CarboeuropeIP, Special Activity INNOV:

6.1.4. Stimulation of Scientific and Technical Innovation and Exploitation of Results

Annual Report 2004

1. Filling Knowledge Gaps

2. Technical Innovation

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1. Filling knowledge Gaps

Despite the continuing worldwide interest in the carbon cycle, and the large number of publications during 2004 in leading journals in this area, there remain significant knowledge gaps which will need to be addressed before the process-level understanding of the carbon cycle is able fully to underpin the development of truly useful predictive models and the development of policy. The knowledge gaps which have been especially apparent in 2004 are listed below.

1.1 Remote Sensing of Photosynthesis and Productivity

The approach first devised by Monteith in the 1970s is still widely used. In this approach, photosynthesis is estimated from the absorbed radiation, which is itself estimated from solar reflectance at two specific wavebands. This early work remains the backbone of most attempts to produce continental or global scale maps of net primary productivity (NPP). The main weakness of the approach is that radiation-use-effficiency (RUE) is assumed to be a constant, or assumed to be a very simple function of environmental variables such as temperature, water balance and CO_2 concentration. We know that this does not work well for vegetation under stress- as we see clearly from studies in the boreal forest (Makela *et al.* 2004, *Tree Physiol.* 24, 369). Presumably the impact of stress is more severe in droughted ecosystems and especially in the Mediterranean forests and scrublands.

What is new in this area is the attempt to probe photosynthetic performance more directly, using hyperspectral sensors from land-based platforms or from satellites, using the reflectance in a narrow spectral range centred on 531 nm and comparing it with a reference waveband at 570 nm. This measures the transformations in the xanthophyll cycle that occur when chlorophyll is no longer able to deal with absorbed energy, and the measured 'photochemical reflectance index (PRI) has been shown to be strongly correlated to CO_2 flux in several ecosytems. **Also new**, is an attempt to use the extremely narrow dark Fraunhofer lines to observe fluorescence of chlorophyll. Both of these developments are discussed further in section 2.6.

1.2 Behaviour of the soil organic matter under climatic warming

We do not know how the rate of breakdown of soil organic matter (SOM) will change in a warmer and probably drier world. Despite the large number of papers appearing

in 2004 on description of CO_2 fluxes from the soil in short-term experiments, we definitely do not understand the long-term (annual, decadal) behaviour and the extent to which the flux depends on the *supply of substrate* in the form of plant material and root exudates, as opposed to the activity of the soil organisms. This introduces uncertainty into the interpretation of the flux, and especially regarding the choice of the temperature coefficient to be used in global models which purport to predict the C-fluxes over several decades.

An associated knowledge gap is the uncertainty in the origins of the CO_2 flux from the soil: how much is autotrophic and how much is heterotrophic; and how sensitive are these to temperature? Conventional methods of measuring the flux do not of course reveal this, although experimental manipulations such as tree-poisoning, bark-ringing and trenching are being used to exclude the autotrophic component from the overall signal in small plots.

What is new in this area is the use of isotopic analysis to try to discriminate between the autotrophic and heterotrophic fluxes (Section 2.2). In the few measurements that have been made, SOM has an isotopic signature that differs by about 2 ^{o}/oo from leaves, suggesting that the decomposition process involves isotopic discrimination. Therefore, continuous measurements of in-canopy Keeling plots to reveal the seasonal changes in the isotopic composition of the ecosystem flux ought to be useful in identifying the changing pattern of autotrophic/heterotrophic fluxes. This is becoming technically possible wit the development of tunable diode lasers which exploit the fact that $^{12}CO_2$ and $^{13}CO_2$ have slightly different absorbtion characteristics in the infra red.

Attempts to measure the accumulation of carbon in forest soils are generally frustrated by the inherent spatial variability of the stocks and the consequent large number of samples needed to demonstrate a change. The use of novel flux measurements, and their integration over time, will therefore be important in identifying the rates of change.

