**Innovation activities**

Activity Leader: John Grace, University of Edinburgh (UEDIN)

Partners and responsibilities:

Reports, organisation of workshops, implementation of activity: J. Grace, UEDIN

Further partners upon request.

**Workpackage objectives and starting point of work at beginning of reporting period**

Objectives (5 years)

INNOV1 To highlight scientific and technological innovation in the CarboEurope-IP

INNOV2 To stimulate scientific and technological innovation in the CarboEurope-IP

INNOV3 To stimulate scientific and technological innovation outside the CarboEurope-IP, needed to better achieve the IP´s research goals

INNOV4 To stimulate the exploitation of the scientific and technological innovation of the CarboEurope-IP

Objectives (months 13-30)

To stimulate innovation related to CarboEurope-IP

Starting point of work at beginning of reporting period:

Reporting period started in Month 13 (January, 2005).

**Progress towards objectives**

The first innovation report was delivered in January, 2006. The innovation report is included below.

**Stimulation of Scientific and Technical Innovation and Exploitation of Results**

**Annual Report 2005**

Compiled by Activity Leader: John Grace, University of Edinburgh

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- Technical Innovation
- Filling Knowledge Gaps

**1. Direct and Diffuse Radiation**

A preliminary analysis of European flux data has revealed that $CO_2$ fluxes over forest canopies are generally higher under cloudy, hazy and overcast conditions than they are when the sun is shining, when compared at the same global irradiance. This has implications for modelling canopy photosynthesis (some models do not capture this behaviour), and especially when using models that are based on a simple Light Use Efficiency. In view of the marked variation in the diffuse component that occurs spatially (over Europe) and temporarily (with interannual variations in aerosols and cloud) it seems important to investigate this topic thoroughly. A workshop meeting was held at Levi, and the participants are currently addressing these questions:

(i) How large is the effect and what is its explanation?

(ii) How does it depend on canopy structure?

(iii) How much of the observed response is actually a response to climatological variables which are correlated to cloudiness

(iv) How far do the existing flux models already simulate the response? Do they need improving?

These issues will be investigated by comparison of European flux data, supplemented with some tropical data to increase the range of parameter space.

**2. Leaf Area Index and canopy structure**

Leaf Area Index (LAI) is a key parameter in most models of GPP, yet it is not always well determined. Its importance now, is that models of C-fluxes need to assimilate the phenology of the canopy. The main methods for LAI determination have been established over many years and are as follows:

(i) Direct measurements: destructive sampling or collection of fallen leaves in winter

(ii) Calculation from gap fraction: Hemispherical photographs and software to infer LAI or canopy analyser (LAI 2000) or Ceptometer

(iii) Calculation from an array of light sensors underneath the canopy

(iv) Calculation from light sensors on flux towers

(v) Calculation from spectral reflectance measured from space, for example using the MODIS LAI product.

The difficulties of measurement using these methods are generally well known: they include conceptual as well as sampling problems (Breda 2003).

In calculations based on optical methods, a significant part of the signal is from the stems and branches, and does not contribute to photosynthesis.

In addition to these methods, the vertical profile of LAI is also often needed in models but rarely measured in forests where destructive harvesting is not practical. However, it may be measured from tower-based measurements of gap fraction in sidewards view (Meir, Grace & Miranda (2000). If we are to make reasonable statements about LAI for European forests we ought to adopt a common protocol. Most groups are using hemispherical photographs, but even this system can give diverse results as there are variations in technique.

The remote sensing community, on the other hand, are generally calculating NDVI from spectral reflectance data and often without comparison with ground-based methods. Of course, the spatial resolution of such measurements is often quite different from that of the more traditional methods. Moreover, the remotely-sensed measurement always includes the herb layer whereas the ground-based method usually does not.

What is needed now is

- A standard protocol which all groups can achieve
- Measurements of vertical profiles to formulate unifying principles
- Innovation, to find better methods

**3. Isotopic measurements: planning a CarboEurope campaign for 2007 (Authors: L. Wingate & J. Grace)**

Amongst the main objectives of Carboeurope-IP, **Component 2** highlighted a need

'*to develop innovative methodologies using Carbon Cycle related tracers and isotopes to attribute the $CO_2$ concentration in the European air shed to each of the constituent parts of the fluxes: fossil, oceanic and terrestrial (MO8, Activity 2.2).*'

Within the 2004 annual report (6.1.4 Simulation of Scientific and Technical Innovation and Exploitation of Results), we highlighted an emerging new field technology 'tunable diode laser absorption spectrometry (TDLAS)', that stands poised to significantly increase the temporal resolution of measurements for the isotopomers of $CO_2$ ($^{12}CO_2$, $^{13}CO_2$ and $^{13}C^{18}O^{16}O$) and potentially augment the suite of measurements currently underway within Activity 2.2.

