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Inception and variability of the Antarctic ice sheet across the Eocene-Oligocene transition

Paolo Stocchi (1), Simone Galeotti (2), Jan-Baptiste Ladant (3), Robert DeConto (1,4), Bert Vermeersen (5), and Maria Rugenstein (6)

(1) NIOZ Royal Netherlands Institute for Sea Research, Physical Oceanography, Den Burg, Netherlands (paolo.stocchi@nioz.nl), (2) Dipartimento Geo TeCA, Università degli Studi di Urbino 'Carlo Bo', Località Crocicchia, 61029 Urbino, Italy, (3) Laboratoire des Sciences du Climat et de l'Environnement, CEA-CNRS-UVSQ, CEA Saclay, Orme des Merisiers, FR-91191 Gif-sur-Yvette, France, (4) Department of Geosciences, University of Massachussets, Amherst, Massachussets, 01003, USA, (5) TU Delft Climate Institute - Delft University of Technology, Delft, The Netherlands, (6) Institute for Marine and Atmospheric Research Utrecht, Utrecht University, Utrecht, The Netherlands

Climate cooling throughout middle to late Eocene ($\sim$48 - 34 Million years ago, Ma) triggered the transition from hot-house to ice-house conditions. Based on deep-sea marine δ18O values, a continental-scale Antarctic Ice Sheet (AIS) rapidly developed across the Eocene-Oligocene transition (EOT) in two $\sim$200 kyr-spaced phases between 34.0 - 33.5 Ma. Regardless of the geographical configuration of southern ocean gateways, geochemical data and ice-sheet modelling show that AIS glaciation initiated as atmospheric CO_2 fell below $\sim$2.5 times pre-industrial values. AIS likely reached or even exceeded present-day dimensions. Quantifying the magnitude and timing of AIS volume variations by means of δ18O records is hampered by the fact that the latter reflect a coupled signal of temperature and ice-sheet volume. Besides, bathymetric variations based on marine geologic sections are affected by large uncertainties and, most importantly, reflect the local response of relative sea level (rsl) to ice volume fluctuations rather than the global eustatic signal. AIS proximal and Northern Hemisphere (NH) marine settings show an opposite trend of rsl change across the EOT. In fact, consistently with central values based on δ18O records, an 60 $\pm$ 20m rsl drop is estimated from NH low-latitude shallow marine sequences. Conversely, sedimentary facies from shallow shelfal areas in the proximity of the AIS witness an 50 - 150m rsl rise across the EOT. Accounting for ice-load-induced crustal and geoidal deformations and for the mutual gravitational attraction between the growing AIS and the ocean water is a necessary requirement to reconcile near- and far-field rsl sites, regardless of tectonics and of any other possible local contamination. In this work we investigate the AIS inception and variability across the EOT by combining the observed rsl changes with predictions based on numerical modeling of Glacial Isostatic Adjustment (GIA). We solve the gravitationally self-consistent Sea Level Equation for two different and independent AIS models both driven by atmospheric CO_2 variations and evolving on different Antarctic topographies. In particular, minimum and maximum AIS volumes, respectively of $\sim$55m and $\sim$70m equivalent sea level (esl), stem from a smaller and a larger Antarctic topography. Minimum and maximum GIA predictions at the NH rsl sites respectively correspond to the lower limit and central value of the EOT rsl drop inferred from geological data. For both GIA models, the departures from the eustatic trend significantly increase southward toward Antarctica, where the AIS growth is accompanied by a rsl rise. Accordingly, the cyclochronological record of sedimentary cycles retrieved from Cape Roberts Project Drillcore CRP-3 (Victoria Land Basin) witness a deepening across the EOT. Most importantly, CRP-3 record shows that full glacial conditions consistent with the maximum AIS model dimensions were reached only at $\sim$32.8 Ma, while ice-sheet volumes fluctuations around the minimum AIS model volume persisted during the first million years of glaciation.