1.3 The impact of vegetation dynamics on carbon fluxes and stocks

Vegetation is not static, as the land is subject to natural and human impacts that clear much of the biomass. The European land surface is especially prone to disturbance and almost all of it is managed. We urgently need to know more about the impact on the stocks and fluxes of agricultures and silvicultures. In terms of the European

carbon balance, the most significant post-Kyoto changes are likely to be in silvicultural practices, which will retain trees in the ground so as to increase stocks. **What is new here** are the findings from flux towers in chronosequences, reported for North America, Siberia and Europe. Much of this work is in the process of being prepared for publication. **What is required now**, are methods of making comparisons of fluxes over the disturbed landscape, and over forests at various stages in their life cycle. Carboeurope needs to develop a capacity to respond rapidly to major disturbances caused by fire and storms, and to track changes in C-fluxes associated with changes in land management. Aircraft platforms for eddy covariance are likely to play a role in such studies, and are being actively developed in CarboeuropeIP (see Section 2.1).

What is also needed are methods of recording biomass, and changes in biomass, from space, given the non-availability of spatially referenced data on forest carbon stocks in Europe. There are several attempts to develop radar methods to be used from satellites (see Appendix vi), but we are a long way from a practical satellite-borne system that can measure biomass in the range needed for forests.

1.4 Effect of drought on all carbon fluxes from terrestrial vegetation

Ciais *et al.* (2005, submitted) show the large impact of the extreme 2003 European heatwave and drought on fluxes, but there are very few stand-scale experiments to investigate the effect of drought on photosynthesis and respiration. Most work on the response to drought has been based on young plants grown in pots, and there is a remarkably rich and extensive literature in this field. But at stand scale there have been few drought experiments. Observational evidence from tree-rings (Granier et al 2004, in prep.) suggests that temperate forests experience a more substantial impact in the year after the drought than in the year of the drought. This needs further investigation.

What is needed are drought experiments where carbon fluxes are being measured, and where cores are taken from the trunks to evaluate inter-annual variability (Section 2.7.1).

Very few flux towers are able to measure fluxes of volatile organic compounds, especially isoprene, although these may comprise a significant fraction of the total carbon flux, and are reported to be especially important in years of drought. More importantly, the volatiles participate in atmospheric chemistry and may therefore

exert a disproportionate effect on the climate. **What is needed** is some co-ordination between the few European centres where VOCs can be measured, and the flux towers where relaxed eddy accumulation or related techniques can be used.

1.5 What is happening to solar radiation, and how are fluxes affected?

Solar radiation at the Earth's surface has been shown to be declining of recent decades by 2.7% per decade (Stanhill & Cohen 2001, *Agric. & For. Met.* 107, 255), although the diffuse fraction is actually increasing. The cause of this decline is unclear, but it may be a combination of increased cloudiness, increased aerosols from anthropogenic sources including biomass-burning, and the impact of contrails from civil aviation. How will global photosynthesis change as a result? Analysis of flux data suggest that an increase in the diffuse fraction generally increases the rate of photosynthesis, but more data are required to see whether this is a universal phenomenon, and to evaluate the overall effect on the global carbon balance. **What is needed** in CarboeuropeIP is for an analysis of our existing flux data, comparing hours where the radiation is predominantly cloudy and hours of bright sunshine. It would be useful to install a radiation sensor to measure the diffuse/ direct components of incoming radiation separately (an inexpensive sensor is available from Delta-T Instruments, Cambridge, UK: the BF3).

1.6 Design of the observing system: a cost benefit analysis

In CarboEurope, the observing system utilises flux stations, tall towers and aircraft-based determinations to estimate the strength of the biological carbon sink of Europe. The establishment and running costs of these installations is large, especially if the system is required to become routine and continuous well into the future. An important question which has not been asked is: what is the relation between the cost of the system and the precision of the result obtained? An associated question is: for cost-effectiveness, what is the best balance of resources between ground-based and atmospheric sampling? **New work is planned** to address these questions.

2. Scientific and technical innovation

2.1 Aircraft

The use of small aircraft for CO_2 flux measurement is developing, and we need to (i) define the user community in Europe and also the rest of the world (ii) exchange experiences and know-how (iii) make the aircraft accessible to others (iv) overcome bureaucratic problems relating to registration and (v) compare and contrast the aircraft available- value for money, payload etc. (vi) consider the possible use of mounting regional campaigns using several aircraft (vii) Make plans for a rapid task force to respond to the need to characterise the fluxes from storm damage and fire.

