Mantle Dynamic Impacts on Cenozoic Sea-Level Evolution

Supervisors

Lead Supervisor: Fred Richards

Research Group

Solid Earth–Fluid Earth Interactions (SoEFEI) Group (https://freddrichards.github.io/team/)

Project Summary

Since the start of the Cenozoic Era (~65 million years ago) our planet has experienced major climatic shifts, including periods of extreme warmth, like the Palaeocene-Eocene Thermal Maximum (~55 million years ago) where global temperatures reached 5–8 °C above their current level, as well as intervals of rapid cooling, such as the Early Pleistocene (~2 million years ago), which coincided with a 4–5°C temperature drop. Accurately determining the amplitudes of ice volume and sea-level variations triggered by these climatic fluctuations is a key priority in climate science, since they hold important clues for understanding the likely response of modern ice sheets to future temperature changes.

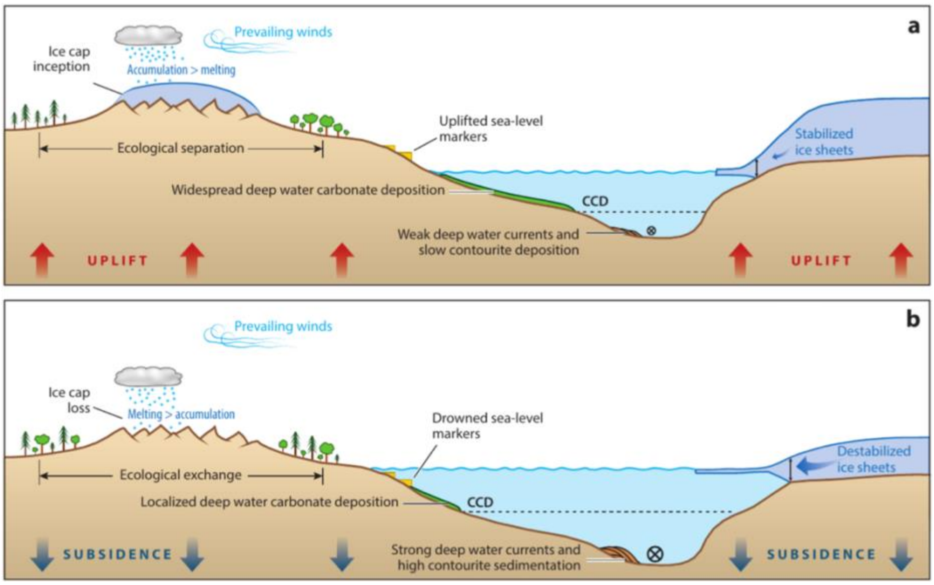

***Figure 1:** Impacts of mantle-flow-driven uplift **(a)** and subsidence **(b)** on Earth's atmosphere, cryosphere biosphere, ocean circulation, and surface processes.*

However, it is increasingly clear that vertical motions of the Earth's surface caused by upwelling and downwelling mantle flow—known as *dynamic topography*—can significantly impact our ability to determine past ice volume and sea-level changes. First, they deflect ancient shoreline deposits by tens to hundreds of meters, making it difficult to disentangle the signal of global glacio-eustatic sea-level variations from local sea-level changes caused by these topographic perturbations. Secondly, they can directly impact the 'carrying capacity' of ice sheets by altering their bedrock topography (Parazin et al., 2025, *GRL*) and by modulating ocean and atmospheric circulation patterns (Parnell-Turner et al., 2015, *G*^{3}).

The successful applicant will combine state-of-the-art geodynamic inverse models with multiple petrological, geomorphic, and palaeoclimatic datasets (including new data they collect during fieldwork in Australia) to reconstruct Cenozoic mantle flow and its impact on the cryosphere. This work will allow them to become an integral part of the global effort to improve the reliability of sea-level projections and better protect the ~700 million people currently living along flood-susceptible coastlines.

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Research Context and Objectives

Until recently, it has not been possible to reconstruct past mantle flow patterns with sufficient accuracy to meaningfully quantify their impact on ice-sheet dynamics and sea-level change. However, recent advances in seismic tomographic imaging and mineral physics experiments, when combined with innovative inverse methods, now enable the temperature, density, and viscosity of Earth's interior to be mapped (Hazzard et al., 2023, *JGR*). In addition, the development of new 'adjoint-based' geodynamic inversion tools (e.g. G-ADOPT) makes it possible to robustly reconstruct mantle flow histories from these estimates of Earth's present internal state. Finally, there has been significant growth in the datasets needed to optimise and validate such reconstructions: palaeo-sea-level indicators are more densely sampled and better dated than before; patterns of large-scale continental uplift and subsidence are increasingly well constrained by geomorphological studies; and spatio-temporal mantle temperature evolution can now be extracted from basalts and xenoliths.

By combining these recent advances, the successful applicant will aim to 'kill two birds with one stone': transforming our knowledge of ice-sheet sensitivity to future climate change, while simultaneously producing reliable reconstructions of our planet's internal state throughout the Cenozoic Era. This will involve:

1) Using novel inverse techniques developed in the SoEFEI group to create an array of optimised estimates of Earth's present-day physical state for different seismic tomographic models.
2) Developing mantle flow reconstructions in G-ADOPT for each endmember Earth state that are optimised to fit petrological mantle temperature constraints and tectonic plate velocities.
3) Building a comprehensive database of sea-level indicators for key Cenozoic warm periods from existing sources and field work in Australia.
4) Fusing machine learning and Bayesian inverse techniques to correct the database for best-fitting mantle flow reconstructions, thereby generating the first probabilistic and geodynamically accurate estimates of global mean sea level for each warm period.
5) Estimating warm-period palaeotopographies using best-fitting reconstructions to quantify the impact of dynamic topographic change on past ice-sheet stability and atmospheric and ocean circulation.

Further reading:

Richards, F. D., Coulson, S. C., Hoggard, M. J., Austermann, J., Dyer, B. & Mitrovica, J. X. (2023). Geodynamically corrected Pliocene shoreline elevations in Australia consistent with midrange projections of Antarctic ice loss, *Science Advances*, **9**, eadg3035, doi: 10.1126/sciadv.adg3035.

Who are we looking for?

The ideal candidate will have a background in Earth sciences, applied mathematics, physics, or a related field. They will have strong mathematical and computational skills, a desire to conduct interdisciplinary research at the interface between geodynamics and palaeoclimate, and—while prior field experience is not necessary—they will be interested in the opportunity to collect palaeo-sea-level data during a two-week field trip to SE Australia (scheduled for January 2027).

The candidate will have the chance to visit and collaborate with project partners at Australian National University and the University of Exeter, will be supported in boosting their profile through annual attendance of national and international conferences, and will be joining a vibrant and supportive group, where training is carefully tailored to individual needs and goals.