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Key Points:
- First observationally based quantification of shortwave radiation depth penetration parameterizations effects on water mass transformation
- The effect of Chl *a* on water mass transformation is as important as that due to differences between freshwater flux products
- Water mass transformation suggest errors in air-sea fluxes in models propagate into mixing parameterizations and the ocean T&S structure

Supporting Information:
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The Effect of Air-Sea Flux Products, Shortwave Radiation Depth Penetration, and Albedo on the Upper Ocean Overturning Circulation

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Abstract Water mass transformation quantifies transport of matter between different density classes of the World Ocean. We present the first observationally based quantification of transformation rates due to air-sea buoyancy fluxes, which considers different parameterizations of shortwave radiation depth penetration, including the influence of albedo and the Chlorophyll *a* concentration. The results provide a range of solutions that can be used to compare model-based transformation rates against. We compared two air-sea flux products with limited representation of ice dynamics at high latitudes. We find that variations in the air-sea heat fluxes due to Chlorophyll *a* and its horizontal distribution are as important for water mass transformation rates than differences between the freshwater flux products. An accurate representation of the effects and spatial distribution of Chlorophyll *a* is required to obtain realistic transformation rates.

Plain Language Summary Air-sea fluxes of heat and freshwater (precipitation, evaporation, warming by the sun, etc.) are difficult to measure accurately. Yet they influence the ocean circulation and, for example, how and how much heat and anthropogenic carbon are absorbed by the ocean. In this study, we measure variations of the effect of air-sea fluxes on ocean dynamics. We found that Chlorophyll *a* in the ocean (a measure for very small biology), changes both the amount of incoming sunlight (through reflection) and how deep the sunlight can reach. Through this effect, Chlorophyll *a* may indirectly affect the climate system. Scientist predicting future climates should therefore include this effect carefully in their numerical ocean models.

1. Introduction

Observations of uniform properties along neutrally buoyant surfaces (neutral surfaces) have led to conceive of ocean circulation as a superposition of (1) movement along neutral directions that extends from air-sea interface into the interior (epineutral transport) plus (2) a dianeutral transport (Griffies, 2004; Iselin, 1939; McDougall & Church, 1986; McDougall et al., 2014; Solomon, 1971; Veronis, 1975). The dianeutral component of the circulation establishes the vertical buoyancy stratification and impacts the vertical transport of mass, and the distribution and storage of dissolved tracers like heat and carbon, in the deep ocean (Bindoff et al., 2007; Bopp et al., 2015; Groeskamp, Lenton, et al., 2016; Iudicone et al., 2016).

Water mass transformation (WMT) is an integral quantification of the dianeutral mass transport. WMT results from a change in a fluid parcels buoyancy due to a net change in its temperature or salinity. Such a net change is the result of convergence of heat and freshwater by either boundary fluxes (e.g., air-sea or sea - ice fluxes) or interior mixing processes (Marshall et al., 1999; Nurser et al., 1999; Speer & Tziperman, 1992; Walin, 1977, 1982).

The related air-sea buoyancy fluxes (Figure 1) are difficult to determine due to inaccuracies representing processes such as boundary layer processes, cloud radiative feedbacks, wind speed, humidity, albedo, and sea state-related variables (Griffies et al., 2009; Yeager & Large, 2008). While a net globally integrated heatflux of about 0.3 W/m^2 is enough to explain the observed increase in global heat content (Domingues et al., 2008; Ishii & Kimoto, 2009; Levitus et al., 2012; Lyman & Johnson, 2013), imbalances at 100 times larger are not uncommon for available heat flux products (Balmaseda et al., 2015; Valdivieso et al., 2017). The dependence