Internal Waves and Mixing in the Aegean Sea

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LONG-TERM GOALS

To identify the major processes producing mixing in the upper ocean and to understand their dynamics sufficiently well to permit accurate parameterization of mixing for use in numerical models.

OBJECTIVES

This project was designed to understand how the very rugged and irregular bathymetry in the Aegean Sea modifies the internal wave field and the mixing it produces. Because tides are weak throughout the Mediterranean, mixing produced by internal waves should stand out, unlike the situation on the U.S. coasts, where tidal currents generate a significant fraction of the mixing. Going to a place where one of the two major processes is weak should allow us to understand better the role of internal waves, e.g., how much of the mixing observed close to sloping bottoms results from scattering of internal waves?

APPROACH

We used moorings and intensive microstructure and towed measurements to examine small-scale fields on the southern slope of the Cycladic Plateau, just west of Santorini in the central Agean (Fig. 1). Colleagues at the Hellenic Centre for Marine Research (HCMR) had previously obtained high-resolution bathymetry of the site, and fishing was not intense in the region. These provided excellent records of internal waves and mixing during the transition from summer to winter conditions in the Aegean. Tides are weak in the Aegean because the Mediterranean basin is much too small to resonate with tidal forcing. During our intensive measurements, HCMR colleagues conducted a hydrographic survey around us from their ship, the R/V Aegaeo.

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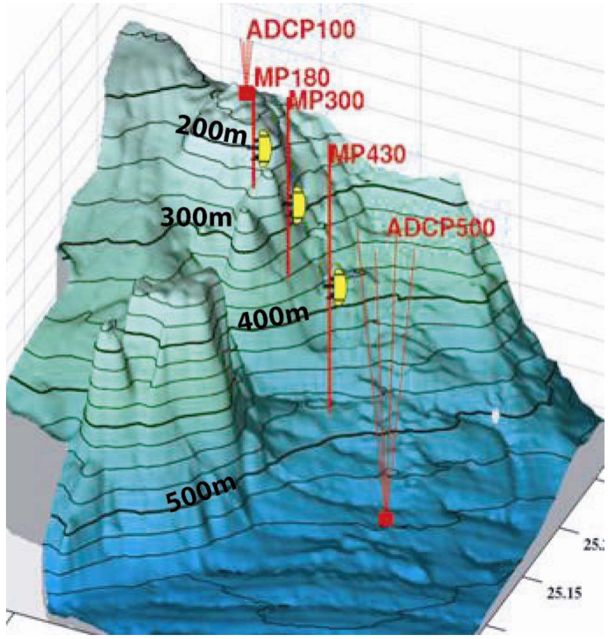

Figure 1. Mooring positions on the southern side of the Cycladic Plateau.
[graph: ADCP100 was a 300 kHz Ocean Surveyor Acoustic Doppler Current Profiler (ADCP) sitting on the bottom at a depth of 100 meters in a trawl-resistant cage. ADCP500 was a 75 kHz Long Ranger ADCP moored just above the bottom at a depth of 520 meters. MPs are McLane Moored Current Profilers moored at 180, 300 and 430 meters. MP sensor packages 'crawled' up and down the mooring lines at 0.25 meters/second measuring currents in addition to temperature and salinity.]

WORK COMPLETED

All data have been processed, and we are now interpreting them to define mixing and the background conditions producing it. During September 2006 we presented a seminar about our preliminary results at HCMR and at the University of the Aegean on the island of Lesvos, where our colleague Vassilis Zervakis is on the faculty. We then held a data workshop reviewing what has been done so far and developing plans for writing papers during the coming year.

RESULTS

Spectra of moored time series all exhibit peaks at near-inertial and M2 frequencies (Fig. 2). We expected weak peaks for the barotropic currents, but are surprised at the strength of the baroclinic peaks, given general statements in the literature that Mediterranean tides are negligible. Nevertheless the peaks are relatively small compared to those found in the open ocean and the internal wave continuum is correspondingly well below GM. Displacement spectra show similar peaks and relationship to GM.

As summer turned into autumn, several storms came over the mooring site, increasing the intensity of near-inertial currents, particularly in the thermocline, well below the surface mixed layer (Fig. 3).

