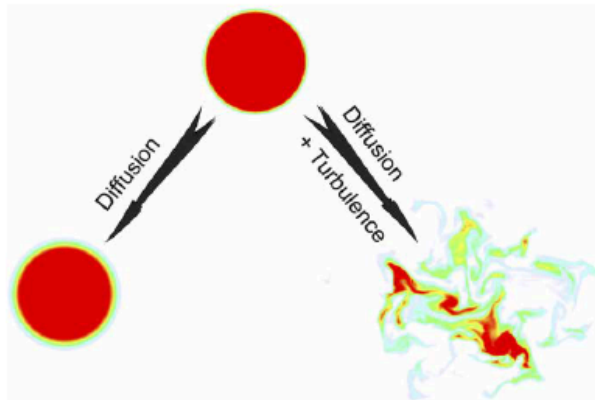


## SCIENCE BOX 1. TURBULENCE → MICROSTRUCTURE → MIXING

The discussion in this paper of the contribution of mixing to modulation of the diurnal warm layer relates to processes beneath the air-sea interface—hence, we refer here to this contribution as **subsurface mixing**. Mixing is an irreversible thermodynamic process by which scalar properties (like heat) diffuse at molecular scales. According to Fick's Law, the molecular diffusive flux of a scalar  $\Phi$  is  $-\gamma \partial \Phi / \partial x_j$ , where  $\gamma$  is the molecular diffusivity and  $\partial \Phi / \partial x_j$  is the mean scalar gradient. The negative sign indicates that molecular diffusion is always a down-gradient process, moving properties from regions of high concentration to regions of low concentration. The  $\gamma$  term is a property of the fluid that is measurable under laboratory conditions and varies weakly with temperature, pressure, and salinity. In the ocean, the molecular diffusivity of heat varies by around 15%, ranging from  $\gamma_T = 1.36 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$  for fresh, cool water ( $0 \text{ gm kg}^{-1}$ ,  $0^\circ\text{C}$ ) to  $\gamma_T = 1.51 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$  for warm, salty water ( $40 \text{ gm kg}^{-1}$ ,  $30^\circ\text{C}$ ).

Fluid dynamic instabilities (e.g., shear instability and convection) lead to fully three-dimensional **turbulence**, a consequence of which is scalar **microstructure**, small-scale eddies and overturns that enhance scalar gradients in all three dimensions as depicted in the lower right-hand corner of Figure SB1. Sensors to measure ocean microstructure, like the fast thermistors on the  $\chi$ SOLOs discussed here, provide a measure of these enhanced gradients. These small-scale gradients can be many orders of magnitude greater than mean background vertical gradients, consequently leading to enhanced molecular mixing that is several orders of magnitude greater than predicted by Fick's law.

We often model the effect of turbulence on mixing in the ocean using a turbulence diffusivity, which is a property of the fluid flow and varies in space and time. The diffusive term in the heat equation is thus modeled as a combination of turbulent and molecular diffusivities,  $\partial / \partial x_j [\rho c_p (K_T + \gamma_T) \partial T / \partial x_j]$ , where  $\rho$  is the density of seawater,  $c_p$  is the heat capacity of seawater, and  $K_T$  is the turbulent diffusivity of heat.  $K_T$ , a property of the flow, is inferred from measurements of the ocean's microstructure. Unlike molecular diffusivity, turbulence diffusivity varies widely, as shown in the  $\chi$ SOLO data, in which  $K_T$  ranges by five orders of magnitude from the molecular value to  $10^{-2} \text{ m}^2 \text{ s}^{-1}$ .



**FIGURE SB1.** A comparison of mixing enhanced by turbulence with mixing due to molecular processes alone, as revealed by a numerical solution of the equations of fluid motion. The initial state (top) includes a circular region of dyed fluid in a white background. Two possible evolutions are shown: one in which the fluid is motionless (save for random molecular motions) as shown on the bottom left, and one in which the fluid is in a state of fully developed turbulence (bottom right). The mixed region (yellow-green) diffuses much more rapidly in the turbulent case. *From Smyth and Moum (2001)*