Changes in biogenic carbon flow in response to sea surface warming

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Human-induced climate change is causing a warming of the surface ocean. Due to widely differing temperature sensitivities of key biological processes, this may have profound implications for marine food web interactions and the biogeochemical cycling of key elements such as carbon. Using a novel indoor-mesocosm approach, we show that rising sea surface temperature shifts the balance between photosynthetic production and respiratory consumption of organic carbon in a plankton community. This may weaken the ocean's capacity to sequester atmospheric CO_2, hence providing a positive feedback to anthropogenic climate change.

Throughout Earth's history the ocean has played a dominant role in the climate system through the storage and transport of heat and the exchange of climate-active gases, such as carbon dioxide (CO_2). While these processes have helped to mitigate the human-induced rise of atmospheric CO_2 and the associated global warming since the beginning of the industrial era, they are in turn also causing profound alterations of the ocean's chemical and physical properties. For instance, the upper 700 m of the ocean have already warmed by 0.1°C within the last 40 years, whereas surface pH values have dropped by 0.1 units. In the next decades, these changes are likely to accelerate with, for instance, a predicted increase in global mean surface temperature between 1.1°C (low CO_2 emission scenario B1) and 6.4°C (high CO_2 emission scenario A1FI) until the end of the 21st century.

Sea surface warming will affect the pelagic ecosystem in two ways; directly through the effect of temperature on the rates of biological processes, and indirectly through reduced surface layer mixing, causing decreased nutrient supply and increased light availability for photosynthetic organisms suspended in the upper mixed layer. It is expected that these changes in the physical and chemical environment will have drastic effects on the marine biota. Concerning the direct temperature effect it has been shown, that key biological processes of the pelagic ecosystem differ greatly regarding their temperature sensitivities. Most prominently, autotrophic growth and photosynthesis of phytoplankton typically display a weaker response to changes in ambient temperature than heterotrophic processes, such as the bacterial degradation of organic matter. Accordingly, surface ocean warming is expected to shift the balance between the sources and the sinks of organic matter. Ultimately, such alterations in the interplay of key processes involved in ocean carbon cycling may affect both pelagic food web structures and the functioning of the biological carbon pump, which transports surface-bound organic carbon to the deep sea and hence contributes to the ocean's capacity to take up atmospheric CO_2.

Figure 1: The indoor-mesocosms at the IFM-GEOMAR. Photo: J. Wohlers.

To investigate how rising sea surface temperature will affect the cycling and fate of organic carbon within a natural spring plankton community we conducted an indoor-mesocosm study using a novel set-up available at the IFM-GEOMAR in Kiel. This approach consisted of eight water tanks with a volume of 1400 L each, so-called mesocosms, which were distributed onto four temperature-controlled climate chambers (Fig. 1). After filling the mesocosms with unfiltered seawater from Kiel Bight (Baltic Sea), the plankton community was exposed to four different temperatures: the *in situ* temperature (T+0), following the natural seasonal temperature regime observed in Kiel Bight, as well as three elevated temperatures according to the projec-