Flux data from aircraft show more scatter than found at towers; there is a need to identify the source of this scatter and to define better the flux footprints and the sampling problem (Franco Miglietta probably has the largest data set, which might be used to conduct a form of power analysis).

Kite-planes (UAVs, unmanned aerial vehicles; or UVS unmanned vehicle systems) have some potential but regulations in Europe may prevent the use of UAVs without a pilot's licence. There is a web site www.uavforum.com which lists manufacturers and users, and there are annual exhibitions in several countries. There are some new restrictions of the use of the platforms as a result of concerns that terrorists may use them.

In some countries it may be possible to explore the use of civil aircraft to routinely measure concentration profiles, and thus to extend the data set available for the atmospheric inversion community. This needs co-ordination. A start has been made in Japan, and there have been discussions involving Lufthansa. How is the user community to take this forward?

2.2 Isotopic measurements

Isotopic measurements offer the possibility of identifying respiratory fluxes, and in principle the emerging technologies are suitable for isotopic eddy covariance (Bowling et al 2003, Ag & For Met 118, 1-19). Another use of isotopic analysis is in the derivation of photosynthesis and respiration of the canopy from vertical profiles of

concentrations, using methods recently devised (Styles et al 2002, Tellus, 54, 655-676).

Campbell Instrument's tunable laser diode (TDL) is capable of fast measurements of isotopic fluxes. It has a fast response time, and it seems possible to apply the instrument to eddy covariance measurements, to measure the fluxes and concentrations of $^{12}CO_2$ and $^{13}CO_2$ in real time. It is eminently suited to making in-canopy concentration profiles, and offers the prospect of being able to make in-canopy Keeling plots and thus attempt to separate autotrophic and heterotrophic soil respiration. It does have some limitations. It needs liquid nitrogen for cooling and is not suited to continuous measurement over periods more than a few days; also it is bulky and heavy, not suitable for mounting on towers or flying in light aircraft. There are some related technologies which may become available over the next few years: the quantum cascade laser (QCL), and the cavity-ring-down laser (CRD) (Los Gatos Research, California). There was a presentation on the latter at the December 2004 AGU meeting. These instruments do not require cooling by N, and they are smaller and more portable. More work is needed to bring these technologies to the user community. One company in the US which may be leading the field is Los Gatos Research, California; in Europe we can only find reference to expertise at the University of Heidelberg.

Portable mass spectrometers are available, and it is possible that a more cost-effective route to measuring isotopic fluxes is through these instruments rather than developing the laser methodologies. We know of one such mobile laboratory, currently being used for evaluation of soil fluxes (Phil Ineson, University of York). This approach does not offer the possibility of rapid measurements as required for eddy covariance, but could be used with eddy accumulation methods.

2.3 Developments in measurement of CO_2 concentrations and fluxes.

2.3.1. Hydra Mark 4

In the UK, the Centre for Ecology and Hydrology, has developed the Hydra Mark 4 (soon to be commercial at circa £25k). It uses only 4W and so will be useful for eddy covariance measurements in remote sites which do not have power. Wind, CO_2 and H_2O are measured in the same volume of air, so corrections for spatial separation are not required. Flash card storage of data is employed. For further information, contact Colin Lloyd, CEH, Wallingford.

2.3.2 Vaisala GMP343

In Finland, Vaisala has developed a new probe for CO_2 concentration, suitable for use in the measurement of soil respiration. It is 'open-path' in principle, relying on gaseous equilibration between the outside air and the air in the sample cell through a perforated chamber. It achieves good performance when output is averaged over several minutes to overcome the inherent noise (raw signal has an accuracy of only a few ppm, drift of less than 1 ppm in six hours) through the use of a reference beam outside the CO_2 absorption bands (single beam dual wavelength principle). It is expected to cost circa $2000 (UK quote from UK distributor December 2004 was £1400). A somewhat similar device is available from Edinburgh Instruments.

2.3.3 LiCor soil respiration chambers

As a result of substantial research effort and good links with the research community, the US company LiCor has developed an outstanding system for soil CO_2 flux measurement: the LI-8100. This has novel features to prevent pressure differences between the inside and outside of the chamber, which have been a problem for most other systems. Moreover, there are two types of chamber: one for long term use and the other is a 'survey chamber' for exploring spatial variability. The system can be supplied as a set of 12 multiplexed chambers, thus enabling good spatial replication.

