Observations of Energy Dissipation in the Wake of a Western Pacific Typhoon

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LONG-TERM GOALS

We are focused on understanding small-scale processes that influence the ocean's thermodynamic and dynamic properties on the sub-mesoscale (scales less than 10 km). This includes the turbulent evolution of cold wakes caused by typhoons, and the subsequent mixing processes the restore the upper ocean stratification after a storm event.

OBJECTIVES

We investigated the energy dissipation properties of the mixed layer and mixed-layer base / thermocline transition layer in the aftermath of typhoon Fanapi in the period 21 September – 11 October 2010. During the initial week of the survey on the R/V Revelle, a well-defined cold wake was identified and sampled in the area east of the Ryukyu Islands. The wake was 3 days old when it was initially sampled, and was crossed on 3 occasions over 4 successive days in the 21-25 September 2010. Turbulence levels were measured with a VMP-500 free-falling turbulence profiler, equipped with dual shear and temperature microstructure probes as well as a Seabird CTD. The system was used to profile to depths of 200 to 400 m, well into the mixed-layer / thermocline transition layer.

Analysis of temperature and dissipation data from the wake crossings are reported here. We find elevated levels of turbulence linger in the wake up to 1 week after its generation. The enhancement is specifically in the deep part of the wake, roughly at 100-m depth for the case of Fanapi. At shallower depths, the turbulence levels appear reduced relative to the areas on either side of the wake, apparently due to the suppression of turbulence caused by the increased near-surface stratification. Within the wake, it appears the turbulence levels are enhanced to the right of the wake's center, consistent with the symmetry in forcing.

APPROACH

Our sample program consisted of shipboard profiling using a Rockland Scientific VMP-500 tethered microstructure instrument system (Fig. 1). The profiler was operated from a hydraulic winch and line puller combination that allowed for the tether to be fast-spooled such that the

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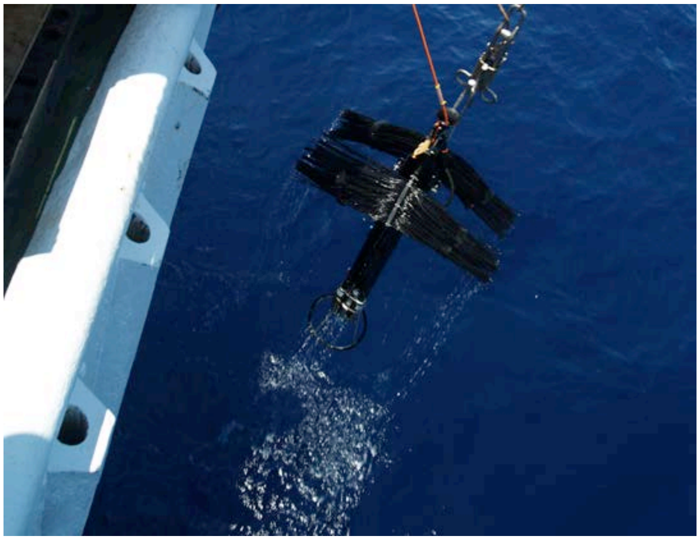

Figure 1: The Rockland VMP-500 turbulence profiler. The system is a fee-falling tethered instrument package with a CTD and microstructure sensors for shear and temperature. A winch to handle the tether is used from the ship's stern.

profiler was in free fall during its descent. This assured high-quality shear microstructure data were available for the estimate of turbulent kinetic energy dissipation rates; ε. The VMP profiling operation was lead by Steve Lambert of FSU (MS student, now a Res. Asst. III at WHOI), with assistance nearly all members of the ITOP project. In all, 172 VMP casts were done over 20 days of survey work. Most profilers were done to 400-m depth. A map of the surbey showing VMP cast locations is shown in Figure 2.

The survey cosisted of an initial 4 days of surveying the cold wake. This sampling consisted of 3 cross-wake transits, labels sections 1, 2 and 3 in Fig. 2. Section 1 crossed the wake at approximately 3 days after its creation. Section 1 was done as the initial survey, as the Revelle came north from Kaohsiung. Section 2 was then done slighty to the east, approximately 12 hours later. Both sections 1 and 2 crossed the wake completely.