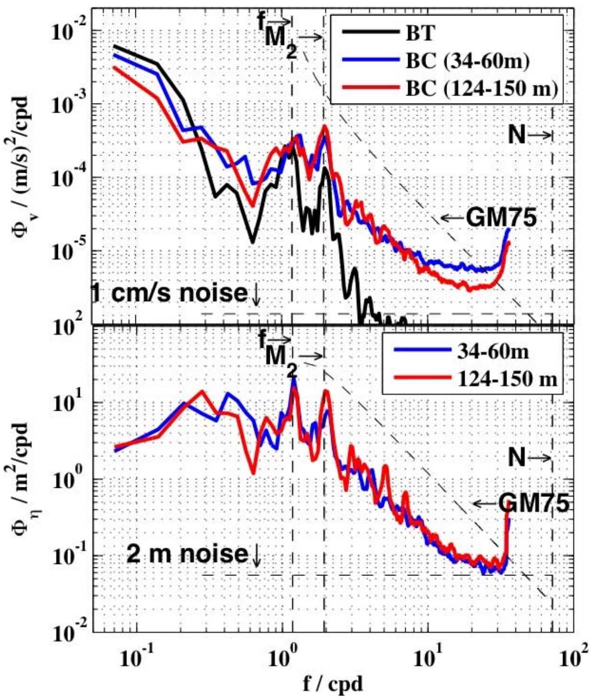

Figure 2. Spectra of MP180 currents and density.
[graph: The barotropic current (BT) is the current component produced by the horizontal pressure gradient resulting from seasurface slope and is constant with depth. The baroclinic current (BC) varies vertically in response to horizontal pressure gradients produced by lateral differences in density. BT and BC both have peaks for the twice-daily lunar tide (M2) and for inertial currents which have frequencies slightly greater than the inertial frequency, f. Internal waves, having frequencies greater than f, are nearly a decade below the Garrent and Munk (GM) level typical of most of the open ocean. The lower graph is a spectrum of vertical displacements of density surfaces and also exhibits peaks near f and M2. They too are much smaller than GM. The horizontal axis shows frequency in cycles per day (cpd).]

When we returned on R/V Oceanus for intensive measurements, varied mixing patterns were found. In general, mixing was moderate in the upper thermocline and decreased rapidly below in response to the rapid decrease in stratification. Except close to the bottom, dissipation rates below the thermocline were often close to the noise level of our microstructure profilers. Elevated levels were always found close to the small seamount. Corresponding diapycnal diffusivities were 1e-4 to 1e-3 meters squared per second. So far, we have identified several processes producing the elevated mixing. The line of elevated dissipation rising from the top of the seamount (Fig. 4, left) falls along a characteristic of the internal tide and appears to be the signature of a tidal beam generated by the tide flowing over the seamount. The vertical column rising from the 200 meter isobath (Fig. 4, right) is in the shear zone above a density current flowing along the slope. We are working through the data to identify other processes that are less straightforward.

