Climate - carbon cycle feedbacks in the 21st century: can they be observed and quantified?

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Observations over the last 55 years demonstrate that only about 50% of the carbon dioxide (CO_2) produced from the burning of fossil fuels, changes in land use (deforestation) and cement production accumulate in the atmosphere. Several independent observational techniques show quite consistently that the ocean absorbs about half of the missing CO_2; the remainder presumably must be taken up by ecosystems on land. Despite substantial scientific efforts during the last 30 years, the dominant land process responsible for this sink is still elusive.

How stable are these carbon sinks on land and in the ocean in view of a changing climate?

The response of the ocean sink is relatively well understood: increasing carbonic acid in sea water changes the ocean chemistry which reduces the buffering capacity of the ocean to excess CO_2 and this effect is exacerbated by higher temperatures. A warming ocean leads furthermore to more stratification, which also reduces the ocean sink capacity. Feedbacks involving the marine biota are more difficult to assess, but are expected to be relatively modest over this century, although the effects of ocean acidification on marine organisms by the invading CO_2 is not known.

On land the situation is more complex: a warming climate will stimulate growth in the extratropics due to the longer vegetation period, at least if water and nutrients are available. On the other hand, warmer soils are expected to be faster decomposed by microbes. Which of these effects dominates is still an open question. There exist many possible additional feedback processes, which are difficult to assess and quantify, e.g. the fate of the large amounts of carbon stored in the Arctic permafrost.

Experiments, global observation analyses and coupled climate - carbon cycle model simulations indicate that the feedback is positive, i.e. in a warming world the CO_2 sinks are expected to weaken, leaving more CO_2 to accumulate in the atmosphere and thus amplifying climate change. Observations from present and past climate variations suggest a modest overall feedback; it enhances climate change likely less than 20%.

However, even though the climate - carbon cycle feedbacks constitute a fascinating problem for Earth System science, in the 21st century they most likely will be dwarfed by direct and indirect anthropogenic impacts on the terrestrial carbon cycle caused by an increasing world population with food demands and associated land reclamation. Assessing and quantifying these effects will dominate the global carbon cycle research agenda for the next decades.