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Recent Biogeochemical trends in the Southern Ocean: Signs of a positive feedback in the climate system?

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The high latitude regions of the Southern Hemisphere have experienced significant climate change over the past several decades, as manifested, for example, in a trend toward more positive phases of the Southern Hemisphere Annular Mode (SAM). Recent climate model simulations suggested that this trend is consistent with global warming, and that this trend likely will continue into the future. Here, we investigate the role and impact of this trend on the carbon cycle and biology in the Southern Ocean using a combination of data analyses and hindcast simulations with a coupled physical/biogeochemical/ecological model that has been forced with varying windfields and air-sea fluxes of heat and water over the past 50 years. We find that in the model, this trend toward more positive phases of SAM has caused a trend toward an anomalous outgassing of CO_2 from the Southern Ocean, thereby reducing the modeled Southern Ocean CO_2 sink considerably over this period. This result is consistent with the interannual response of the Southern Ocean air-sea fluxes of CO_2 to interannual variations in SAM. A more detailed analysis of the model results suggests that this anomalous outgassing is primarily driven by the increase in the meridional overturning circulation in the Southern Ocean that arises from the southward shift and intensification of the westerly windbelt over the Southern Ocean, which brings increased amounts of waters rich in dissolved inorganic carbon (DIC) to the surface. Although we find a slight increase in biological productivity over time in our model, this

change is too small to offset the increased DIC transport to the surface, so that most of this anomalous DIC is vented to the atmosphere. The results from our model simulations suggest that the Southern Ocean carbon cycle, in interaction with the Southern Hemisphere atmosphere-ocean circulation, could be enhancing the anthropogenically-induced global warming. Given the possible link between global warming and the positive trend in the SAM, this mechanism could constitute a positive feedback loop in the climate system, confirming an earlier suggestion by R. Toggweiler and colleagues. Additional global warming induced changes in the Southern Ocean, such as increased ocean stratification, may further enhance this effect, so that the Southern Ocean may represent one of the Achilles' heels of Earth's climate system.