# Thermal adaptation evolution of the biosphere regulates Earth's long-term climate

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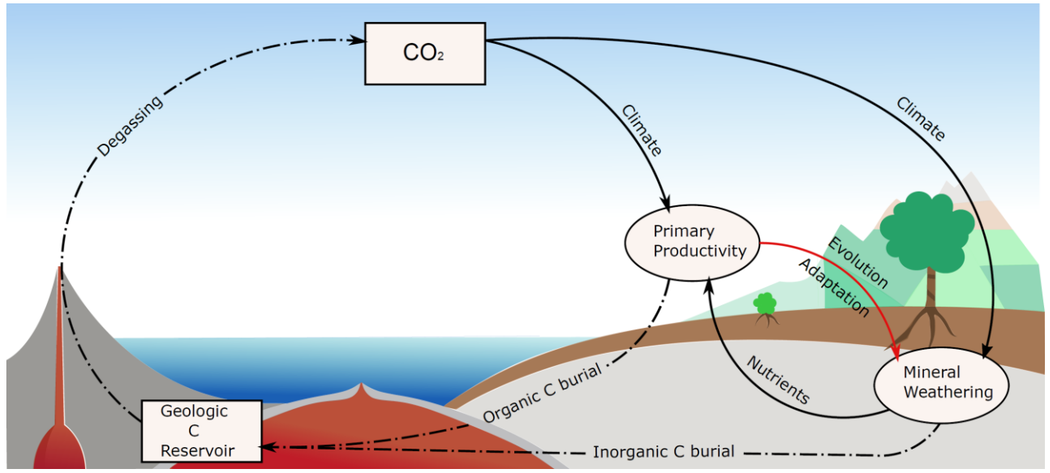
Climate regulation mechanisms of atmospheric $CO_2$ are key for the persistence and diversity of life on our planet. Over geological time scales, climate is driven by the balance of carbon fluxes between geologic reservoirs and Earth's oceans, atmosphere and the biosphere. On a million-year timescale, there is a need for a mass balance in Earth's surface carbon pools to avoid runaway climate states [1]:

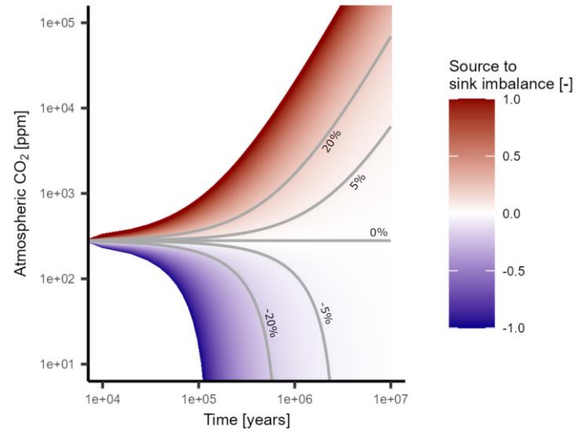
$$F_{degassing} + F_{org.\ C\ weathering} = F_{silicate\ weathering} + F_{org.\ C\ burial}$$

Here, we investigate the role of the **evolving** biosphere on organic and inorganic carbon fluxes and the resulting atmosphere-ocean carbon mass balance over the last 400 Myr. **How important are biological dynamics to maintain a close to steady state carbon mass balance over geologic time?**




Carbon fluxes and processes of the geologic carbon cycle.

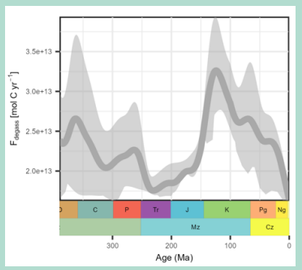
The interactions of the terrestrial biosphere with the organic and inorganic carbon system depend on the state of ecological and evolutionary adaptation to the prevailing environment.

