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ABSTRACT

Constraints on the global transformation of seawater from interactions with the atmosphere and implications for polar climate

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Earth's polar and sub-polar climates are critically reliant on heat transported from the tropics by the ocean and atmosphere. This heat transport is a consequence of oceanic and atmospheric circulations, both of which have complex spatial patterns and are fundamentally coupled to each other. While major strides have been made in understanding the dynamics of the ocean and atmosphere, some fundamental questions persist regarding the drivers of the ocean's Meridional Overturning Circulation (MOC), which describes the poleward and vertical movement of seawater and the heat it carries. For instance, why does the downwelling branch of the MOC form in the North Atlantic and not the Pacific? How sensitive is the strength of this downwelling branch of dense waters to influxes in freshwater at the ocean's surface? What is the relationship between the downwelling of waters in the North Atlantic, and the upwelling of waters in the Southern Ocean?

Here we argue that these distinct questions can be addressed concurrently by the examining the relationship between the regional and global transformation of seawater at the ocean surface [e.g. "watermass transformation", Walin, 1982]. The surface watermass transformation quantifies the volume flux across surfaces of constant density (or "isopycnals") in the ocean as required by the patterns of heat and freshwater fluxes between the ocean and atmosphere. Regionally, this transformation drives the local meridional circulation. Globally, we argue, the total surface transformation reveals the thermodynamic coupling of the ocean and atmosphere. We compare results from a high-resolution, fully coupled global climate model, its lower resolution counterpart (each a version of the Community Climate System Model 3.5), and a suite of idealized climate models with differing configurations of idealized continents (each versions of the MIT Global Climate Model). We show that, regardless of continental geometry or model used, certain characteristics of the total watermass transformation emerge on a global scale. We argue that these invariant features can be considered constraints on the interaction between the ocean and atmosphere on a global scale and can provide a link between seemingly distinct behaviors of distant ocean regions. We show that the high latitude Pacific and Southern Ocean surfaces provide a freshwater transformation sink that both enables deep water to *downwell* in the North Atlantic,

and to *upwell* in the Southern Ocean. This quantifies a linkage between (spatially) remote processes. This linkage provides new insights into the relationship between the response high latitude Northern and Southern Ocean circulations and heat transports to increases in atmospheric CO2 and sheds light on the response of the possible climatic implications in the polar regions.