The South China Sea Warm Current

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Abstract

The northeastward flowing South China Sea Warm Current (SCSWC) is explained theoretically as a consequence of the onshore leakage of mass of the southwestward flowing South China Sea Branch (SCSB), a branch of the Kuroshio that has intruded through the Luzon Strait. The leakage occurs across the continental slope and necessitates a flow turn-around that initiates the formation of the SCSWC. A simple channel-flow model demonstrates the relevant dynamics.

1. Introduction

It has long been observed that strong but puzzling alongshore currents are found over the outer continental shelf off the coast of southeastern China (Guan, 1978). These currents are directed to the northeast and are thus particularly conspicuous in winter when the winds are to the southwest, as are currents near the coast. In addition, later observations, both hydrographic and short-duration (~a week), direct-current-measurement-based, indicate the remarkable existence of a strong current to the southwest in water of depths about or greater than 600m, just seaward of the northeastward alongshore currents roughly over the 200m isobath, the shelf break (Guo et al., 1985). The southwestward deep current has since been traced to the Kuroshio in the Luzon Strait and named the South China Sea Branch (SCSB). The northeastward alongshore current over the outer shelf the South China Sea Warm Current (SCSWC). A close examination of the temperature field in the top 200m indicates a surprising degree of water mass connectivity between the two currents, across an intervening, sharp shelf-break. The dynamic height field relative to 500m shows an elongated high situated roughly between the two currents, further suggesting a connection (Zhong, 1990). It is thus of interest to exploit the possibility of a leaky current offshore feeding a return flow just inshore.

2. Theory

For simplicity, consider joining a flat-bottom deep ocean (approximately, the upper layer of a reduced-gravity ocean model) with a continental shelf region with a constant bottom slope (Hetland et al., 2000). In the deep ocean, a geostrophic flow is assumed. On the shelf, the flow is barotropic, with a linear bottom friction with coefficient r (see Hetland et al., 1999). The inclusion of friction on the shelf breaks the geostrophic degeneracy, and the circulation everywhere on the shelf can be calculated unambiguously.

The matching at the shelf break (x=0) of the cross-shelf transport and pressure leads to

$$\zeta(x,y)=(Z_o-Z_1)\exp(\kappa\alpha^2 y+\alpha x)\,erfc\left(\frac{x}{\sqrt{4\kappa y}}+\alpha\sqrt{\kappa y}\right)+Z_1 \quad (1)$$

where ζ is the sea-level height on the shelf (x>0), $\alpha \equiv -h_x/(H_0-h_0)$, shelf bottom slope over the deep ocean depth minus the shelf depth at the shelf break, $\kappa \equiv -\frac{r}{fh_x}$, Z_o and Z_1 upstream sea-level heights at y=0 respectively at the shelf break and on the shelf, and the deep ocean current is in the positive y direction.

(1) yields a decay in sea-level height along the shelf break in the direction of continental shelf wave propagation (y>0), giving rise to an onshore geostrophic flow. This flow

feeds a barotropic current, the SCSWC, mainly on the outer shelf in the negative y direction.

3. Model

To substantiate the analytical results, a numerical model is used to solve for the flow in a channel with a cross-channel topography similar to that of the continental margin. The flow is driven with an inflow-outflow condition at one end (y=0). The governing equation is the vorticity equation:

$$\frac{\partial q}{\partial t}=-\left(u\frac{\partial q}{\partial x}+v\frac{\partial q}{\partial y}\right)+\left[q+f\right]\frac{u}{h}\frac{\partial h}{\partial x}-\frac{\partial}{\partial x}\left[\frac{rv}{h}\right], \tag{2}$$

where, in terms of the stream function ψ,

$$u=-\frac{1}{h}\frac{\partial\psi}{\partial y},$$

$$v=\frac{1}{h}\frac{\partial\psi}{\partial x},$$

$$q=\frac{\partial}{\partial x}\left[\frac{1}{h}\frac{\partial\psi}{\partial x}\right].$$

(2) states that the potential vorticity is modified along a streamline only by friction.

The solution confirms the theoretical results for sea-level height decay which leads to the SCSWC formation. The balance of terms of (2) across the channel suggests that the SCSWC grows from vortex foreshortening as the flow crosses the slope/shelf junction.

4. Conclusions

The SCSWC is explained as a consequence of an onshore leakage of mass from the SCSB as the latter flows along the upper portion of the continental slope and experiences friction. The frictionally induced pressure drop in the SCSB proves fundamental in that it is the geostrophic flow associated with this pressure drop that is responsible for the leakage.

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