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How does heat flux affect potential vorticity in the Southern Ocean?

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Surface heat loss leads to thick winter mixed layers over the Southern Ocean, which feeds the formation of subsurface mode water pools through subduction. One such water class is Subantarctic Mode Water (SAMW), which is characterised by its low absolute potential vorticity. SAMW occurs in several regions of the Southern Ocean on the northern side of the Antarctic circumpolar current and it extends into the subtropics below the surface on different density surfaces. Using the ECCOv4 global ocean circulation model, we conduct a series of adjoint sensitivity experiments and forward perturbation experiments at key Southern Ocean SAMW formation sites, focusing on how different surface forcing affects potential vorticity. This adjoint approach produces time-evolving sensitivity maps that identify where and when surface heat loss potentially impacts the formation of mode waters. Over the first year in lead time, we find that greater surface heat loss leads to stronger convection and lower SAMW potential vorticity. On lead times longer than one year, in some regions of high sensitivity, the sensitivity reverses its sign, such that more surface heat loss ultimately leads to higher values of potential vorticity in the subduction regions. This reversal of sign of the sensitivity can be attributed to a shift from local convective forcing to upstream advective forcing and the associated redistribution of potential temperature and salinity. Surface adjustment also plays a role in the upstream sensitivities due to the tendency for temperature anomalies to be weakened through compensating salinity before reaching the subduction zone. We use the adjoint sensitivity fields to design a set of forward, non-linear perturbation experiments to provide physical insight into how ventilation affects the uptake of heat and carbon. This physical insight is important for identifying which physical mechanisms affect the subducted properties in the Southern Ocean, especially as the ocean warms through climate change.