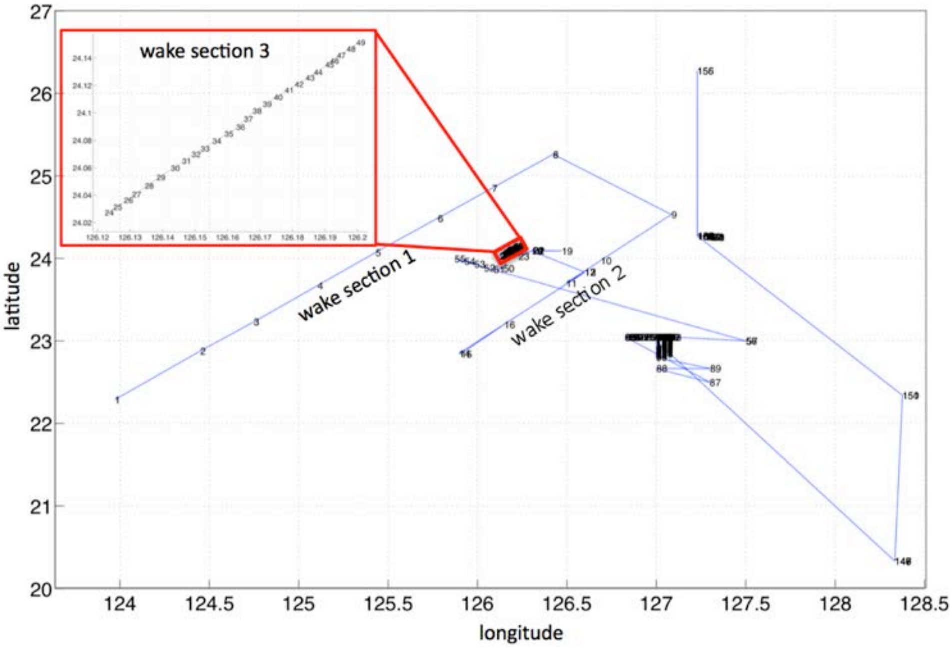

Figure 2: Map showing the survey transect of the R/V Revelle during the Fanapi cold-wake study. The cold wake was sampled only during the first week of the survey, as during that time the wake was advected west into the East China Sea. While a robust wake signal was present, it was crossed on three separate sections, as indicted.

Section 3 was initiated on the 4th day after the wake's creation. It was done from roughly the core of the cold wake signal, outward past the edge of the wake. Additional surveys later in the cruise included some along-wake sampling, as well as extensive sampling of the low potential vorticity pool left after the signal of the wake as dissipated.

RESULTS

The analysis for microstructure shear was done following standard methods (Gregg 1999), and we have examed the vertical structure of dissipation relative to the temperature stratification in each of the 3 sections we completed in the first 5 days of the survey (Figs 3 and 4). Data collected after the initial 5 days was examined as part of a time-series analysis (Fig. 5). Figures 3 and 4 show the turbulence signal across the wake. Elevated dissipation levels are clearly apparent in the core of the wake, around 100-m depth spanning down to the transition later with the thermocline stratification. These are most dramatic in section 2 (Fig. 3, bottom), where the turbulence patch scales are 50-m in vertical extent.

The top panel of Fig. 4 shows a section across the northern wake edge, with the wake stratification transitioning into the background roughly halfway along the transect. Here, the enhancement of disspation is clearly on the northern side of the wake, i.e.: to the right of the storm track, consistent with the long established trend of a rightward enhancement to a ocean storm-response (e.g., Price 1981). This is particularly apparent at depth, below 150 m, presumably in the region recieveing elevated energy and shear from near inertial radiation. Interestingly, the near surface values of dissipation are actually supressed. Integrated levels of dissipation, $\int \rho\epsilon \, dz,$ above 100-m depth for the section are shown in the bottom panel of Fig. 4. Energy dissipation levels in the upper layer just to the north of the wake are about 5-times larger than in the wake. This is presumably due to the enhanced near-surface stratification in the cold wake supressing the input of wind and wave energy into the upper ocean.

Viewing the whole energy dissipation rate dataset as a time series is instructive. To do this, we binned all dissipation profiles for a given day, and computed depth integrals of dissipatrion, $\int \rho\epsilon \, dz,$ both above and below 100-m depth. The resulting records are shown in Fig. 5. Above 100-m depth, we see the general subdued dissipation levels in the 2-weeks after the storm. Below 100-m depth, we see the general decay of the deeper turbulence levels over the same 2-week period. Both records indicate that any massive increase in turbulence level must decay very quickly after the storm, within the first 2 days, before we occupied the site.