A number of recently published papers have successfully demonstrated that a commercially available TDLAS (TGA100, Campbell Scientific Instruments, Logan, Utah) is capable of running long-term in the field and providing a more than respectable precision for obtaining isotopically important parameters relevant to the carbon cycle research community. For example, the TGA100 was recently deployed in a subalpine coniferous forest (the Niwot Ridge Ameriflux Tower Site) and ran continuously for >100 days collecting high temporal resolution data on diurnal and seasonal changes in forest canopy profiles of $^{12}CO_2$ & $^{13}CO_2$ (Bowling et al. 2005) in an effort to partition the ecosystem component fluxes of photosynthesis and respiration and improve understanding of environmentally driven isotopic signals from the biosphere such as canopy photosynthetic discrimination against $^{13}CO_2$ ($^{13}\Delta$) and the carbon isotope signal of ecosystem respiration ($\delta^{13}_R$) both of which exert a strong influence on the global atmospheric carbon isotope signal ($\delta^{13}_A$). Another example demonstrating the potential of this technology to probe some presently topical and difficult to measure processes within ecosystems was provided by Griffis et al (2005). By deploying the instrument within a flux-gradient configuration over an agricultural site they demonstrated how one could partition autotrophic and heterotrophic respiration fluxes from ecosystems where a change in land use, for example from C3 to C4 pasture conversion had taken place. Both of these applications resonate strongly with the overarching objectives of **Component 1** *Activity 1.2*

*" to partition the net C flux in European ecosystems into its constituent parts"*

Within the Carboeurope network significant progress has been made to bring us up to speed with developments outside Europe in this face-paced and opening field. At least two Carboeurope partners (University of Edinburgh, UK – P.I. J.Grace and INRA, France – P.I. D.Loustau) will obtain the same instrument described above in the early part of 2006. At the annual meeting for the Carboeurope network which took place in Levi, Finland the development and innovative application of these instruments to address scientific knowledge gaps was given a high priority, especially within the Forest Ecosystem (Component 1) and Regional Experiment Activities (Component 3). The above mentioned Carboeurope partners have fostered a collaboration and timetable for testing these instruments at a number of novel scales i.e. chamber and ecosystem during 2006. By 2007 both partners anticipate being fully prepared to then participate within the forthcoming regional scale experiment planned for S.W. France weaving innovation activities inside the framework of the **Component 3**, *Activity 3.1.* Bringing the two instruments to bear at the same site and experiment we can attempt to measure multiple components (soil, branch and ecosystem fluxes) and ecosystems such as C3, forest (*Pinus pinaster*) and C4, agriculture (*Zea mays*) simultaneously for the first time. This activity will also crosscut into **Component 4**, for instance placing the instruments at the component and ecosystem scale will allow us to validate in the field existing theoretical models of biosphere isotopic fractionations against $^{13}C$ and $^{18}O$ using the long-term time-series. This will allow us to develop our present bottom-up models of biosphere impacts on atmospheric isotope signals and thereby provide a useful means of constraining our additional approaches such as the inversion techniques currently used to obtain the magnitude and variability of C sources and sinks in Europe, linking to

Activities 2.1 "to provide the high precision, high frequency, long-term atmospheric concentration measurements needed to invert for magnitude and variability of sources and sinks in Europe"

*Activities 4.2 "to test a multiple constraint approach by applying top down and bottom up methodologies to achieve the best possible estimate of the European carbon balance to determine the variation in biospheric fluxes over Europe"*

A further advantage of placing our instruments at the component and ecosystem scale makes it a convenient tool for improving our understanding of post-photosynthetic fractionations important during the construction of cellulose. The carbon and oxygen isotope composition of cellulose archived in the annual tree-ring can provide a powerful proxy of intra- and inter annual variations in climate and plant water use efficiency (a useful integrator of plant carbon and water exchange). By teaming high resolution measurements of instantaneous photosynthetic $^{13}C$ and $^{18}O$ discrimination alongside ancillary observations on plant metabolites (sugar and starch), water sources (atmospheric and soil water) and environmental drivers we will attain a position to make real head-way in our understanding of post-photosynthetic fractionations during cellulose construction. This will improve our ability to interpret isotopic tree-ring information and constrain our ability to interpret past climatic events recorded in tree rings e.g. the severe droughts experienced across the European network in 2003 and 2005. This tree ring proxy and our improved models of environmental isotopic signals in cellulose can then be applied to larger spatial scales with the additional collection of tree rings across the region and perhaps the network. Within the forest synthesis cluster discussions at Levi, led by A Granier, INRA, substantial interest in the collection of tree cores across the European forest network was raised to obtain spatial archives on changes in WUE recorded in tree ring cellulose using isotope tracers, this would be a particularly powerful biological archive to fuse with the net ecosystem exchange collected within the flux site network as date now spans some 7yrs at a number of sites.

The co-ordination of this collaborative cross cutting isotope experiment within the innovation/forest synthesis/regional experiment workpackages will be undertaken by Lisa Wingate at The University of Edinburgh (l.wingate@ed.ac.uk) who will work in conjunction with the Carboeurope partners in Bordeaux (Denis Loustau (loustau@pierroton.inra.fr) and Jérôme Ogée (ogee@pierroton.inra.fr)) and Edinburgh. Any enquiries regarding aspects of this particular innovation activity should be directed to L.Wingate and J.Grace.