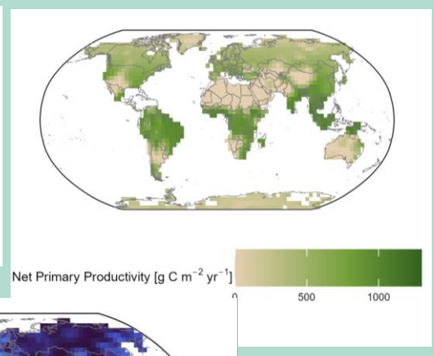


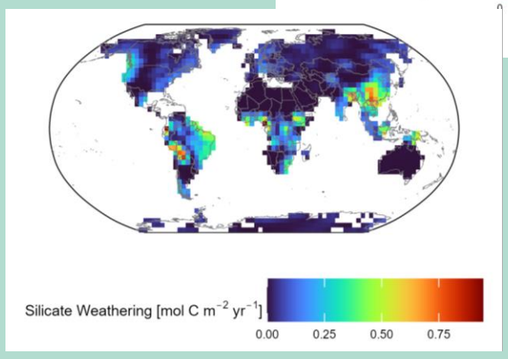

The effect of an imbalance in the geologic carbon cycle [2].

## A

Model based reconstruction of inorganic and organic carbon fluxes over the Phanerozoic.

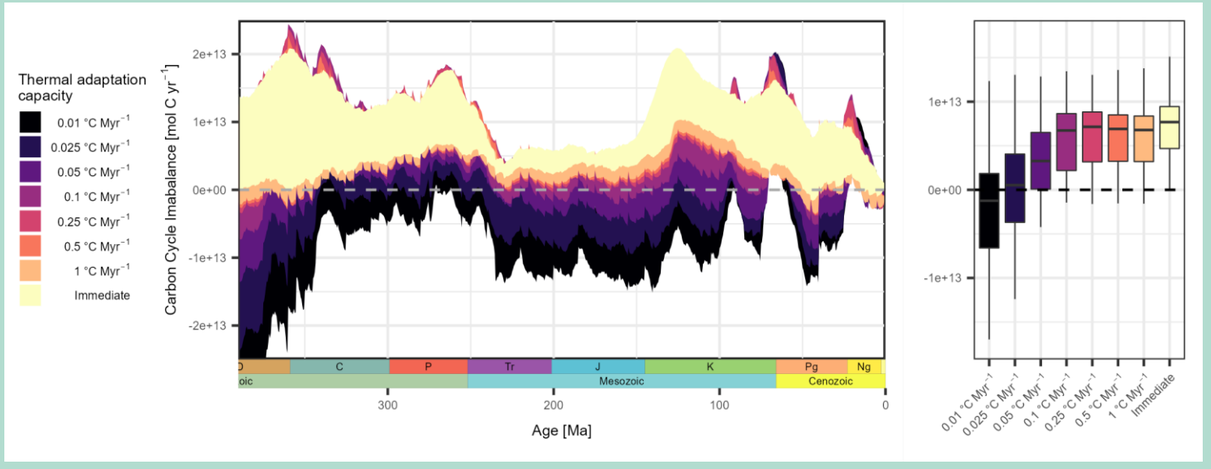



## B

Implement a biosphere model that considers ecology (dispersal of plant biotas) and evolution (thermal adaptation of plant climatic niche). Plant biotas continuously adapt to a changing climate and paleogeography. Interactions with the carbon cycle are weaker after an abrupt environmental change and intensify with the continuous adaptation to the new conditions.




## C

The necessary mass balance in the atmosphere-ocean carbon pool over geologic time is only met when considering a biosphere with an adaptation lag to the changing environment (climatic changes and plate tectonics).

The biosphere is often neglected or strongly simplified in continuous deep time climate reconstructions. We show that ecological and evolutionary biosphere dynamics play a fundamental role in the carbon-climate system. Considering these dynamics may help to understand large climatic shifts and hyperthermal events over Phanerozoic time.

[1] Walker et al., Journal of Geophysical Research. (1981) [2] Berner & Caldeira, Geology. (1997)