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Surge in studies on

Carbon Cycles of the Ecosystems of the World

Interest in the global carbon cycle has grown greatly in recent years. Mankind is completely dependent upon primary production and interacts with the biota through different activities, such as agriculture, forestry and fish farming. The production of these basic resources will be very much affected by climate change and the growing human population.

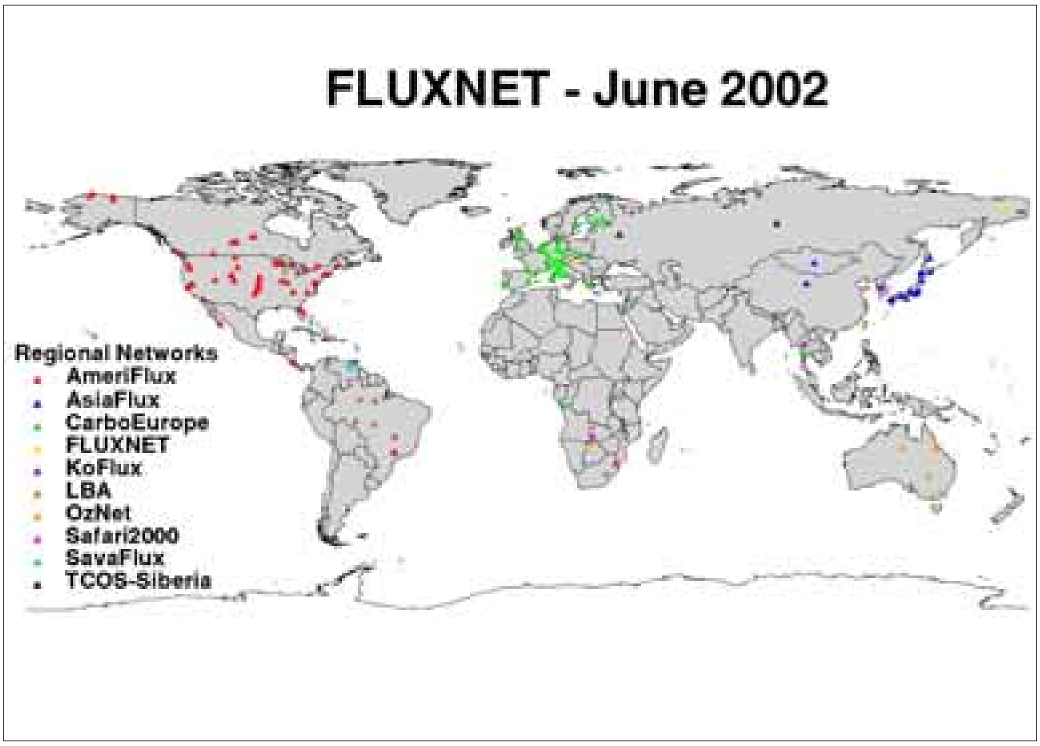

Figure 1. Most of the multiyear micrometeorological CO_2/H_2O flux sites have provided data to the FLUXNET-network, which has a Data and Information System unit at Oak Ridge National Laboratory, Tennessee.

In the 1990s, emissions of carbon dioxide from fossil fuel and cement production were, on average, 6.3 PgC (one PgC = one petagram of carbon = 1 billion tonnes of carbon) per year (IPCC, 2001)[1]. The rate of increase in atmospheric CO_2 concentration has been, on average, 1.5 ppm per year, which corresponds to 3.2 PgC per year in atmospheric storage. It is estimated that oceanic uptake is 1.7 PgC per year. To reach a balance, there has to be a net sink of atmospheric CO_2 to terrestrial areas that amounts to about 1.4 PgC per year. Land use changes, especially deforestation in tropical regions, cause a net CO_2 release to the atmosphere that was estimated to be about 1.7 PgC per year during the 1980s. From inversion modeling of atmospheric CO_2 concentrations and isotopic studies, we know that there is a large net sink (about 2 PgC per year) to the terres-

