carboscope

CarboScope Release 4.1

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The Carbon Dioxyde Budget

The atmospheric concentration of the greenhouse gas carbon dioxide (CO_2) has globally increased during the last 200 years by more than 37% over the long-term preindustrial level of 280 ppm (molecules of CO_2 per million molecules of air) that had prevailed over the last 10,000 years.

There is no doubt that this increase is primarily the result of the massive global emissions of CO_2 generated from the burning of fossil fuels (oil, coal and natural gas). The most compelling evidence comes from measurements of the associated decrease in atmospheric oxygen, which is consumed in burning fossil fuels. The CO_2 source from fossil fuel burning can be quantified rather accurately from the statistics of energy production, amounting today to about 8 PgC/yr (= 29.3 billion tons of CO_2).

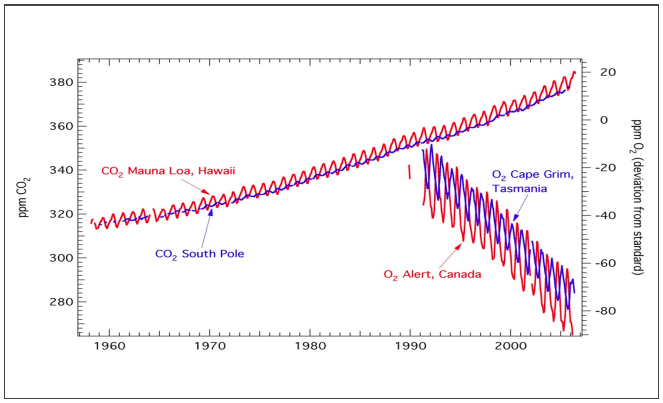

Figure 1. Increasing trend of the atmospheric CO_2 concentrations observed at the stations Mauna Loa (Hawaii) and the South Pole (left scale) and the corresponding decreasing trend in atmospheric oxygen (right scale, deviation from a standard corresponding to about 21% oxygen in air) observed at the stations Cape Grim (Tasmania) and Alert (Canada) since 1990. The seasonal cycles in both gases reflect the seasonal activities of the biosphere on land and in the ocean in the northern and southern extratropics.

A secondary, smaller source of anthropogenic CO_2 stems from changes in land use and land management, foremost deforestation. During the conversion of forested areas to pasture and agricultural fields, the organic carbon stored in the vegetation is largely removed, in part burned and released as CO_2 into the atmosphere. In addition, the freshly exposed soils also tend to loose carbon by oxidation to the atmosphere. This source of CO_2 is estimated to amount globally to about 1.5 PgC/yr (=5.5 Billion tons of CO_2) in recent years, albeit there exist still large uncertainties regarding magnitude and spatial distribution.

However, by comparing the atmospheric CO_2 increase with the global emissions one observes that only about 40% of the emitted carbon accumulates in the atmosphere, the other 60% are being taken up by the ocean and the land biosphere (see Table 1). In fact, if all anthropogenic emissions since preindustrial times would have accumulated in the atmosphere, the CO_2 concentration would today be more than 510 ppm instead of the observed 380 ppm. Obviously, the carbon sinks in the ocean and on land constitute a very important process in the Earth system. What are these sink processes? What controls them? Where are they located and how large are they? Will these sink processes continue to operate in the future? These are the fundamental questions of global carbon cycle research.

Sources:	
Fossil fuel burning	7.0
Land use change	1.6
Total sources	**8.6**
Sinks:	
Accumulation in atmosphere	3.6
Ocean uptake	2.2
Land uptake	2.8
Total sinks	**8.6**

Table 1. Global carbon budget averaged for the years 1990-2006 (Canadell et al., 2007).
Units: PgC yr-1 (1 PgC = 1 billion tons of carbon = 3.7 billion tons of CO_2).

The CO_2 uptake by the ocean is primarily a physico-chemical process, which is relatively well understood. The increasing partial pressure of CO_2 increases the CO_2 pressure differences between the air and the sea and thus presses CO_2 into the ocean. The dissolved CO_2 rapidly equilibrates with the carbonate and bicarbonate ions in surface waters and is subsequently transported as inorganic carbon into the interior ocean by currents and mixing. It is believed that the marine biosphere is not directly involved in the ocean absorption of anthropogenic CO_2, since plankton growth is limited by several other nutrients but not by the abundant inorganic ocean carbon. The increase of the

oceanic inorganic carbon reservoir can be directly measured from seawater samples taken worldwide by oceanographic surveys. Also the air-sea flux of CO_2 can be directly inferred from ship-based measurements of the partial pressure difference between the atmosphere and the sea. From these observations one can infer that the ocean currently absorbs about 30 % of the anthropogenic CO_2.