**5. Gas analysis using Tunable Diode Laser (TDL) technology: Requirements and State of the Art.**

The technology opens up several possibilities that are important to the aims of Carboeurope **(i)** continuous and high resolution of measurements of the isotopomers of $CO_2$ ($^{12}CO_2$, $^{13}CO_2$ and $^{13}C^{18}O^{16}O$). The resolution appears to be good (0.3 per mil), and soon it should be possible to deploy such instruments on tall towers, thus supplementing or even replacing the use of flask measurements. Moreover, the flux measurements are rapid and it has become technically possible to carry out eddy covariance measurements of isotopic fluxes, although we know of no published work in this area so far; **(ii)** instruments are available for eddy covariance methane measurements. Following the report that plants may emit substantial quantities of methane even in aerobic conditions (Keppler *et al.*, Nature 12 Jan 2006), many groups may wish to install methane sensors.

In 2005 a major international conference was held in Florence on TDL (http://tdls.conncoll.edu/gen_info.html), and the results should appear in *Spectrochimica Acta: Part A* in early 2006.

Main commercial suppliers are:

Los Gatos Research (http://www.lgrinc.com/index.asp?subid=diolab) has its Fast Methane Analyser which has a data rate of 20 Hz, weighs 22 kg, costs $31,900 in the USA. Also its CO2 isotope analyser with a response time of 1 minute, weighs 22 kg and costs $50,000 in the USA. Also, its High Accuracy CO2 analyser which measures $CO_2$ to an accuracy of 1 part in 2000 (ie at 400 ppm expect resolution of 0.2 ppm); weighs 22 kg costs $32,950 in the USA.

Campbell Scientific (http://www.campbellsci.com) has been producing the trace gas analyser TGA100a for a few years. It can measure $^{13}CO_2$ to 0.1 per ml (as good as a mass spectrometer), but requires calibration gases on site, and is heavy (74 kg), expensive, and requires refilling with liquid nitrogen every five days. However, there are several in the Carboeurope project, and this provides capability of the proposed campaign discussed above. The instrument can be converted to a methane analyser by replacing the lead-salt laser with one which is specified for an absorption line of that gas.

## 6. Innovation Workshop

We plan to hold a workshop in late 2006 to encourage innovation for young Carboeurope scientists. Details will be circulated soon.

## References Cited

Bowling DR et al. (2005 )Extensive observations of $CO_2$ carbon isotope content in and above a high-elevation subalpine forest. *Global Biogeochemical Cycles*, 19, doi:10.1029/2004GB002394).

Breda NJJ (2003) Ground-based measurements of leaf area index: a review of methods, instrumentation and current controversies. *Journal of Experimental Botany* 54, 2403-2417.

Griffis TJ et al, (2005) Seasonal dynamics and partitioning of isotopic $CO_2$ exchange in C3/C4 managed ecosystems. *Agricultural and Forest Meteorology* 132, 1-9

Keppler F (2006) Methane emissions from terrestrial plants under aerobic conditions. *Nature* 439, 187-191.

Meir P, Grace J, Miranda AC (2000). Photographic method to measure the vertical distribution of leaf area density in forests. *Agricultural and Forest Meteorology* 102, 105-111.

Wang et al. (2004) Evaluation of the MODIS LAI algorithm at a coniferous forest site in Finland. *Remote Sensing of the Environment* 91, 114-127.

**Table 2-INNOV.1: Deliverables List**

| Del. no. | Deliverable name | Workpackage no. | Date due | Actual/Forecast delivery date | Lead contractor |
|---|---|---|---|---|---|
| INNOV 1 | Annual innovation reports to be distributed and discussed at the Steering Committee and placed on the web site | INNOV | 24 | 26 | UEDIN |
| INNOV 2 | Network of contacts outside the CarboEurope community, including the private sector and the forestry agencies in the Partner countries | INNOV | 18 | 18 | UEDIN |
| INNOV 3 | First brainstorming workshop to identify new measurement techniques and emerging technologies | INNOV | 18 | 18 | UEDIN |
| INNOV 4 | Contacts with private sector and interesting private investors in carbon-related issues | INNOV | 18 | 18 | UEDIN |
| INNOV 5 | Links with related and evolving projects in Europe and elsewhere | INNOV | 18 | 18 | UEDIN |

**Table 2-INNOV.2: Milestones List**

| Milestone no. | Milestone name | Workpackage no. | Date due | Actual/Forecast delivery date | Lead contractor |
|---|---|---|---|---|---|
| | Innovation reports | INNOV | 12, 24 | 13, 26 | UEDIN |
| | Brainstorming workshop | INNOV | 18 | 13 | UEDIN |
| | Dissemination of network of contacts and links with private sector | INNOV | 18 | 18 | UEDIN |