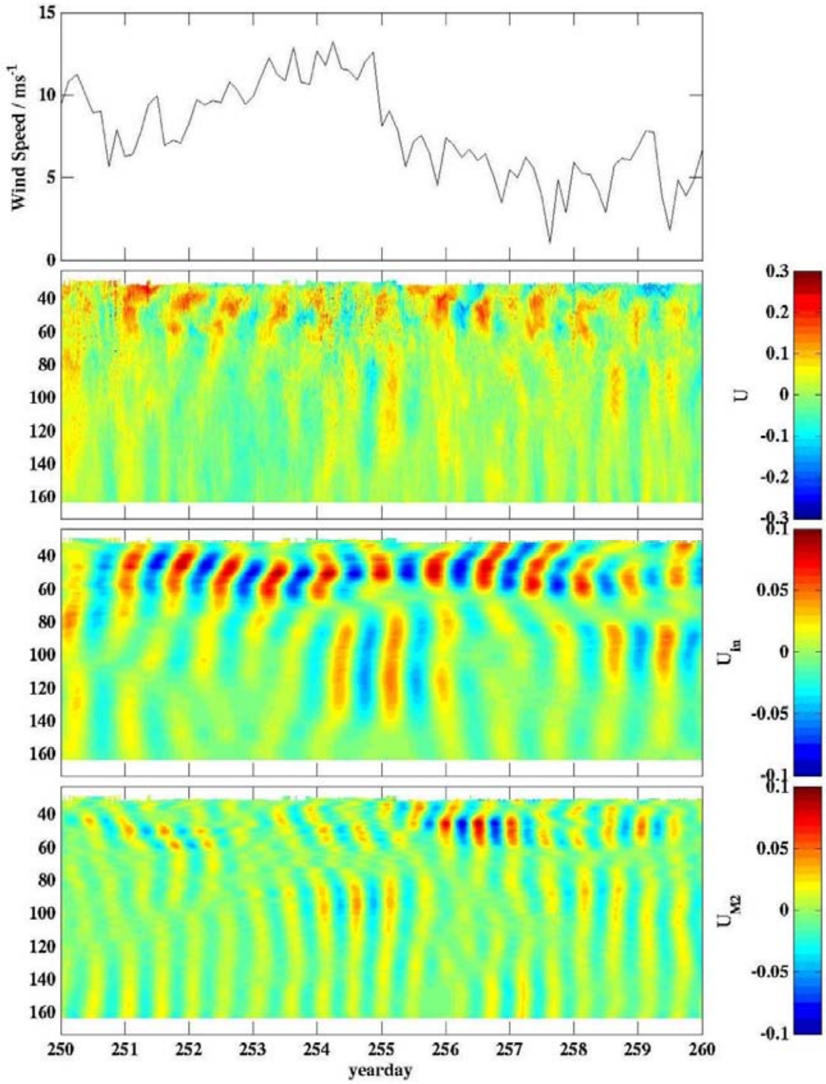

Figure 3: Windspeed, total eastward velocity (U), band-passed near-inertial eastward velocity, and band-passed M2 currents. [graph: near-inertial currents increased following the increased winds which peaked during day 254.]

IMPACT/APPLICATIONS

The patterns of dissipation and diapycnal diffusivity demonstrate that numerical models of the Aegean, and likely other marginal seas, must change their parameterization of diapycnal mixing. In all cases we know of, models use constant diapycnal diffusivities. These results demonstrate that mixing rates vary by many decades with location. Also, we found significant variability in time in response to changes in the internal wave field.

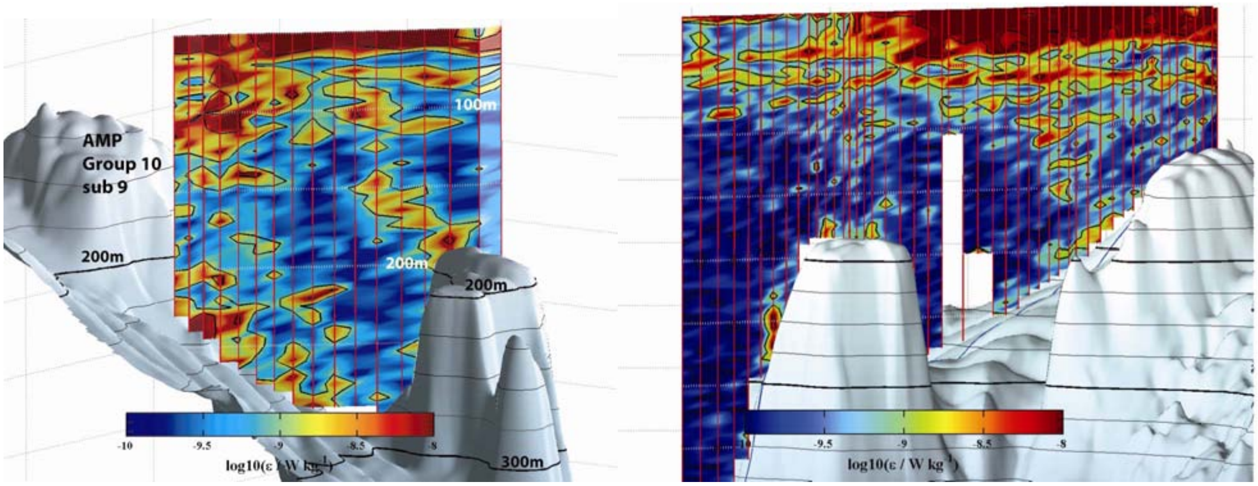

Fig. 4 Two sections of dissipation along the mooring line.
[graph: The section on the left shows elevated mixing along a characteristic of the internal tide coming from the top of the small seamount. The section on the right has a vertical column of mixing rising from the 200 m isobath. The simultaneous density section and the shipboard ADCP reveal that the column originates in a density current flowing along the slope.]

RELATED PROJECTS

The Aegean project is similar to measurements taken by Gregg in the Black Sea during 2003, using NSF funding. Because the Black Sea also has weak tides, comparison of the two data sets should show which features are common to marginal seas and which are particular to the study areas.

HONORS/AWARDS/PRIZES

During January 2006 Gregg received the Henry Stommel Research Award from the American Meteorological Society.