By difference, processes on land must take up the other 30% of the emitted anthropogenic carbon. Land plants take up CO_2 by photosynthesis and incorporate the carbon into their tissue (leaves, stems, roots), from where it is subsequently transferred as dead plant material to litter and soils. Ultimately, this organic carbon is recycled back as CO_2 to the atmosphere by the respiration of microbes and higher creatures, but also by other disturbance factors e.g. wild fires. Ecosystems on land sequester carbon if the uptake by photosynthesis exceeds the return flux from the sum of all decay processes. The complexity of these processes makes the exact quantification of the terrestrial carbon balance a very difficult task. It is believed that increasing atmospheric CO_2 levels have stimulated in many environments of the world the photosynthesis of land plants by the so-called CO_2-fertilization effect and thus contributed to the inferred global land carbon sink. In addition, at least in Europe and North America, re-growing forests during the last 50 years, as well as the inadvertent deposition of nitrogen from agricultural practices and also from air pollution may have stimulated terrestrial CO_2 uptake.

Figure 2 shows the global budget of atmospheric carbon over the last 50 years. The solid lines show the annual emissions from fossil fuel burning and from changes in land use (a.o. deforestation). The colored areas depict the annual uptake by the ocean, the atmosphere and the land biosphere. It is seen that the atmospheric accumulation shows a large interannual variability, which is caused by corresponding strong variations in terrestrial CO_2 uptake, while the ocean uptake, globally, does not vary much from year to year. This interannual variability is driven primarily by climate variations. Drought conditions in important large terrestrial ecosystems, e.g. in the Amazonas basin during El Niño phases induce carbon losses by decreased photosynthesis, increased decomposition and/or increased wildfires. These losses show up in the atmosphere as anomalous CO_2 increases during these years.

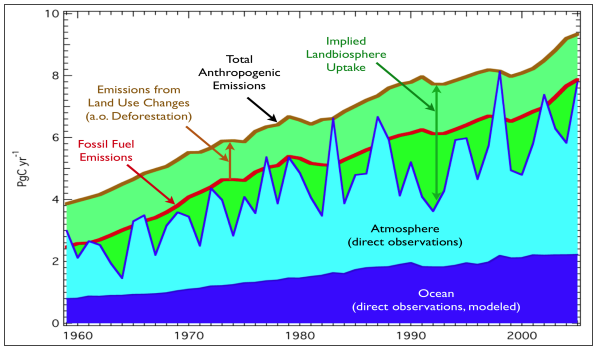

Figure 2. Temporal evolution of the atmospheric carbon balance over the years 1958-2006. Red line: CO_2 emissions from fossil fuel burning. Brown line: total emissions (fossil emissions + emissions from land use changes). The colored areas show the uptake by the three carbon reservoirs: blue: ocean, light blue: atmosphere, green: land biosphere. Units: $PgC.yr^{-1}$ (1 $PgC.yr^{-1}$ = 1 billion tons of carbon = 3.7 billion tons of CO_2).

The interannual carbon cycle variations reflect the response of the global carbon cycle to climate perturbations. Understanding these processes is of great importance, as they allow us to investigate the second critical carbon cycle research question: how does climate change and climate variations affect the carbon cycle and thus feed back on the atmospheric CO_2 concentration? Will global warming be amplified e.g. by releases of carbon from faster decomposing soils or because of smaller ocean CO_2 uptake caused by ocean warming and increased ocean stratification, i.e. less vertical mixing? How will the marine biosphere be affected by changes in ocean circulation and mixing, and how will these effects feed back on the air-sea exchanges of CO_2 and thus the global carbon cycle? The understanding of the multitude of possible feedbacks between the carbon cycle and the climate system is still very limited. Current comprehensive models of the coupled carbon cycle - climate system show a large spread of responses, which implies large uncertainties in any climate change scenario calculation over the next century.

Improving the knowledge about carbon cycle processes necessitates a long-term global monitoring strategy. One critical element in such a strategy is provided by the so-called “top-down atmospheric inversion” method, which is based on atmospheric concentration measurements from a global network of observation stations. Highly accurate and comparable measurements from this network permit the detection of the atmospheric signatures of the spatial and temporal variations of surface sources and sinks of CO_2. Using meteorological models of atmospheric transport, the atmospheric concentration variations are translated into spatially and temporally resolved surface-atmosphere flux patterns. These flux fields can then be compared to so-called “bottom-up” estimates derived from *in situ* point measurements, and they can also be related to potential drivers: e.g. insolation, temperature or precipitation, but also to human activities e.g. deforestation. CARBOSCOPE provides a visualization of these surface flux patterns as determined by several inversion modeling systems using the currently existing network of observation stations.

Beyond the basic carbon cycle science interest in a regional quantification of surface-atmosphere carbon fluxes, there exists a second motivation for an atmospheric monitoring network. In principle, the method allows the quantification of the regional net carbon balance and its variation in time. This could be used to monitor in an independent way the efforts to reduce the CO_2 emissions of individual countries or country groups in the context of international climate treaties. However, because of the high accuracy needs in this case several additional advances in observations (substantially increased density of monitoring stations in the target area) and in modeling (improved representation of

References

1. Josep G. Canadell et al. Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks . PNAS, vol. 104, no. 47, 18866-18870 (2007).

‹ Carbon Greenhouse Gases Budget up The Methane Budget ›

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