Processes Coupling the Upper and Deep Ocean on the Continental Slope

D. Randolph Watts
Graduate School of Oceanography
University of Rhode Island
South Ferry Road
Narragansett, RI 02882
phone:(401)874-6507; fax: (401)874-6728; email: rwatts@gso.uri.edu

Award Number: N000149710138

LONG-TERM GOALS

We seek to understand the physics of vertical coupling in ocean processes over topography.

OBJECTIVES

We wish to conduct a comprehensive investigation of the dynamical mechanisms of vertical coupling over topography.

- We have characterized and published, for realistic models, the observed potential vorticity (PV) distribution on density layers across the Gulf Stream.
- We wish to conduct new analyses on existing data to determine the vertical and lateral structure of topographic Rossby waves (TRWs) and to resolve their temporally evolving frequencies.
- We seek evidence of vertical coupling between the upper and lower layers in the following hypothesized feedback loop:
  - (a) TRWs near Cape Hatteras trigger meanders in the upper layer jet, which
  - (b) propagate and grow to form steep troughs and rings farther downstream, and
  - (c) in turn radiate new TRWs, that
  - (d) propagate back to Cape Hatteras.
- We wish to test the degree to which model dynamics can account for the observed TRW characteristics.

APPROACH

Our studies combine analyses of existing observations with theoretical and numerical modeling studies. This three-pronged approach has required a combination of expertise from R. Watts, G. Sutyrin, and I. Ginis (who have a coordinated ONR-supported study at URI) in a true collaboration of efforts. A graduate student, O. Logoutov, has facilitated this collaboration by working jointly with all three scientists. This integrated approach has been designed to overcome the deficiencies in individual approaches to study vertical coupling processes.

WORK COMPLETED

A journal article is now in press (Logoutov *et al.* 2000), which presents a potential vorticity gradient model of the Gulf Stream. Some of those figures were included in last year's annual report. The abstract follows:
"Based upon highly resolved direct observations, we have produced a layered idealization of the Gulf Stream (GS) potential vorticity (PV) structure, capable of being inverted to produce realistic velocity and density fields. The data came from a two-ship survey northeast of Cape Hatteras specifically designed for simultaneous velocity and density measurements across the Gulf Stream. It included two repeated sections of finely spaced (12 km) CTDs (Endeavor-087) and simultaneous Pegasus velocity observations (Cape Hatteras-017).

A strong positive PV gradient ($\partial\pi/\partial y$) dominates the upper layers ($\sigma_\theta = 26.00 – 26.75$), weakens with depth and reverses sign in the lower main pycnocline ($\sigma_\theta = 27.30 – 27.70$). A PV-gradient (PVG) model was used to invert the input PV to generate the velocity and density fields by solving an elliptic problem. By comparing the observed and PVG-modeled fields of velocity, corrections to the PV-structure were made to improve agreement. In this manner essential PV features can be retained while reducing noise which would otherwise result from differentiating observed fields of density and velocity.

We offer two approximations of the Gulf Stream PV in 4 ½ density layers. Retaining the PV gradient in just one (18^o-water) layer can reproduce the basic GS structure. This 1-PVG-layer approximation captures the core velocity, the width and the vertical tilt of the GS velocity structure. The asymmetry of the flow with higher lateral shear on the cyclonic side, although reproduced in the upper layer, is misrepresented in deeper layers with this 1-PVG-layer approximation. The velocity core strength in the upper main thermocline is also underestimated. To account for these features, a more complete representation of the GS PV is also presented which includes two additional PV-gradients, positive in the upper and negative in the lower main thermocline (a 3-PVG-layer approximation)."

Oleg Logoutov, who completed his MS thesis in August 2000, was supported by this project. The leading statements of his abstract follow:

"Topographic Rossby Waves (TRW) have been shown to be strikingly energetic and persistent in the Mid-Atlantic Bight, and mounting observational suggests that they may couple to the Gulf Stream (GS) in the Cape Hatteras region, affecting GS meander development processes downstream. This thesis presents a detailed study of TRW properties from a quasi-geostrophic (QG) framework, with an aim to address the problem of TRW-GS coupling."

Logoutov's thesis makes a thorough summary of TRW properties and dispersion relevant to the slope region off Cape Hatteras, in various (possibly baroclinic) realistic stratifications, with and without realistic mean current structures. The properties under these general background PV states may be calculated as a 2-D eigenvalue problem, and compared under various simplifications with analytical theory. A sloping bottom eliminates orthogonality of the wave modal structure – opening the possibility of mode coupling and, in particular, baroclinic / barotropic coupling.

RESULTS

Preliminary observational evidence is shown in Figure 1 supporting the linkage between the upper jet and deep barotropic eddies. We identified time periods during which meandering events in the SST front determined from AVHRR data over an 800-km path-segment were associated with pulses in the deep along-shore currents off Cape Hatteras. Some of the deep current bursts were followed by southerly displacements in the SST paths near Cape Hatteras. These meanders were observed to propagate downstream, where they sometimes stalled, developed into steep troughs, and formed rings. After these strong meandering events, bursts of TRW energy were observed in the deep currents back at Cape Hatteras about one month later. These data suggest a "feedback loop" between TRWs and GS meandering.