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Figure 2. Flux measurement site on a field at Jokioinen in southern Finland. The soil at this site is peat and one of the objectives of the study is to measure the decomposition rate of the peat and compare it to the carbon uptake by the cultivated plants. The sonic and inlet tube to the CO_2/H_2O monitor is mounted on a boom on top of the short mast. The monitoring and data acquisition computers are housed in a box on the ground. The other mast is equipped with meteorological sensors such as radiation components, temperature and humidity sensors. Also, soil temperature, moisture and heat flux to the soil are measured. During the growing season, CO_2 efflux from the soil uptake by plants is also measured by chambers to get data for ecosystem models.

trial biota, which is mostly located in temperate and boreal regions of the Northern Hemisphere. The reasons for this uptake are nitrogen deposition and increasing atmospheric CO_2 concentration, which act as fertilizers. Recent studies indicate that land use changes, especially the forestation of abandoned agricultural land, are also important contributors.

International cooperation to reduce emissions

To combat global warming, substantial reductions of fossil fuel emissions are needed. In Kyoto 1997, nations agreed upon an international protocol that aims at worldwide reductions of CO_2 emissions. To assist in reaching an agreement in negotiations, it was decided that additional terrestrial sinks might be partly used to compensate for anthropogenic emissions, i.e. human-induced emissions. The Kyoto Protocol remained on a rather general level. The negotiations thereafter, on how to define which biological sinks may be considered in the calculations, were long and difficult at many international conferences before the final text was approved in the Marrakech Accord in 2001.

Many nations would like to facilitate reduction of their emission burden through using carbon sequestration by vegetation. The problem is our insufficient knowledge of where the sinks are located and how they may change in the future. Our understanding is very much lacking in which land-use classes they are related and how forestry or agricultural practices may increase or decrease the sequestration. It is stated that the sinks should be verifiable, which is a normal condition in international agreements. However, it will be a very challenging task to develop the tools for carbon sequestration monitoring, because of different measurement approaches and the limited understanding of the processes.

Carbon dioxide budget measurements

There are several ways to study carbon balances at different scales, but all of them have severe limitations. The global CO_2 budget mentioned above is based on the very accurate atmospheric CO_2 concentration measurements, which are performed on global measurement networks. The Global Atmosphere Watch (GAW) network, coordinated by the World Meteorological Organization (WMO), and the network run by the CMDL group in the National Oceanic and Atmospheric Administration (NOAA) in the U.S., are the most important sources of this data. However, the network is too scarce to provide information on CO_2 balances at regional level. The calculations are based on inversion modeling, which has many limitations and relies on additional data.

Measurements of changes in stock of biomass are a direct way to monitor carbon uptake. It is a straightforward, though labor-intensive, task to measure the changes in tree trunk biomass every 5 years or so. Because most of the carbon is stored in the soil, it is a practically impossible task to measure changes in this carbon reservoir.

Micrometeorological flux measurement methods

Micrometeorological flux measurement methods offer an interesting way to study CO_2 fluxes in a scale that is comparable to the size of a typical ecosystem, for example 30 hectares. The core of a standard set-up is a fast-re-

