# Reports

## Local Influences on Shear-Flow Turbulence in the Equatorial Ocean

Abstract. *A 12-day series of 1749 profiles of turbulent kinetic energy dissipation above the equatorial undercurrent at 140° west showed that, in the upper 110 meters of the ocean, the dissipation radically decreased during the solar heating period each day. Daily averages were linearly related to the local wind power. When integrated over the depth range of 10 to 110 meters, the dissipation was 10.6 ergs per square centimeter per second or 0.92 ± 0.10 percent of the wind power, a proportion not substantially different from those found in mid-latitude surface mixed layers. These results suggest that much of the energy dissipated above the equatorial undercurrent may be extracted directly from the local wind.*

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Although frictional energy dissipation is believed to play a crucial role in the dynamics of equatorial currents (*1*), direct measurements have been limited to ancillary studies on three cruises (*2–4*). None of these studies yielded a regularly sampled series because of other demands on station time. Only 40 profiles, scattered in both space and time, have been made within 1° of the equator in both the Atlantic and Pacific oceans. On the basis of these 40 measurements, it appeared that dissipation was greater at the equator than elsewhere in the ocean. The increased dissipation was assumed to be caused by the production of turbulence by the vertical shear in the large-scale currents. However, the 40 profiles were not adequate to verify this assumption with any degree of certainty or to define properly the processes involved. As a result of more extensive and systematic sampling on a recent expedition, we found that the dissipation, and hence the three-dimensional turbulence, is closely related to local solar heating and wind and that the energy source for the dissipation may be linked more closely to the local wind than expected.

In November and December of 1984, as part of the TROPIC HEAT project (*5*), we made a series of 1749 good RSVP (*6*) casts (of 1784 attempts) distributed fairly evenly over 12 consecutive days and nights. These casts were made from the R.V. *Wecoma* at 140°W while the ship maintained station near the surface buoy of a current-meter mooring (*7*). During the time we were on station we encountered only one serious interruption in data acquisition due to instrumentation failure; this resulted in a 6-hour data gap on 24 November. Instrumentation aboard the *Wecoma* also measured and recorded wind speed and direction, solar radiation, and a number of other environmental quantities.

The RSVP (*6*) is a 120-cm long cylindrical instrument (diameter, 5 cm; weight, 3.5 kg in air) that carries sensors for the measurement of pressure, temperature, electrical conductivity, and small-scale shear. It descends through the water on a cable that is kept slack so that ship motion is not communicated to the instrument. The cable carries power to the instrument and returns signals to the ship for recording. After data are acquired on descent, the RSVP is winched back for another deployment.

Two airfoil probes (*8*) protrude 6.5 cm from the nose of the RSVP. These probes (diameter, 0.4 cm; length, 1.4 cm) detect horizontal small-scale velocity fluctuations (spatial scales of 50 to 1.5 cm). From their signals we compute small-scale shears, from which an estimate is made of $\epsilon$, the viscous rate of turbulent kinetic energy dissipation (*9*). The probe signals must be corrected [by means of a measured transfer function (*10*)] for dynamic response at the large values of $\epsilon$ above the equatorial undercurrent.

For processing, each cast was divided into 512-point segments (approximately 1.2 m vertically), and the Fourier spectrum of each sensor's signal was computed for each segment. Every spectrum was inspected for spurious effects; these consisted mostly of spiking caused by the interception of plankton by the sensors (and two shark attacks). Another problem was the effect on the airfoil probe signals of the cable strumming in the current, an effect that was prominent at depths of 110 m and deeper when the instrument was in or below the undercurrent core. This problem was not significant for the data discussed here, which come from the region above the core. The profiles were averaged in several ways. To exhibit temporal effects, we averaged $\epsilon$ over depths from 10 to 110 m for each profile and plotted the value against time (Fig. 1). The vertical variation was emphasized by computing individual 20-m depth-range averages and plotting these on a daily basis (Fig. 2). To avoid signal contamination by the ship's wake, we discarded signals from depths less than 10 m. Because of the nature of the diurnal cycle, daily averaging began and ended at 0000 Greenwich mean time (GMT, 1400 local time).

According to the ship's drift and initial results from the hull-mounted acoustic Doppler velocity profiler, the surface current during this period was directed

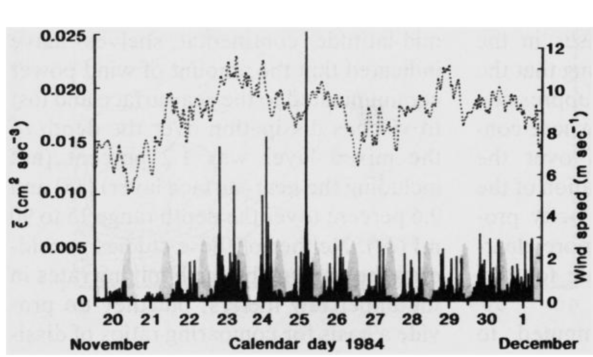


Fig. 1. One-hundred-meter depth averages (10 to 110 m) of the rate of dissipation of turbulent kinetic energy plotted against GMT calendar day 1984; the data represent 1749 vertical profiles over a 12-day span. The large ticks are plotted at GMT midday (0200 local time). The lightly shaded areas represent shipboard measurements of incoming solar radiation (peak values, 1000 W $m^{-2}$; nighttime values, 0 W $m^{-2}$). Hourly winds are superimposed.