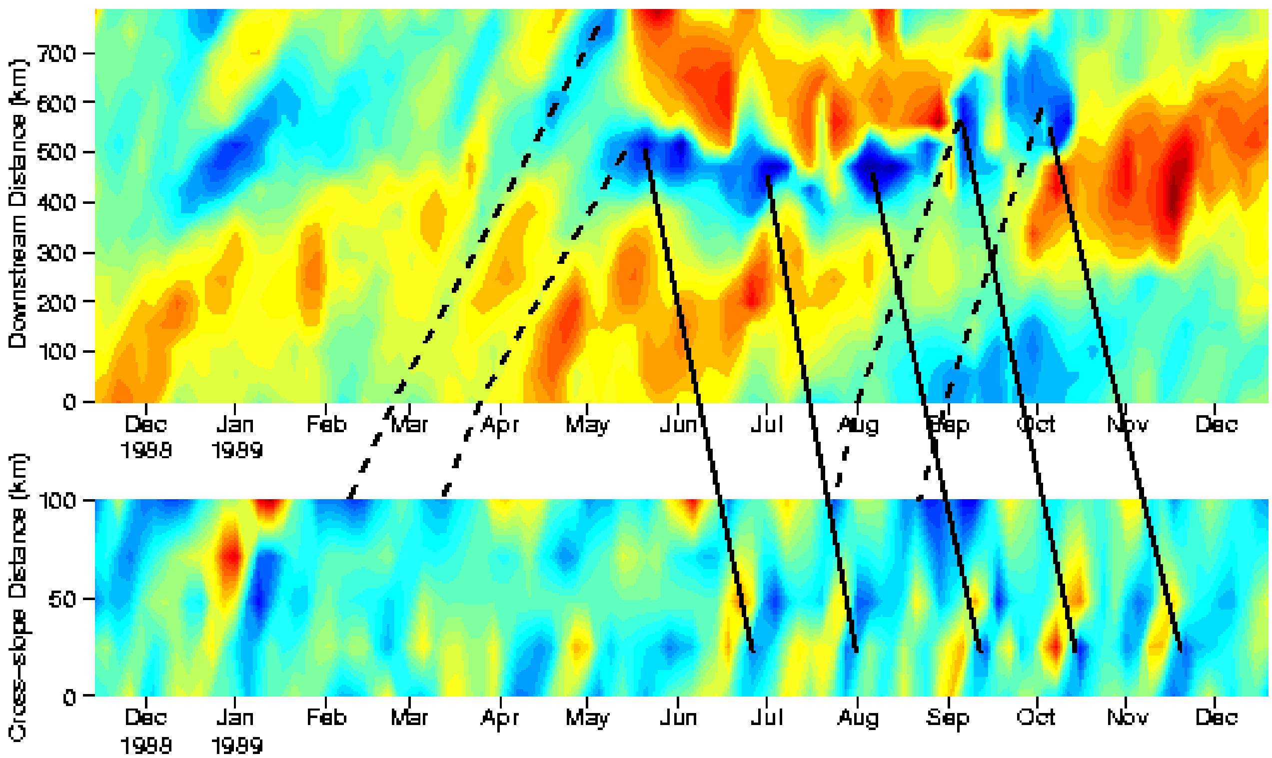

***Figure 1.* Evidence of a feedback loop between TRWs and Gulf Stream Meanders.**
(Upper) *Displacements of the Gulf Stream relative to its mean path contoured vs. downstream distance from 74°W and time. Southerly (northerly) displacements are blue (red) hues. 2-day composite satellite images 74°W to 65°W provided by Cornillon (URI).*
(Lower) *Alongslope current meter velocities, off Cape Hatteras 100m above bottom, contoured vs. cross-slope distance and time. Southwestward (northwestward) velocities are blue (red) hues.* Dashed lines *connect southwest TRW pulses at Cape Hatteras with meander troughs propagating 500-800 km downstream. Some meanders stalled near 68°W (~500 km) and developed into steep troughs and crests which formed rings. One such energetic sequence is illustrated here. Subsequently, bursts of deep TRW energy arrived back at Cape Hatteras about one month after the strongest events, as indicated by* solid lines.

The dynamical mechanism of coupling can be motivated from the vertical stretching exerted upon the upper layer jet by the quasi-barotropic currents of the TRWs crossing it. While the data are not sufficient to conclusively demonstrate this process, the zonal wavenumbers and the ~20-60 d periods match well to the most unstable meander modes of the upper jet (Kontoyiannis, 1997). Hence perturbations introduced at Cape Hatteras with the right wavenumber and frequency may be expected to grow rapidly.

IMPACT/APPLICATIONS

Presently most numerical models do not capture the importance of the deep eddy variability, nor do they capture the feedback between the upper and lower layers. However, the collaborative modeling studies by Sutyrin and Ginis have focussed on this problem and do indeed show the generation of energetic deep eddies and TRWs under a meandering jet. We hope jointly to make further improvement to this situation to demonstrate the feedback of TRWs to the upper jet, and to understand the physics.

TRANSITIONS

Our work indicates that it is crucial to know the deep eddy current and/ or pressure field in order to successfully predict the evolution of the upper baroclinic front. This will have an important impact on strategies for observations, data-assimilation, and modeling. We currently have a field program underway in the Japan/East Sea to observe vertical coupling between the upper and lower layers.

RELATED PROJECTS

This work is closely integrated with that of I. Ginis and G. Sutyrin who are conducting modeling studies of the coupling processes. Using a PVG-model initialization, Ginis, Frolov, and Sutyrin have demonstrated truly substantial improvement in long-term model performance (i.e., achieving realistic resilience and contiguity of the model Gulf Stream in runs spanning many model months.)

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