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Turbulence variability in the upper layers of the Southern Adriatic Sea under a variety of atmospheric forcing conditions

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ABSTRACT

As part of the DART06B observational campaign in late August 2006, a microstructure profiler was deployed to make turbulence measurements in the upper layers of the Southern Adriatic Sea. Of the nearly 300 total casts, 163 were made near Station B90, where various moorings were deployed in the 90 m deep water column to measure water column properties and meteorological and surface wave conditions. We were able to measure turbulence properties in the upper layers under a variety of atmospheric forcing conditions that included strong wind forcing, night-time convection, mixed convection and wind forcing, weak wind forcing and strong insolation. The resulting dataset provides a kaleidoscope of turbulence properties and turbulent mixing above, below and in the strong pycnocline present at a depth of 15–25 m in the coastal waters of the Southern Adriatic Sea during late summer. A slightly modified scaling of the dissipation rate of turbulence kinetic energy in the Mixed Layer (ML), based on the observed friction velocity u_* and the surface buoyancy flux J_{b0}, reproduces the measured values reasonably well. In the interior, below the ML, the dissipation rate scales like $L_T^2N^3$, where L_T is the Thorpe scale and N is the buoyancy frequency. Analysis of velocity and density profile measurements from Station B90 and the nearby Station B75 suggest that anticyclonic eddies and near-inertial waves can interact in these coastal waters to produce significant horizontal advective density fluxes in the pycnocline.

1. Introduction

Turbulent mixing in the upper ocean is important to many aspects of oceanography, such as air–sea interactions and near-surface properties, as well as practical applications such as search and rescue and oil spill tracking. Yet, turbulence measurements are not carried out routinely in oceanographic surveys, and even when they are made, they are not often done in concert with auxiliary measurements necessary for interpretation of turbulence properties. Thus, datasets which contain measurements of on-site meteorological parameters and of ocean currents together with microstructure profiles provide valuable case studies of one dimensional mixing budgets and help to improve our understanding of turbulent mixing parameterizations.

As part of the Naval Research Laboratory/NATO Undersea Research Center (NRL/NURC) Dynamics of the Adriatic in Real Time (DART) Project, we performed turbulence measurements in the upper layers of the Adriatic Sea during DART 06A (see Carniel et al., 2008) and 06B cruises in late March and August of 2006, respectively. We were able to deploy a turbulence microstructure profiler from the NATO RV *Alliance* and measure the dissipation rates of Turbulent Kinetic Energy (TKE) and temperature variance, and infer eddy diffusivities in the water column. Nearly, 500 profiles were obtained, 300 of them during the DART 06B cruise of which 163 were made at a single station outside the Gulf of Manfredonia in the Southern Adriatic Sea under a variety of environmental conditions. This station was selected for turbulence measurement focus as it provided the maximum amount of auxiliary observational data for interpretation.

There has been an upsurge of interest in recent years in the Adriatic Sea: Dynamics of Localized Currents and Eddy Variability in the Adriatic (DOLCEVITA: Lee et al., 2005), Adriatic Circulation Experiment (ACE: Book et al., 2007), and ADRIA01-03 carried out in the early 2000s in the northern Adriatic, and the Joint Research Project undertaken by NRL, NURC, and other partners in the southern Adriatic under the DART-06 campaigns. Although each of these campaigns had diverse and multiple focuses, several have included direct measurements of the turbulent properties of the

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Adriatic Sea (Peters and Orlic, 2005, Peters et al., 2007, Carniel et al., 2008, and this study). As part of DART, several moorings were deployed in the coastal waters around the Gulf of Manfredonia (see Fig. 1). These included moorings capable of measuring the velocity structure in the water column using upward-looking ADCPs deployed in trawl-resistant bottom mounts. Many of these were the relatively new SEPTR moorings, which also had profilers and sensors to measure water column properties as well as meteorological and wave conditions (Book et al., 2008). One such mooring was deployed at Station B90 (41.67°N, 16.60 E°) in 90 m deep waters east of Manfredonia, close to the Western Adriatic Current (WAC) frontal system. During the August 2006 DART 06B cruise, we spent considerable amount of time in the immediate vicinity of B90 (Fig. 1) making microstructure measurements (Table 1) in the upper layers of the water column.