2.4 Motes.

Motes are tiny, self-contained computers with radio links which enable them to exchange data with each other. They have low power requirements (1-50 mW) and so

can run for a long time without attention. Built into environmental sensors, they enable small units which may be implanted in soils or canopies, opening up tremendous possibilities to improve spatial sampling and recording of environmental and physiological variables. For many applications at the stand level, such as the recording of temperature and radiation inside canopies, spatial variation introduces major uncertainties. For an introduction to motes, see http://computer.howstuffworks.com/mote.htm
http://www.intel/com/research/exploratory/motes.htm
Intel is strongly developing motes with the University of California, Berkeley; for first-hand experience contact Todd Dawson.

2.5 Data communications.
Devices are available from the telecommunications company Globalstar. For example, Qualcom GSP-1620 delivers digital data from virtually anywhere using the Globalstar constellation of 48 Low-Earth-Orbit satellites. The AXtracker with GPS sends to satellite and then to your email, and is extremely economical. AXtracker is a battery-operated, ready-to-go telemetry device designed to communicate with the Globalstar Simplex Data Service. It is designed for 'asset tracking' (tells the user where his goods are), and has limited environmental sensing. It works for small packages of data, and in one direction. See www.globalstar.com and contact Franco Miglietta.

2.6 Photosynthetic light use efficiency. The changes in photosynthetic efficiency which occur in bright light, in cold and at high temperatures are not well understood, and ought to be investigated over the flux network. There is a small portable sensor, quite suited to attaching to flux towers, which measures narrow band radiances at 531 and 570 nm, enabling the photochemical reflectance index to be calculated (available from Skye Instruments, Powys, UK; cost about 400 $). Contact John Grace or Caroline Nichol, University of Edinburgh. In California, John Gamon is trying to develop SPECNET on a global scale, linking spectral reflectance to fluxes (jgamon@calstatela.edu).
Remote measurement of photosynthetic performance using solar-induced chlorophyll fluorescence is technically possible but quite demanding. The basic idea here is to view the canopy at the very narrow wavebands that correspond to the 'dark'

Fraunhofer lines. Ismael Moya (Universite de Paris X1, Orsay) has developed a special sensor to do this; however, it has to be temperature controlled to keep the wavelength calibration to within a fraction of a nanometer.

2.7 Response of CO_2 flux to drought- the need for experimental methods

2.7.1 Drought experimentation

2003 was an exceptionally hot and dry year over most of Europe, resulting in anomolous fluxes of CO_2. Ciais et al. (2005, in preparation) found that such a collapse of primary productivity is unprecedented over the past 100 years and raised the question of how changes in the return frequency of extreme events will alter carbon cycling and the supply of food and timber in the future.

Our ability to predict the impact of heat-waves and drought is quite imperfect as there have been few field-scale drought experiments in which CO_2 fluxes have been measured. It is important to raise the level of understanding because it is predicted that summer rainfall will decrease over much of Europe, and that drought will become more frequent and more intense for the world as a whole. This will impact directly on CO_2 fluxes as photosynthesis and respiration are likely to be affected; and it may also have indirect effects at the ecosystem level caused by outbreaks of pests, especially defoliating insects. In discussions with the Global Canopy Programme we have designed and costed a stand-scale drought experiment which would enable ecophysiological analysis of the drought response and also bring the biodiversity research community into closer contact with CarboeuropeIP, to investigate the impact of drought and ecosystem carbon fluxes on biodiversity in the soil and canopy. The experiment utilises a canopy crane to access the canopy. The cost of implementation of this experiment is approximately Euro 2M over five years.

2.7.2 Measurement of soil water by satellite and on the ground

A new ESA satellite to measure soil moisture and ocean salinity is planned for 2007, known as SMOS (Soil Moisture and Ocean Salinity Mission). The satellite utilises the fact that soil emissivity at a microwave wavelength depends on moisture. At L-band (1.4 GHz) radiation temperature is sensitive to soil moisture for areas which are

vegetated (up to 5 kg m-2) whereas atmospheric variations and surface roughness have little effect. Both photosynthesis and respiration are strongly influenced by soiol moisture, and so it should be possible to 'calibrate' the satellite systems using existing flux towers.