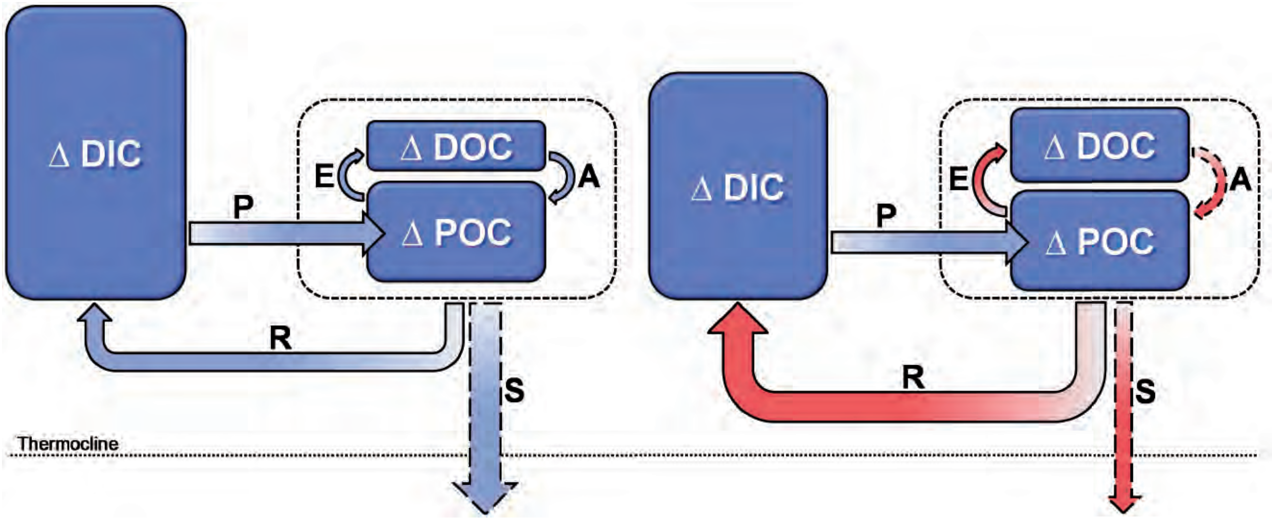

Figure 2: A schematic illustrating the surface layer carbon flow during an algal spring bloom under present (left) and elevated (right) sea surface temperature. Boxes (ΔDIC, ΔPOC, ΔDOC) represent the change in the reservoirs of dissolved inorganic carbon (DIC) and dissolved and particulate organic carbon (DOC, POC) over time. Arrows depict processes (P = primary production, E = exudation, R = respiration, S = sinking, A = aggregation). Processes found to be sensitive to warming in this study are marked in red in the right panel. According to our findings, rising sea surface temperature leads to enhanced respiratory consumption of organic carbon relative to its photosynthetic production. This results in a decline in net DIC consumption, enhanced accumulation of DOC and a lowered availability of organic carbon for export processes.

tions of the Intergovernmental Panel on Climate Change (IPCC), i.e. *in situ* +2°C (T+2), *in situ* +4°C (T+4) and *in situ* +6°C (T+6). In each of the mesocosms the build-up and decline of the spring bloom was closely monitored over 30 days.

In line with theoretical considerations, rising sea surface temperature clearly stimulated both the bacterial decomposition and the respiration of the plankton community relative to the photosynthetic production of organically bound carbon by phytoplankton cells (illustrated in Fig. 2). This led to a rapid replenishment of CO_2 at elevated temperatures, hence reducing the biological net drawdown of dissolved inorganic carbon (DIC) significantly by up to 31%. Moreover, warming markedly shifted organic carbon accumulation from the particulate (POC) to the dissolved form (DOC). Together, these changes in the biologically-mediated flow of carbon within a natural plankton community indicate an enhanced organic matter flux through the microbial loop, hence reducing the transfer of energy and matter to higher trophic levels of the food web, and decreasing the availability of POC for export to depth. In concert, sea surface warming thus has a strong potential to alter pelagic food web structures and to reduce the efficiency of the biological carbon pump in sequestering carbon from the surface to the deep ocean, with implications for the sustainability of global fisheries and the ocean's mitigating effect on anthropogenic climate change.

Based on our findings, surface ocean warming is indicated to be one of the most powerful drivers of future changes in ocean productivity, biogeochemical cycling and air-sea CO_2 exchange. Additional effort of both experimental and observational scientists and modellers is needed to further improve our understanding of the sensitivities of upper-ocean, biotically-driven processes to global change and their feedback potential to the climate system.

Reference

Wohlers, J., Engel, A., Zöllner, E., Breithaupt, P., Jürgens, K., Hoppe, H.-G., Sommer, U. and Riebesell, U., 2009: Changes in biogenic carbon flow in response to sea surface warming. *Proceedings of the National Academy of Sciences of the United States of America*, **106**, 7067-7072.