Center for Environmental & Applied Fluid Mechanics

Turbulent Mixing Controls on Air-Sea Gas Exchange

Presented by
Professor Christopher J. Zappa
Lamont-Doherty Earth Observatory, Columbia University

Air-sea gas transfer influences CO_2 and other greenhouse gas fluxes on regional and global scales, yet the magnitude of the transfer is not well known. The CO_2 flux over the open ocean is typically determined by the product of the concentration difference across the mass boundary layer at the air-sea interface and the gas transfer velocity. For sparingly soluble gases like CO_2, theory predicts that the gas transfer velocity, k, is controlled by turbulence in the surface aqueous boundary layer, which dictates the rate at which gases can be brought into contact with the surface to exchange with the atmosphere. Considerable effort has gone into determining k in the field and developing parameterizations based upon wind speed since the wind stress at the ocean surface plays a central role in the generation of turbulence through the transfer of momentum to waves and currents. However, a variety of processes are generated from wind that may not all contribute equally.

For a wind-driven system, turbulence is generated near the air-water interface primarily through shear, Langmuir circulation, or large- and micro-scale wave breaking. Less dependence is observed under low wind speed conditions since buoyancy may dominate the production of turbulence in the near-surface layer and under conditions of surface contamination by thin organic films. At high winds, bubble-mediated effects also play a role. The acknowledged role of physical processes, including those not related to wind (e.g., tidal currents, internal waves, rain, stratification, surfactants, and shallow-water depth), suggest that a new paradigm is necessary for parameterizing gas exchange. In particular, it is argued to scale gas exchange explicitly with turbulence near the surface aqueous boundary layer. The scaling is consistent with mass diffusion across a layer of the thickness of the Batchelor scale.

Here, measurements are presented on the turbulent dissipation rate and gas transfer velocity in the coastal ocean, a macro-tidal estuary with wind and tidal forcing, a large tidal freshwater river, and a model ocean. The measurement and model results clearly show that gas transfer under wind, waves, currents, rain, and surfactants indeed scales with the hypothesized model based explicitly on the turbulent dissipation rate over a wide range of environmental systems with different types of environmental forcing and processes. The effects of bubbles are considered for the case at high winds in the coastal ocean when the gas exchange was enhanced relative to the model based on turbulence. These results have important implications for carbon cycling and management of carbon sequestration.

Friday, December 5, 2008
11:00 a.m., 110 Maryland Hall