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Emergence of North Atlantic Deep Water during the Cenozoic: A Tale of Geological and Climatic Forcings

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The modern thermohaline circulation in the Atlantic Ocean plays a crucial role in shaping the climates of Europe and North America. It also significantly influences ocean carbon storage and biological productivity through processes such as deep ocean ventilation and nutrient advection. A pivotal element of this intricate circulation system is the deep convection in the North Atlantic, which is essential for the Atlantic meridional overturning circulation. Paleogeographic studies based on data from the Cenozoic era propose that the establishment of this ocean conveyor belt occurred between the Middle Eocene (approximately 48 to 38 million years ago) and the Late Miocene (around 11 to 5 million years ago). This period witnessed significant climate fluctuations, notably exemplified by the Eocene-Oligocene transition (34 million years ago), marked by a sudden global temperature cooling and the emergence of the Antarctic Ice Sheet (AIS). Did these changes have a significant impact on the stability of the North Atlantic Ocean? To address this question, we investigate the mechanisms behind the initiation of deep water in the North Atlantic during the Eocene to Miocene transition, using the Earth System model IPSL-CM5A2. Our Eocene simulation indicates an absence of convective instabilities in the North Atlantic, whereas deep convection is evident in our Miocene simulation, enabling the presence of a proto-Atlantic Meridional Overturning Circulation (AMOC) cell. In order to investigate the processes triggering North Atlantic Deep Water (NADW) initiation under Miocene conditions, we conducted sensitivity tests involving a reduction in atmospheric CO2 concentration from 1,120 ppmv to 560 ppmv and the introduction of AIS for Eocene conditions. Our findings reveal that halving the CO2 concentration and initiating AIS during the Eocene is insufficient to destabilize the water column in the North Atlantic and instigate the formation of NADW. The Eocene paleogeography emerges as a key factor, contributing to an inflow of fresh water into the Atlantic Ocean, resulting in low surface water density. This process reinforces stratification, hindering the onset of convection.