RELATED PROJECTS

This project also invested in a turbulence profiling glider system. A Rockland Scientific microrider has been successfully integrated to work with a Slocum glider. This system is quite operational, and was intended for use in the ITOP cold wake survey. Unfortunately, the unit designated for ITOP encountered a problem with its digifin just before the shipping deadline used for all the other gear, and we sent to Teledyne-Webb for repair. The instrument was eventually repaired at the beginning of September, but a logistical solution for getting on to the Revelle during the quick turn around for the cold-wake survey was not found. The system will hopefully get used in alternate up-coming upper ocean response study.

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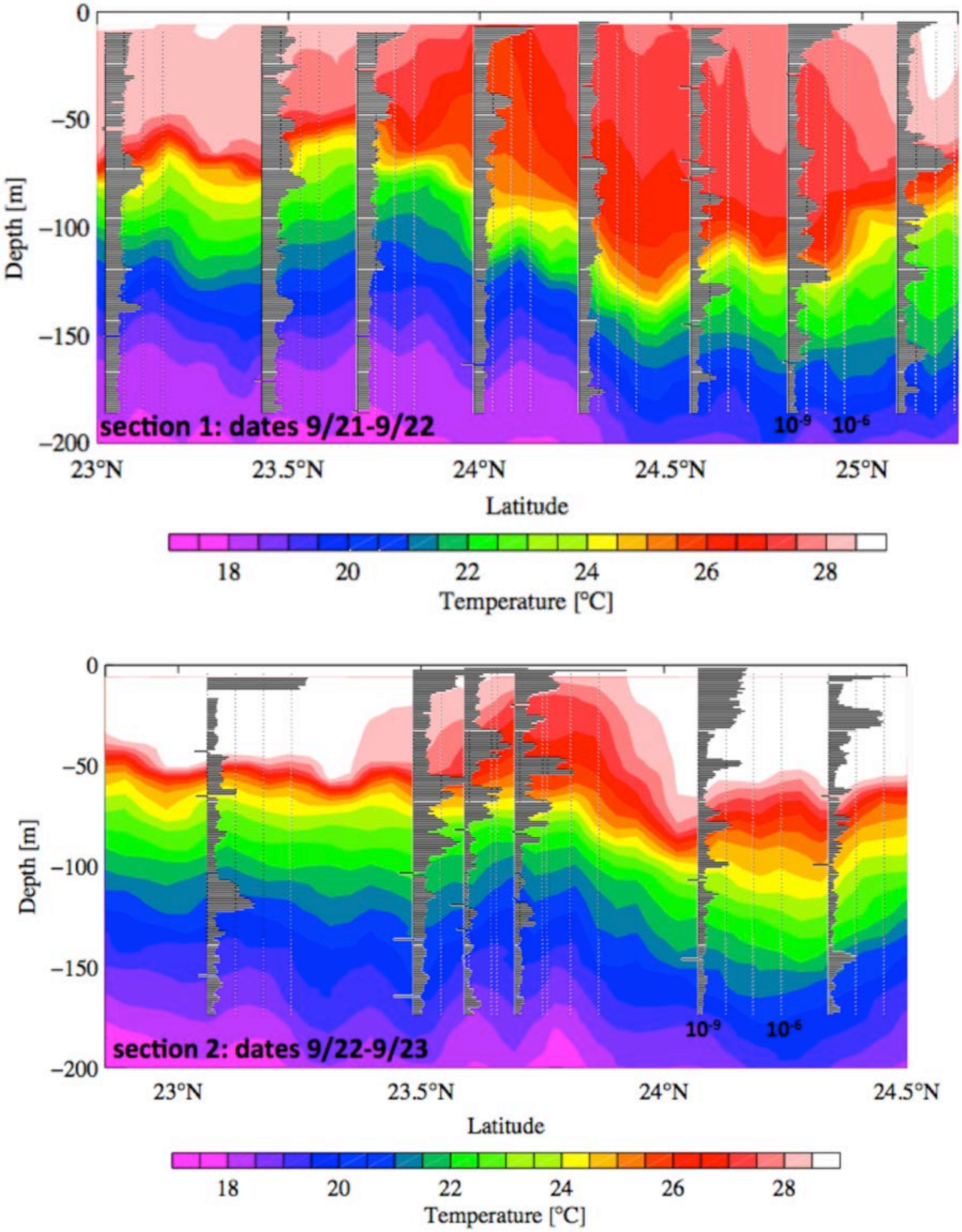

Figure 3: Temperature and turbulent dissipation rate (ε) across the region of the cold wake for section 1 (top) done at t=3 days after the passage of the typhoon. Distance along the transect runs from south to north. Temperature contours are from 15 to 30 C, and the cold wake signal in clearly visible between the 200 to 400 km section of the transect. Section 2 (bottom) done at t=4 days after the passage of the typhoon. Distance along the transect runs from south to north. Temperature contours are from 15 to 30 C, and the cold wake signal in clearly visible between the 50 to 150 km section of the transect. Temperature sections shown here come from the uCTD transects.

