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Hypersensitivity of Southern Ocean air-sea carbon fluxes and biological productivity to turbulent diapycnal fluxes

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The Southern Ocean (SO) connects major ocean basins and hosts large air-sea carbon fluxes due to the resurfacing of deep nutrient and carbon rich waters, driven by strong surface winds. Strong vertical mixing in the SO is induced by breaking waves excited by strong surface winds and interaction of tides, jets and eddies with rough topography. Vertical mixing has primarily been considered of importance for biogeochemical cycles due to the role of mixing in setting the underlying dynamics of the meridional circulation on a centennial timescale. Using an eddy-permitting ocean model that assimilates an extensive array of observations, we show that altered mixing can cause up to a 40% change in SO air-sea fluxes in only a few years by altering the distribution of dissolved inorganic carbon, alkalinity, temperature and salinity. Biological productivity is also highly altered, with strong regional and seasonal variations in the sensitivity and response to enhanced mixing. This altered biological productivity could lead to alterations in the biological carbon pump over longer time scales. The high sensitivity of carbon fluxes and biological productivity shown over short time scales is due to high vertical gradients in nutrients, DIC, alkalinity and temperature found in the upper waters of the SO. Further carbon flux and other biogeochemical observations are to better constrain the rates of vertical mixing from observations. Vertical mixing processes are unresolved in climate models, yet essential for the modelling of SO carbon cycles.