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A synthesis of observations of aerosol-cloud interactions over the pristine, biologically active Southern Ocean and their implications for global climate model predictions

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The change in planetary albedo due to aerosol-cloud interactions (aci) during the industrial era is the leading source of uncertainty in inferring Earth's climate sensitivity to increased greenhouse gases from the historical record. Examining pristine environments such as the Southern Ocean (SO) helps us to understand the pre-industrial state and constrain the change in cloud brightness over the industrial period associated with aci. This study presents two methods of utilizing observations of pristine environments to examine climate models and our understanding of the pre-industrial state.

First, cloud droplet number concentration (N_d) is used as an indicator of aci. Global climate models (GCMs) show that the hemispheric contrast in liquid cloud N_d between the pristine SO and the polluted Northern Hemisphere observed in the present-day can be used as a proxy for the increase in N_d from the pre-industrial. A hemispheric difference constraint developed from MODIS satellite observations indicates that pre-industrial N_d may have been higher than previously thought and provides an estimate of radiative forcing associated with aci between -1.2 and -0.6 Wm^{-2}. Comparisons with MODIS N_d highlight significant GCM discrepancies in pristine, biologically

active regions.

Second, aerosol and cloud microphysical observations from a recent SO aircraft campaign are used to identify two potentially important mechanisms that are incomplete or missing in GCMs: i) production of new aerosol particles through synoptic uplift, and ii) buffering of N_d against precipitation removal by small, Aitken mode aerosols entrained from the free troposphere. The latter may significantly contribute to the high, summertime SO N_d levels which persist despite precipitation depletion associated with mid-latitude storm systems. Observational comparisons with nudged Community Atmosphere Model version 6 (CAM6) hindcasts show low-biased SO N_d is linked to under-production of free-tropospheric Aitken aerosol which drives low-biases in cloud condensation nuclei number and likely discrepancies in composition. These results have important implications for the ability of current GCMs to capture aci in pristine environments.