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Parameterization of air–sea gas fluxes at extreme wind speeds

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Abstract

Air–sea flux measurements of O_2 and N_2 obtained during Hurricane Frances in September 2004 [D'Asaro, E. A. and McNeil, C. L., 2006. Measurements of air–sea gas exchange at extreme wind speeds. Journal Marine Systems, this edition.] using air-deployed neutrally buoyant floats reveal the first evidence of a new regime of air–sea gas transfer occurring at wind speeds in excess of 35 m s^{-1}. In this regime, plumes of bubbles 1 mm and smaller in size are transported down from near the surface of the ocean to greater depths by vertical turbulent currents with speeds up to 20−30 cm s^{-1}. These bubble plumes mostly dissolve before reaching a depth of approximately 20 m as a result of hydrostatic compression. Injection of air into the ocean by this mechanism results in the invasion of gases in proportion to their tropospheric molar gas ratios, and further supersaturation of less soluble gases. A new formulation for air–sea fluxes of weakly soluble gases as a function of wind speed is proposed to extend existing formulations [Woolf, D.K, 1997. Bubbles and their role in gas exchange. In: Liss, P.S., and Duce, R.A., (Eds.), The Sea Surface and Global Change. Cambridge University Press, Cambridge, UK, pp. 173–205.] to span the entire natural range of wind speeds over the open ocean, which includes hurricanes. The new formulation has separate contributions to air–sea gas flux from: 1) non-supersaturating near-surface equilibration processes, which include direct transfer associated with the air–sea interface and ventilation associated with surface wave breaking; 2) partial dissolution of bubbles smaller than 1 mm that mix into the ocean via turbulence; and 3) complete dissolution of bubbles of up to 1 mm in size via subduction of bubble plumes. The model can be simplified by combining "surface equilibration" terms that allow exchange of gases into and out of the ocean, and "gas injection" terms that only allow gas to enter the ocean. The model was tested against the Hurricane Frances data set. Although all the model parameters cannot be determined uniquely, some features are clear. The fluxes due to the surface equilibration terms, estimated both from data and from model inversions, increase rapidly at high wind speed but are still far below those predicted using the cubic parameterization of Wanninkhof and McGillis [Wannikhof, R. and McGillis, W.R., 1999. A cubic relationship between air–sea CO_2 exchange and wind speed. Geophysical Research Letters, 26:1889–1892.] at high wind speed. The fluxes due to gas injection terms increase with wind speed even more rapidly, causing bubble injection to dominate at the highest wind speeds.

Keywords: Air–Sea Exchanges; Hurricanes; Parameterization; Dissolved Gases

1. Introduction

The functional dependence of air–sea gas transfer rates on wind speed has received much attention in the literature, and a large range of dependencies have been proposed, including piecewise linear (Liss and Merlivat,

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