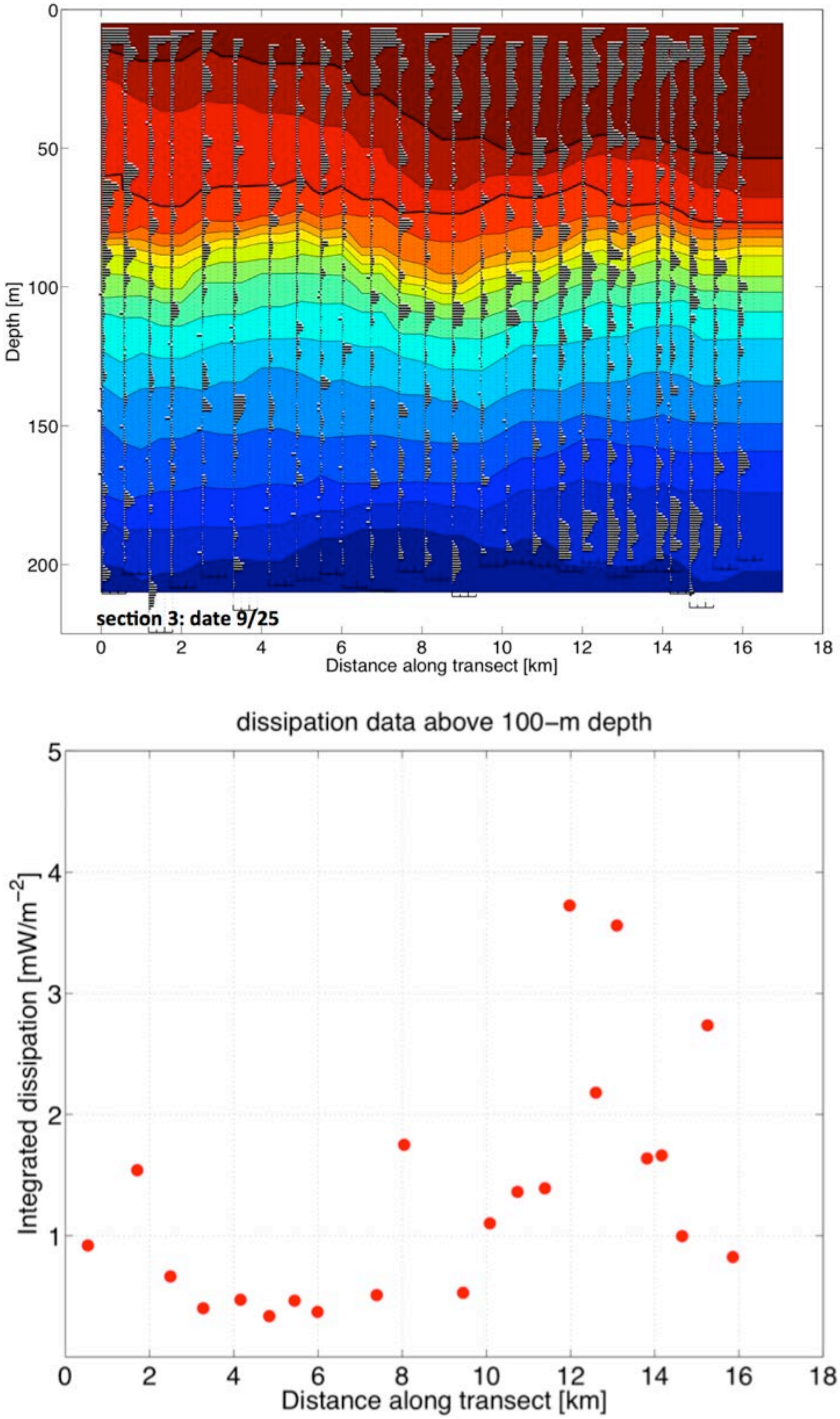

Figure 4: Section 3 (top) showing temperature and turbulence levels across the northern half of the cold wake region, as measured on t=5 days after the passage of the storm. The section crosses out of the cold wake at the 10 km mark along the transect. Integrated dissipation levels (bottom) show the suppressed nature of the turbulence inside the wake.

