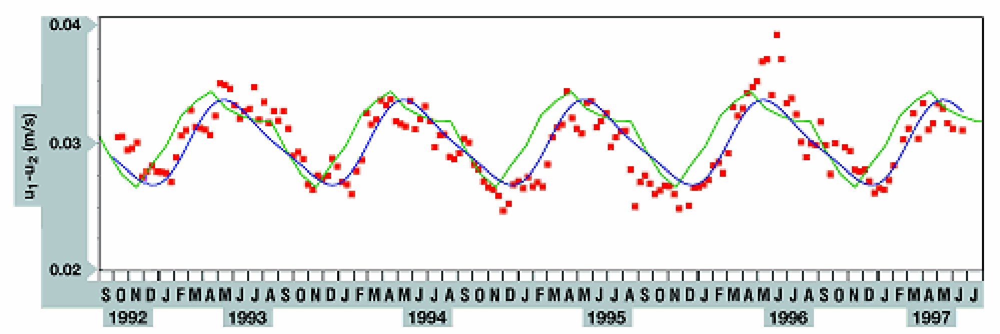

Figure 5

Seasonal change in the vertical velocity shear (in m/s) between the STCC and the NEC (green line) versus the seasonal change in the eddy kinetic energy level of the STCC from the T/P observations (blue line, same as Figure 3a). Here, the vertical velocity shear is computed using the XBT data (Figure 4) with the reference level assumed at 300 m.

It is likely that as the vertical shear intensifies in late winter and early spring, the STCC becomes baroclinically unstable, whereas this instability weakens when the vertical velocity shear reduces in the summer and fall seasons. We speculate that the distinct annual cycle in the eddy kinetic energy level of the STCC is a manifestation of the intensity of this instability and that the 1.5-month lag is the length of time the unstable waves need to fully grow. At present, we are developing simple theoretical and idealized numerical models to test this hypothesis.

References :

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