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Turbulent Mixing and Resource Supply to Phytoplankton

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Abstract

The temporal and spatial variability of turbulence was determined by profiles of temperature-gradient microstructure or from surface energy budgets in three shallow and two deep lake basins. Rates of dissipation of turbulent kinetic energy ε, length scales of turbulent eddies, the coefficient of eddy diffusivity, and irradiance measurements were used to infer the light climate of phytoplankton. Time scales of mixing τ_{mix} are contrasted with time scales for photoadaptation τ_a. On calm days in a stratified basin, phytoplankton circulated within eddies that were at most 10% of the depth of the euphotic zone and could have experienced fluctuations that were up to 20% of surface irradiance. τ_{mix} was rapid enough that phytoplankton in the surface layer would not have had time to develop differences in photoadaption if $\tau_a \geq 15$ minutes. On windy days, overturns extended throughout and even beyond the depth of the euphotic zone. When overturns at the surface were larger than 1 meter, differences in the extent of photoadaptation would develop within overturns if $\tau_a = 15$ minutes. For $\tau_a = 6$ hours, photoadaptation was unlikely within weakly stratified surface overturns.

The turbulence data also were used to assess physical mechanisms important for fluxes of biologically important materials. Convective motions due to heat loss at night were more important than wind mixing in the day for vertical transport of solutes in a shallow, equatorial lake. Either intrusions or the inefficiency of mixing where turbulent Froude numbers are less than one led to persistent stratification during the day of heat, particles and solutes in a eutrophic lake despite moderate wind forcing. Wind forcing in a seasonally stratified lake led to upwelling and mixing in the thermocline. Because concentrations of PO_4-P increased below the depth of mixing, algae remained phosphorus limited. The muted biological response to high winds was in contrast to the five-fold increase in algal biomass in a shallow, attached basin in which phosphorus limitation was briefly alleviated due to sediment resuspension. Boundary mixing in a meromictic lake led to values of ε and nutrient fluxes that were two to four orders of magnitude higher at an onshore site than they were at an offshore site at similar depths.

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