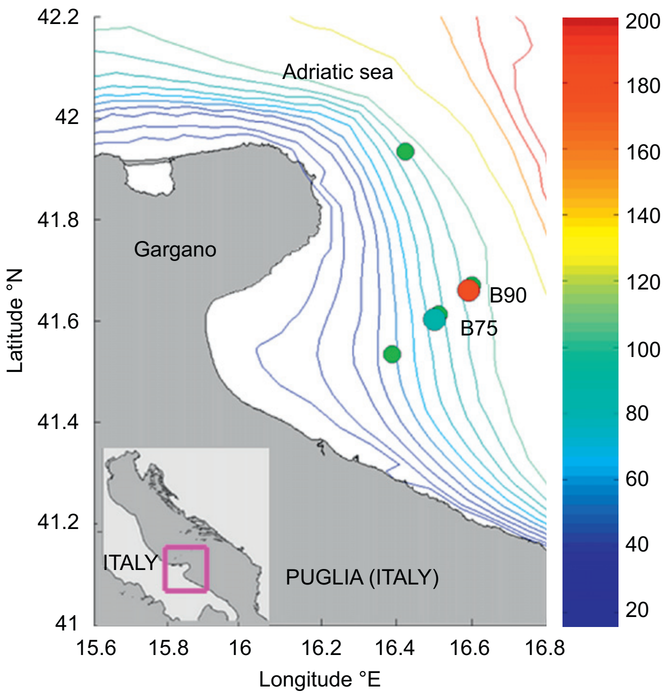

Fig. 1. Station B90 (red circle) was where microstructure observations were made near moorings deployed under the NRL/NURC DART06B campaign. Station B75 is indicated by a cyan circle. SEPTR buoy are represented with green circles. (For interpretation of the reference to color in this figure legend the reader is referred to the web version of this article.)

We were able to measure turbulent mixing in the summertime strongly stably stratified water column under a variety of meteorological forcing conditions. In this paper, with the help of the meteorological measurements made by the NRV *Alliance* and other data collected there, we describe the turbulence and mixing properties that characterized the conditions at B90. These measurements highlight the natural variability that characterizes these kinds of observations over various atmospheric forcing conditions. Additionally, the adjacent mooring, SEPTR B75, was used together with SEPTR B90 to make a first estimate of some factors affecting the three dimensional mixing budget of this coastal frontal system.

2. Measurements framework

Microstructure measurements were carried out from August 21, 13.09 UTC, to August 26, 15.13 UTC in 6 Observation Periods (OPs, see Table 1, indicating also the number of profiles during each experiments). The microstructure profiler used was the MSS 90 L, an advanced version of that described by Prandke et al. (2000) for simultaneous precision measurements of microstructure and physical parameters in marine and limnic water. The suite of sensors consisted of two shear probes for turbulence measurements, a thermistor for temperature microstructure, a precision CTD and a turbidity probe. The profiler was also equipped with a vibration control sensor, a two-component tilt sensor and a water surface detection sensor. The sampling rate for all sensors was 1024 samples per second; the resolution was 16 bit. All sensors were mounted at the measuring head of the profiler, the microstructure ones being placed about 150 mm in front of the CTD sensors. Simultaneous measurements of micro-scale temperature and velocity shear enables turbulence dissipation rates and diffusivities to be inferred (see Appendix A for details and Fig. A1, representing a sketch of the apparatus used).

The profiler was balanced with negative buoyancy, which gave it a sinking velocity of about 0.6 m s^{-1}, and was operated via a dedicated winch, with disturbing effects caused by cable tension (vibrations) and the ship's movement isolated by sufficient slack in the cable to ensure free fall. All MSS measurements were carried out from the most forward point on the bow of NRV

Table 1
List of microstructure measurements at Station B90 during the DART06B cruise.

Station	**Date and time (UTC)**		**Names of micro-structure profiles**	**Number of profiles**	**Notes**
Lat °N, Long °E (from–to)	**Begin**	**End**			
OP–1 41.6788, 16.6013 41.6876, 16.6399	2006-August-21 13.09	2006-August-21 15.26	D06B0081 D06B0119	39	Water depth 90 m, low wind speed
OP-2 41.6770, 16.6000 41.6222, 16.6333	2006-August-21 17.03	2006-August-21 18.48	D06B0120 D06B0143	24	Water depth 90 m, high wind speed
OP-3 41.6773, 16.6002 41.6610, 16.6320	2006-August-22 23.29	2006-August-23 02.17	D06B0164 D06B0203	40	Water depth 90 m, light wind, clear sky
OP-4 41.6786, 16.6016 41.6671, 16.6597	2006-August-24 22.31	2006-August-25 01.05	D06B0239 D06B0270	32	Water depth 90 m, moderate to strong wind, clear sky
OP-5 41.6677, 16.5920 41.6389, 16.5969	2006-August-26 13.08	2006-August-26 14.40	D06B0271 D06B0292	22	Water depth 90 m, light wind, increasing, clear sky
OP-6 41.6375, 16.5976 41.6292, 16.6000	2006-August-26 14.45	2006-August-26 15.13	D06B0293 D06B0298	6	Water depth 90 m, high wind, clear sky