Toward understanding the mechanisms of natural climate changes

Development of an Earth system model coupled with a sediment diagenesis model toward long-term paleoclimate simulations

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In Short

- A simulation of the history of the atmospheric carbon dioxide (CO_2) concentration during the last glacial cycle is one of the crucial tasks of the PalMod project [1].
- The marine carbon cycle plays a crucial role in the variations of the CO_2 concentration in the atmosphere during the last glacial cycle.
- Diagenetic processes within ocean-floor sediments have a large influence on the marine carbon cycle at long timescales, hence coupling a sediment model is essential for reconstructing and understanding the climate history of the last glacial cycle.
- The sediment model will also act as a "bridge" between the ocean model and paleoceanographic data including the carbon isotopic compositions as an important fingerprint for the paleo-carbon cycle.

It is well known that the CO_2 concentration in the atmosphere (hereafter, CO_2 level) has been increasing since the industrial revolution due to human's CO_2 emission, so that it has reached a level that is unprecedented for at least the last 800,000 years. Our life in the future can suffer from climate changes induced by the increase in the CO_2 level and/or from the CO_2 increase itself (e.g., ocean acidification). In order to reliably project the history of the CO_2 level in the future, it is essential to understand the mechanisms for CO_2 level changes and have comprehensive Earth System Models (ESMs) including the latest knowledge and skills. The last glacial cycle in the last 100 kyrs is considered to be one of the most qualified research targets serving as a test case because they demonstrate historical (natural) climate changes with large variations in the CO_2 level.

A major issue in this respect is the cause of the variation of the CO_2 level between interglacial and glacial periods on the order of 100 ppmv. Thus far, comprehensive models are unable to explain such a large change, which demonstrates the lack in our understanding of the coupling between the physics and biogeochemistry. This project will tackle this issue by focusing on the marine carbon cycle because

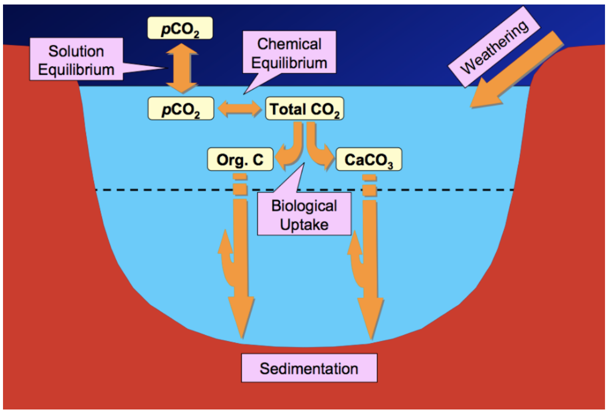

__Figure 1:__ Marine carbon cycles as an "open" system: schematic diagram of the marine carbon cycle. In long-term climate evolution, the chemical state of the global ocean is determined by the balance between the inflow of chemical matter by land weathering and its outflow at the seafloor through sedimentation.

it is widely considered that the ocean would have played a key role in the variations of atmospheric CO_2 levels.

In particular, the budget of calcium carbonate ($CaCO_3$) in the global ocean, that is to say, the balance of the $CaCO_3$ inflow by land weathering and the outflow by sedimentary burial, has a substantial effect on the distribution of total carbon to the ocean and atmosphere, hence the CO_2 level, by changing the acidity or basicity of the entire ocean (Fig. 1). For example, a more basic ocean would lead to a lower CO_2 level because more atmospheric CO_2 can dissolve in such an ocean. Therefore, it is highly important to properly simulate the global preservation and dissolution of $CaCO_3$ at the seafloor, which will require a sediment model that handles early diagenetic processes in the upper sediments.

Therefore, we plan to use a new coupling scheme for the Community Earth System Model version 1.2 (CESM1.2) [2] and Model of Early Diagenesis in the Upper Sediment A (MEDUSA) [3] to investigate the role of processes in the upper sediment in the climate changes in the last glacial cycle. Considering that diagenetic processes within ocean-floor sediments have a large influence on the marine carbon cycle at long timescales, coupling a sediment model to a state-of-the-art comprehensive climate model is essential for reconstructing and understanding the climate changes during the last glacial cycle in a realistic way. The coupling will also contribute to the better modelling of exchange of biogeochemical matter between the bottom seawater and seafloor

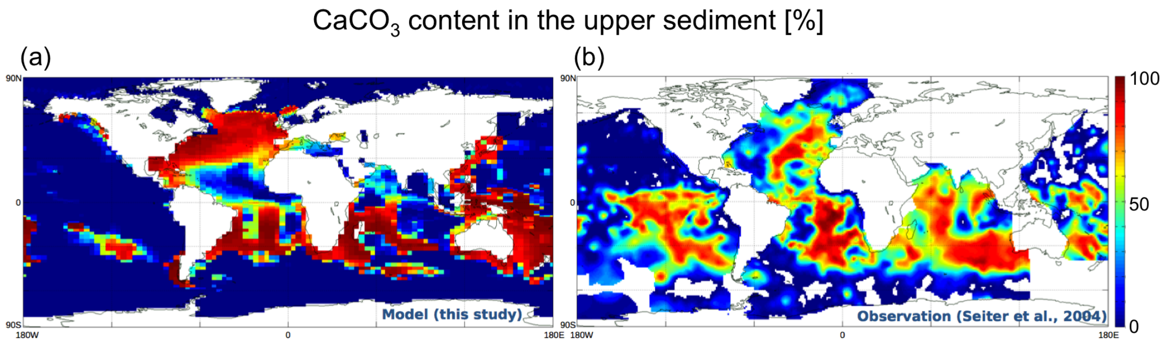

Figure 2: *The weight fraction of $CaCO_3$ out of total solid components in the upper sediments. (a) A model result, and (b) observations [4].*

sediments, which would lead to the improvement of model representation of seawater chemistry. Moreover, the sediment model will act also as a "bridge" between the ocean model and paleoceanographic data including the carbon isotopic compositions as an important fingerprint for the paleo-carbon cycle.

In this project, focusing on two characteristic time slices in the last glacial cycle, we will carry out simulations for the Last Glacial Maximum (LGM, 19–23 kyr BP) and the preindustrial (PI) period. In addition to a contribution to understanding the dynamics for the particular ages, this work will become an indispensable step toward a coming ambitious application of the coupled model to long-term (spanning a full glacial cycle; i.e., $\sim 10^5$ years) climate simulations with a higher-resolution setting.

Some preliminary work has been done to evaluate the general and basic performance of the models. The weight fraction of solid components in the upper sediment is a useful measure for the performance of the combined models because it contains information from both models and because it is a typical quantity given by observation. The weight fraction for calcite is of special interest in this project. Since the modelled global pattern of weight fraction in the preliminary work shows a fairly good agreement with the modern observations (Fig. 2), we assume that the general model behaviour at this stage is adequate for the purpose of this project.

WWW

https://www.marum.de/Michael-Schulz.html

More Information

[1] https://www.palmod.de/

[2] http://www.cesm.ucar.edu/

[3] G. Munhoven, *Deep Sea Research Part II* **54**, 722–746 (2007). doi: https://doi.org/10.1016/j.dsr2.2007.01.008

[4] L. Seiter, C. Hensen, J. Schröter, and M. Zabel, *Deep Sea Research Part I* **51**, 2001–2026 (2004).

Project Partners

AWI, CAU, DKRZ, GEOMAR, HZG, IfBM, University of Mainz, FUB, KIT, TROPOS, MARUM, MPI-C, MPI-M, MUN, University of Bonn / HErZ, PIK, University of Hamburg

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