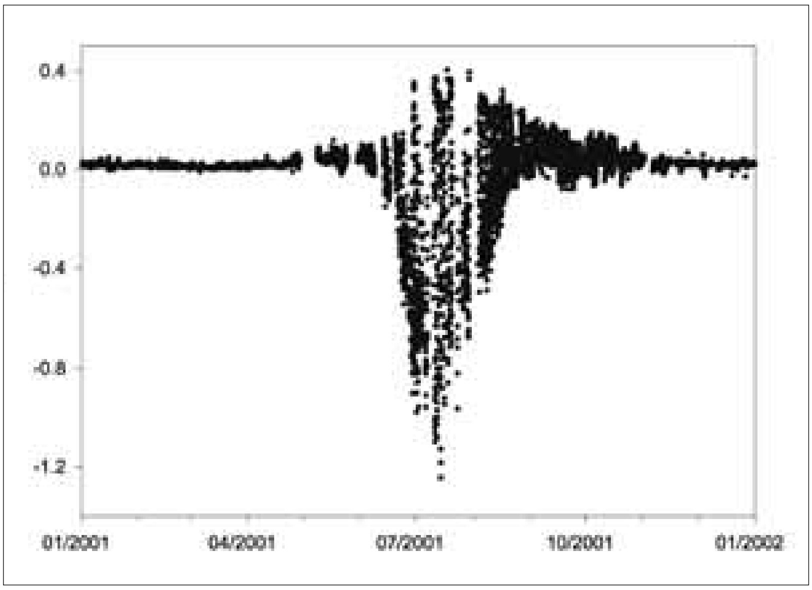

Figure 3. Annual cycle of CO_2 fluxes between the agricultural field at Jokioinen and the atmosphere in 2001. The half-hourly flux values in winter and spring show flux upward (positive numbers) when the peat is gradually decomposing. Barley was sown at the end of May and negative fluxes during the day (CO_2 uptake) appear in June reaching their maximum in mid-July. In August, the crop ripens and the CO_2 uptake gradually ceases. Harvest took place in September. Positive fluxes are highest during nights in summer when heterotrophic efflux from soil and autotrophic maintenance respiration from plants have their seasonal maximum. A typical feature of the micrometeorological observations is that the time series are not complete because of technical problems and an absence of turbulence during calm periods. These gaps have to be filled before long-term averages are calculated, which is one source of uncertainty. Outlayers typically result from non-ideal turbulent conditions. After gap filling the data, we can calculate the annual balances in 2001. This agricultural field on organic soil lost 200 g C m^{-2} to the atmosphere and 160 g C m^{-2} was transported away in harvest as grains, resulting in a total yearly carbon loss of 360 g C m^{-2}. We can estimate that during the growing season, carbon uptake by plants and respiration from soil were both about 550 g C m^{-2}.

sponse sonic anemometer and a fast-response (5-10 Hz) CO_2/H_2O monitor, which are located several meters above the ecosystem to be studied. Direct observation of the flux between the atmosphere and an ecosystem, including trees, undervegetation and soil, is obtained at 30-min. (half-hourly) resolution as a covariance between the vertical wind speed and gas concentration variations in a turbulent flow field.

A great advantage of micrometeorological measurements is that measured fluxes may be used in process studies and model verification. For example, temperature response of ecosystem respiration, light use efficiency of CO_2 assimilation or effects of drought on carbon balances, may be plotted from observations. Water vapor fluxes, which are measured in parallel, tie hydrological processes, evaporation and transpiration to the carbon fluxes. Micrometeorological flux measurement is the only tool to get daily and annual balances, which are obtained by summing up half-hourly observations. These measurements have provided a great deal of quite new information on the interannual variation of carbon fluxes and the factors behind these variations. The drawback of the method is the fact that to establish and run a station is not cheap. The costs for equipping a station lies at around 100 000 EUR and, usually, service visits are needed several times a week. In addition to flux measurements, measurements of other physical and biological parameters have to be conducted for a profound understanding of the functioning of the ecosystems. The instrumentation to obtain information on CO_2 fluxes of different components, leaves, stems, roots, ground vegetation and soil, are also needed for many applications. These are usually measured with different kinds of chamber systems.

Fluxnet for global measurements

After the development of field-proven instrumentation and data acquisition systems for flux measurements during 1990s, the network of permanent sites is expanding. The sites are usually run by research groups at universities as a part of their ecophysiological studies. Most of the multiyear sites are part of a global network FLUXNET (http://www-eosdis.ornl.gov/FLUXNET/). There are also regional networks such as CARBOEURO in Europe (http://www.bgc-jena. mpg.de/public/carboeur/) and AMERIFLUX in America.

The main task of these stations will be to act as reference sites to support the global endeavor to reach a better understanding of CO_2 fluxes and annual net balances. Remote sensing from space will be a central tool in the verification of the Kyoto Protocol. However, remote sensing measurements are entirely indirect and they have to be supported by extensive modeling activities and ground-based reference measurements if we aim to reach reliable net carbon balance estimates. ●

References:

1. IPCC, 2001: Climate Change 2001; The Scientific Basis, Cambridge University Press, Cambridge, 881 pp.