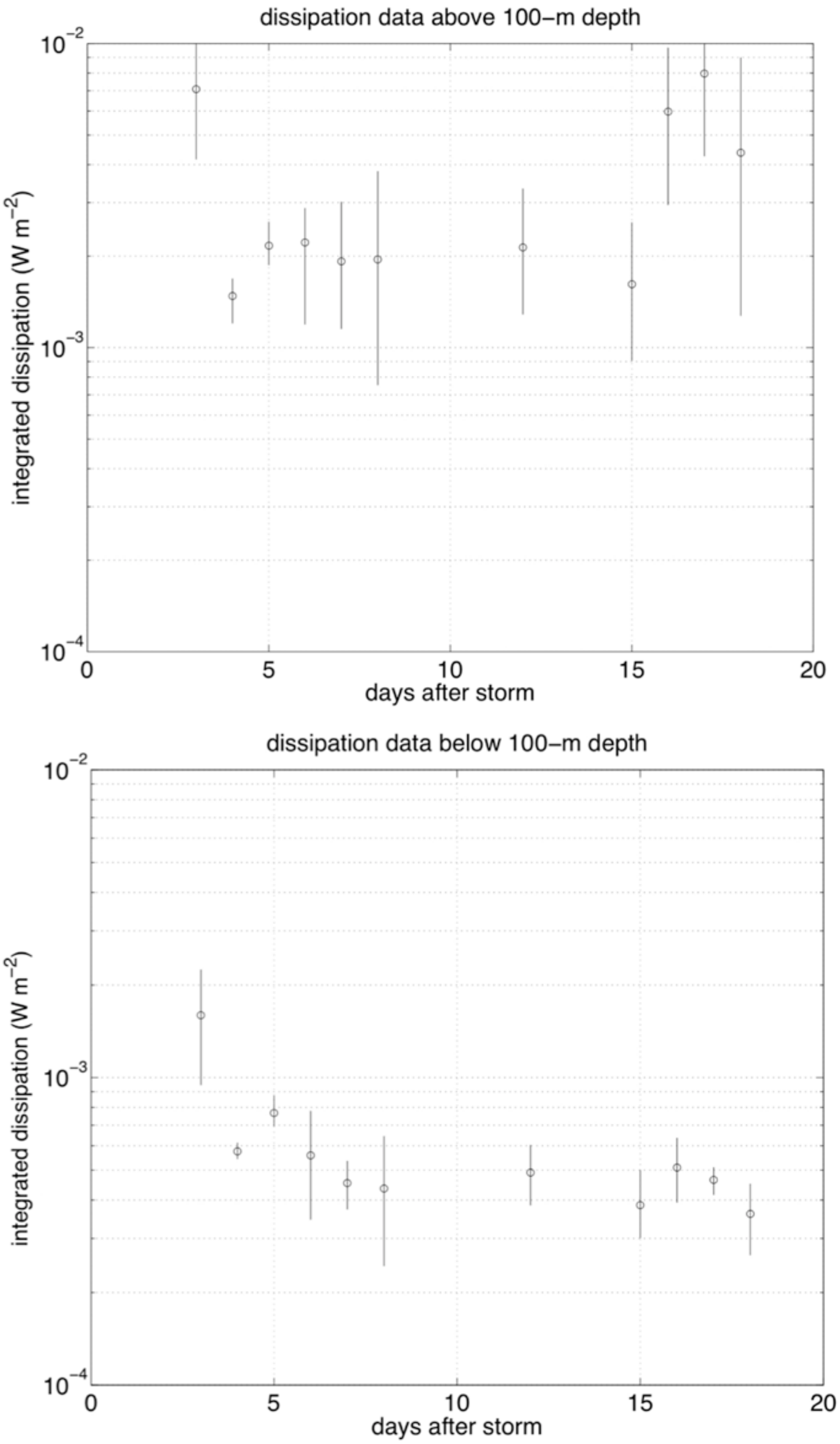

Figure 5: Time series showing integrated dissipation levels in the upper 100-m (top) and 100-m to 200-m depth layer (bottom). All 172 profiles were binned to compute a daily average and standard error. The upper layer estimates do no indicate any trend associated with the wake (instead showing the general trend of the wind during the survey). The lower panel estimates show a mild decay in the subsurface turbulence levels over two weeks following the storm.