

# Vigorous ocean overturning and its contribution to warm Southern Ocean during the early Eocene in the IPSL model

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## Abstract

The early Eocene (~55Ma) was an extreme warm period in the geological history, which was also characterised by a different ocean state from the present-day. Based on the analysis of simulations of the Eocene performed with the coupled IPSL-CM5A2-VLR climate model with different levels of atmospheric CO<sub>2</sub>, and comparison with simulations set up for pre-industrial (PI hereafter), we explore the ocean circulation and its relationship with the oceanic meridional heat transport. The 55Ma simulations are characterised by a strong abyssal overturning circulation (44 Sv) in the Southern Hemisphere, associated with deep water formation in the 3 sectors of the Southern Oceans, but no deep water formation in the Northern Hemisphere. The North Atlantic basin is very limited north of 50°N and has almost no subpolar gyre. The North Pacific subpolar gyre has a much lower salinity, hence density, than the Southern Oceans, because of strong precipitation and runoff induced by the topographic uplift of moist westerlies above the paleo-Rocky Mountains. In contrast the Southern Ocean receives much lower precipitation and runoff as the lower atmosphere winds around Antarctica largely follow the continental orography. In addition, the closed Drake and Tasman passages provide western boundaries for the build-up of strong subpolar gyres in the Weddell and Ross Seas, that further aids deep convection and deep-water formation through isopycnal doming. Finally, the strong overturning circulation and subpolar gyres sustain the poleward advection of saline subtropical water to the Southern Oceans convection regions and maintain the deep-water formation: this salt-advection feedback mechanism works similarly in the present-day North Atlantic overturning circulation. This strong abyssal overturning circulation in the 55Ma simulations primarily results in an enhancement of poleward heat transport (OHT) by 0.5 PW in the Southern Hemisphere compared to PI, reaching 1.8 PW southward around 20°S. Such an increase in OHT can trigger feedback between OHT and atmospheric radiative, as suggested by Rose and Ferreira et al. (2013). This feedback contributes to maintain the high latitudes of the Southern Ocean so warm in the Eocene. Comparisons of simulations with different atmospheric CO<sub>2</sub> levels suggest that ocean circulation and heat transport are relatively insensitive to CO<sub>2</sub>-doubling, at least in the range tested, whereas the ocean temperature response is much larger in the 55Ma simulations than in PI in the absence of the sea-ice buffering effect.

**Keywords:** the Early Eocene, overturning circulation, deep water formation, ocean convection, salt-advection feedback, gyre circulations, oceanic heat transport.