Vertical Gradients in Atmospheric CO_2 as a Constraint on Southern Ocean Fluxes

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The Southern Ocean plays an important role in the global carbon cycle and climate system, but net carbon dioxide (CO_2) flux into the Southern Ocean is difficult to model because it results from larger opposing and seasonally-varying fluxes due to thermally-forced outgassing and biological uptake. We present an analysis to constrain the seasonal cycle of net CO_2 exchange with the Southern Ocean and magnitude of summer uptake using the large-scale vertical gradient in atmospheric CO_2 as measured during three aircraft campaigns with coverage in the southern polar region. The O_2/N_2 Ratio and CO_2 Airborne Southern Ocean Study (ORCAS) was an airborne campaign that intensively sampled the atmosphere at 0-13 km altitude and 45-75 degrees south latitude in the austral summer (January-February) of 2016. The global airborne campaigns, the HIAPER Pole-to-Pole Observations (HIPPO) study and the Atmospheric Tomography Mission (ATom), provide additional measurements within the Antarctic Polar Cell from other seasons and multiple years. A compilation of vertical profile data from these campaigns provides a generalized description of the seasonal pattern of Southern Ocean air-sea fluxes and no evidence of large interannual variability in the seasonal pattern. The observed vertical gradients may also have significant contribution from long-range transport of terrestrial flux signals from northern latitudes. We use measurements of atmospheric methane (CH_4), which has no Southern Ocean source, a significant terrestrial source, and well-understood sink processes, to account for long-range transport in the observed CO_2 gradient. Comparison of observations and model simulations using multiple transport and flux models reveals a large spread in models' ability to reproduce the observed vertical gradient and seasonal cycle. We attempt to evaluate whether some model's tendency to underestimate the observed vertical gradient is due to too-small fluxes or too-large vertical mixing.

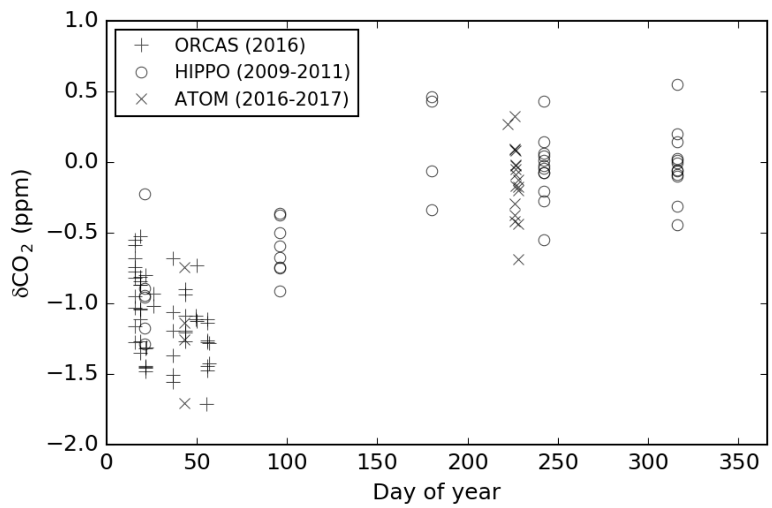

Figure 1. Observed atmospheric CO_2 vertical gradients by day of year in the southern polar region (35-75 degrees south latitude) from on three airborne campaigns spanning the years of 2009-2017. Gradients are calculated as the difference in mean CO_2 at 270-280 K and 290-300 K potential temperature for individual profile maneuvers.