At stand level, researchers have measured soil moisture by traditional techniques including time-domain-reflectometry, capacitance, psychrometry and gamma probes. All these techniques suffer from the problem of spatial variation. What is needed is a method that can scan over a wider area. At a brain-storming meeting during the International FLUXNET meeting (Florence, December 2004) a new approach to the sensing of soil moisture was identified, using existing GPS technology to measure water in the soil surface. Contact Marco Esposito (MESPOSITO@ISPAIM.NA.CNR.IT).

List of Contacts and web sites relating to topics raised in this report

(i) Role of Stable Isotopes in Understanding the Carbon Cycle

Links

- BASIN, http://www.basinisotopes.org
- SIBAE, http://www.esf.org/esf_article.php?activity=1&article=221&domain=3
- NETCARB, http://www.wzw.tum.de/netcarb/
- http://www.esf.org/esf_article.php?language=0&article=91&domain=3&activity=1

Technical Developments

- Measurement of isotopic fluxes by eddy covariance using tunable diode laser, Campbell Trace Gas Analyser, TGA 100, contact Bert Campbell: bert@campbellsci.com . See Bowling et al (2003) Agric. For. Met. **116**, 159.
- Erik Kerstel's site for TDL, http://www.cio.phys.rug.nl/HTML-docs/Kerstel/Kerstel.html

European Centres with world class analytical facilities

Max-Planck Institute for Biogeochemistry, Willi Brand, Jena: www.bgc-**jena**.mpg.de

Scottish Universities Environmental Research Centre SUERC: http://www.gla.ac.uk/centres/surrc/suerc.html

CARBOEUROPE-IP contacts

Dan Yakir, Nina Buchmann

(ii) Use of Spectral Reflectance Index to Remotely Sense Photosynthesis

Links

● SPECNET http://vcsars.calstatela.edu/SpecNet/SpecNet_full.html, contact John Gamon: jgamon@calstatela.edu

Technical Developments● See paper: Asner GP *et al.* (2004) Drought stress and carbon uptake in an Amazon forest measured with spaceborne imaging spectroscopy *Proceedings of Nat. Acad. of Science* 101, 6039-6044.

(iii) Uncertainty Analysis in Carbon Modelling

Links

● CTCD, Centre for Terrestrial Carbon Modelling http://www.shef.ac.uk/ctcd/, contact: Shaun Quegan S.Quegan@sheffield.ac.uk and Tony O'Hagan a.ohagan@sheffield.ac.uk

Technical Developments

● coming shortly

(iv) SPECTRA: proposed satellite for hyperspectral sensing

The proposed satellite instrument is a hyperspectral sensor covering the range 450-2350 nm. The main advantage is that it is 'pointable' and can be set to revisit certain sites every three days. Although the proposal was supported by Carboeurope's Executive Board in early 2004, it was not chosen for funding in late 2004.

Web

● http://www.iaanet.org/symp/berlin/IAA-B4-0401neu.pdf

● http://esamultimedia.esa.int/docs/sp_1257_5_spectrasc.pdf

Contact for Informed Comment

Massimo Menenti MENENTI@SEPIA.U-STRASBG.FR

(v) FLEX: Remote sensing of chlorophyll fluorescence via Fraunhofer lines

The spectrometer would have a spectral resolution of 0.1-0.3 nm, sufficient to look at the 'filling-in' of the Fraunhofer lines by fluorescence of chlorophyll. Hence, it may be possible to measure accurately the photosynthetic efficiency from space.

Web

- http://www.tpd.tno.nl/Docs/DOI/Publications/SPACE/FLEX.pdf

(vi) Radar measurements of biomass

Contacts : Thuy LeToan, CESBIO, Toulouse, France : email Thuy.Letoan@cesbio.cnes.fr;
Shaun Quegan, University of Sheffield, UK: email S.Quegan@sheffield.ac.uk
Previous EU projects in this area are EUFORA and FMERS

(vii) External Contacts

China:

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Research Institute of Forest Ecology and Environmental Science, The Chinese Academy of Forestry, Wan Shou Shan, Beijing 100091, China. Contact: Deying Xu deyingxu@fee.forestry.ac.cn