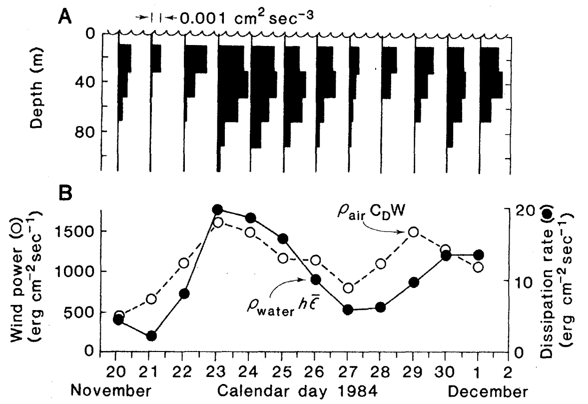


Fig. 2. (A) Daily 20-m depth averages of dissipation rate and (B) daily averages of wind power and total dissipation rate over the depth range of 10 to 110 m plotted against GMT calendar day 1984 (1 erg $cm^{-2}$ $sec^{-1}$ = 0.001 W $m^{-2}$).

westward at approximately 1 knot (0.55 m $sec^{-1}$), and the undercurrent (located at a mean depth of approximately 115 m) was directed eastward at approximately 2 knots (1.1 m $sec^{-1}$). The casts were all made within 5 km of the buoy. Winds were slightly higher than normal and the sky was nearly cloudless (Fig. 1). The water column was stratified in the daytime, with a nighttime mixing layer extending as deep as 40 m.

The mean dissipation rate showed an unexpectedly strong diurnal cycle (Fig. 1) somewhat similar to diurnal mixing cycles in lakes or other ocean sites away from the equator (*11*). Averages over 100-m depth and 1-hour time bins for the 12-day series differed by up to a factor of 8; the largest (0.0019 $cm^2$ $sec^{-3}$) occurred at night and the smallest (0.00024 $cm^2$ $sec^{-3}$) in the afternoon. Large values of $\epsilon$ occurred during the later part of the daily heating cycle only when the winds were at their strongest (on 24 November for example). The winds showed little uniform diurnal variation; on average they blew only 4 percent faster at night than in the daytime during this period. It might be hypothesized that the turbulence is generated by convective overturns caused by nighttime cooling, but this seems unlikely in view of the observation that $\bar{\epsilon}$ was larger in the 30- to 50-m depth range than it was in the 10- to 30-m range on many of the nights. We might also hypothesize that in the daytime the stratification induced by solar heating suppresses the turbulence generated by wind-induced increases in the mean shear. If so, it is surprising that the effect of solar turbulence suppression penetrates to 90 m, at a site where considerable mean shear exists over the upper 110 m. Detailed examination of the temperature, salinity, and velocity profiles should help us to define more clearly the mechanisms responsible for this behavior.

Daily averages were computed to eliminate the diurnal cycle. Remarkably, the daily dissipation integrated over 100 m (Fig. 2) correlated well with the daily local wind. We found a linear relation (slope, 0.0092 ± 0.0010) between the rate of energy dissipated in the water column between 10 and 110 m depth and the rate of energy input by the wind, $\rho_{air}C_D\overline{W}^3$ [where $W$ is the wind speed, $\rho_{air}$ is the density of air taken as 0.00125 g $cm^{-3}$, and $C_D$ is the drag coefficient taken as 0.0012 (*12*)]. Also, there was a coincident deepening or shallowing of the actively mixing layer as the wind speed increased or decreased. The time-averaged rate of energy lost to viscous dissipation in this depth range during the 12-day period was 10.6 ± 1.2 erg $cm^{-2}$ $sec^{-1}$ (mean ± standard deviation) or 0.92 percent of the wind power. Previous results from the Pacific between depths of 20 and 120 m have indicated integrated viscous dissipation rates of 13.9 erg $cm^{-2}$ $sec^{-1}$ (*2*) and 3.3 erg $cm^{-2}$ $sec^{-1}$ (*3*). The paucity of data from these previous studies, however, precluded any attempts to determine a relation such as that suggested here. Curiously enough, the measurements with the larger integrated dissipation rate (*2*) were made exclusively during daylight hours, whereas the smaller values (*3*) were found mostly at night. However, the profiles that dominate the larger average were made after a prolonged period of winds higher than those found in either of the other two studies.

Two previous turbulence measurements in surface mixed layers (both over mid-latitude continental shelves) have indicated that the amount of wind power communicated to the sea surface and lost to viscous dissipation over the depth of the mixed layer was 1.2 percent (not including the near-surface layer) (*13*) and 0.6 percent (over the depth range 15 to 90 m) (*14*). Neither of these studies considered the presumably high mixing rates in the upper few meters, but they do provide a basis for comparing ratios of dissipation loss to wind-power input below the top few meters. Because the ratio found in our equatorial study was not substantially different from either of the mid-latitude results, we suggest the possibility that a large part of the energy dissipated above the undercurrent core is due to the local (in both space and time) wind. On the other hand, if the wind during this time is representative of the climate of the wind, then the turbulent energy may result from the mean shear set up by the large-scale equatorial zonal pressure gradient, which in turn is a response to the wind that blew some time previously. In this case, the strong relation we found would have to be merely fortuitous, and hence we consider this possibility to be less likely.

Although we do not know to what extent our 12-day period is typical, we computed an annual mean value of the dissipation rate by correcting for the difference between the winds during the period and the annual winds, assuming that 0.92 percent of the wind power is dissipated year-round. The averaged wind-power input over a 1-year record of winds at 152°W (*15*) during 1979–80 was 510 erg $cm^{-2}$ $sec^{-1}$. In response to this wind, a long-term mean of 4.7 ± 0.5 erg $cm^{-2}$ $sec^{-1}$ is estimated to be lost to dissipation.

**References and Notes**


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