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Spatial and seasonal variability of the air-sea equilibration timescale of carbon dioxide

Daniel Jones (1,2), Takamitsu Ito (2), Yohei Takano (2), Wei-Ching Hsu (2,3)

(1) British Antarctic Survey, Cambridge, UK (dannes@bas.ac.uk), (2) School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, Georgia, USA , (3) Department of Oceanography, Texas A&M University, College Station, Texas, USA

The exchange of carbon dioxide between the ocean and the atmosphere tends to bring near-surface waters toward equilibrium by reducing the partial pressure gradient across the air-water interface. However, the equilibration process is not instantaneous; in general there is a lag between forcing and response. The timescale of air-sea equilibration depends on several factors involving the depth of the mixed layer, temperature, salinity, wind speed, and carbonate chemistry. In this work, we use a suite of observational datasets to generate climatological and seasonal composite maps of the air-sea equilibration timescale. The relaxation timescale exhibits considerable spatial and seasonal variations, which are largely set by changes in mixed layer depth and wind speed. The net effect is dominated by the mixed layer depth; the gas exchange velocity and carbonate chemistry parameters only provide partial compensation. Broadly speaking, the adjustment timescale tends to increase with latitude. We compare the observationally-derived air-sea gas exchange timescale with a model-derived surface residence time and a data-derived horizontal transport timescale, which allows us to define two non-dimensional metrics of gas exchange efficiency. These parameters highlight the Southern Ocean, equatorial Pacific, and North Atlantic as regions of inefficient air-sea equilibration where carbon anomalies are likely to form and persist. The efficiency parameters presented here can serve as simple tools for understanding regional air-sea disequilibrium in both observations and models.