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Zonal asymmetry of Southern Ocean air-sea carbon fluxes

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The Southern Ocean modulates the climate system by exchanging heat and carbon dioxide (CO_2) between the atmosphere and deep ocean. While this region plays an outsized role in the global oceanic anthropogenic carbon uptake, CO_2 is released into the atmosphere across large swaths of the Antarctic Circumpolar Current (ACC). Southern Ocean outgassing has long been attributed to remineralized carbon from upwelled deep water, but the precise mechanisms by which this water reaches the surface are not well known. Using data from a novel array of autonomous biogeochemical profiling floats, we estimate Southern Ocean air-sea CO_2 fluxes at unprecedented spatial resolution and determine the pathways that transfer carbon from the ocean interior into the mixed layer where air-sea exchange occurs. Float-based flux estimates suggest that carbon outgassing occurs predominantly in the Indo-Pacific sector of the ACC due to variations in the mean surface ocean partial pressure of CO_2 (pCO_2). Within the Polar Frontal Zone and Antarctic Southern Zone of the ACC, the annual mean pCO_2 difference between the Indo-Pacific and Atlantic is 40.1 ± 12.9 µatm and 17.9 ± 12.4 µatm, respectively. We show that this zonal asymmetry in surface pCO_2 and consequently air-sea carbon fluxes stems from regional variability in the mixed-layer entrainment of carbon-rich deep water. These results suggest that long-term trends of the Southern Ocean carbon sink inferred from sparse shipboard data may depend on the fraction of measurements from each basin in a given year. Furthermore, sampling these different air-sea flux regimes is necessary to monitor future changes in oceanic carbon release and uptake.