



## **Report on the TCO/GCP Terrestrial Carbon Observations and Model-Data Fusion Workshop**



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**with contributions from**

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**Sheffield, UK, 3-6 June 2003**

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# Background

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## *Workshop sponsors and collaborators*

Hosted by the UK National Environmental Research Council (NERC) Centre for Terrestrial Carbon Dynamics and sponsored by the Terrestrial Carbon Observations Initiative (TCO-GTOS) and Global Carbon Project (IGBP, IHDP, WCRP) with support from ESA, NASA, the Joint Research Centre of the EU, Ispra, and the NERC.



## *Organization and meeting background*

The global carbon cycle is of intense interest to policy-makers, the scientific community, and public organizations. As a result, numerous new programmes and projects have been developed over the last few years. TCO and GCP are two such complementary initiatives which share a common goal of advancing the availability of more accurate and mutually consistent estimates of terrestrial carbon sources, sinks and processes, regionally and globally, through syntheses of observations and models.

TCO was developed by the Global Terrestrial Observing System (GTOS) in support of the Integrated Global Observing Strategy Partnership (IGOS-P) which is focused on meeting policy-relevant interests of governments. GCP has been developed through collaboration among the International Geosphere-Biosphere Programme (IGBP), the World Climate Research Programme (WCRP), and the International Human Dimensions Programme (IHDP). Additional information can be obtained at the following links: [www.fao.org/gtos/TCO.html](http://www.fao.org/gtos/TCO.html) and [www.globalcarbonproject.org](http://www.globalcarbonproject.org).

The workshop was intended to advance the availability of more accurate and mutually consistent estimates of the distribution of carbon sources and sinks at a regional and global level. This goal can be achieved by convergence of *in situ* and satellite observations, experiments and modelling strategies; improvements in data acquisition and sharing; and product generation, distribution and use. The workshop focused on the following questions and associated issues:

- 1. What carbon cycle data products could be routinely produced from a carbon observation system based on model-data and model-data fusion?*
- 2. What are the main conceptual approaches to assimilating atmospheric carbon content, terrestrial carbon flux and remotely sensed data into coupled atmospheric circulation-carbon cycle models?*
- 3. What is the present and eventual uncertainty regarding the main carbon fluxes at global and regional scale, and how will it be reduced by projects currently underway and about to begin?*
- 4. In what regions, and on what topics, will new data inputs make the largest contribution to reducing the residual uncertainties? What actions should be taken to overcome the gaps and limitations identified?*

The above questions were tackled in working groups that focused on (1) Modelling; (2) Data; (3) Uncertainty analysis and reduction.

Participating scientists represented key regional and global projects, organisations leading the preparation and assembly of critical data sets, major modelling groups active in regional and global projects and the enabling agencies (see appendices for agenda, and list of participants).

## Results and Recommendations

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### *Recommendation to IGOS-P*

It would be helpful for IGOS-P to clarify the relations between the many current programmes aimed at improving our understanding of the Earth's carbon cycle, and to promote consistency in their responsibilities and priorities.

### *Recommendations to CEOS and the space agencies*

#### **Generic recommendations**

**1.** The space agencies are strongly encouraged to develop a **joint** strategy for **systematic long-term acquisitions with adequate repeat frequency** of the crucial land measurements identified in recent reports from the IGCO and GCOS (and the TCO Implementation Plan, to be published shortly). These measurements are:

- a.** Fire occurrence and burnt area;
- b.** Land cover and land cover change;
- c.** LAI and fAPAR.

This strategy must ensure **global coverage or coverage over key regions** selected to answer specific scientific questions. It must also ensure **access to these datasets** by the whole international scientific community

**2.** Ensure **inter-agency collaboration** on:

- a.** Prioritising missions needed to fill crucial gaps in the global carbon observing system.
- b.** Joint planning and compatibility of similar data types gathered by different sensors (e.g., for L band radar, ESA discussions on TerraSAR should take full account of the NASDA ALOS mission).

#### **Specific recommendations**

- It is clear that **high resolution column content CO<sub>2</sub> measurements** from space, like those to be provided by the Orbital Carbon Observatory (OCO) to be launched in 2007, will have a major impact on our understanding of the global distribution and variability of CO<sub>2</sub> sources and sinks. OCO has a planned lifetime of two years, which is insufficient to detect trends or to cover natural cycles, such as that of El Nino/La Nina. The space agencies should be encouraged to plan follow-on missions to **provide a long-term data record**.

- P-band radar shows considerable promise as a means of providing **global high resolution measurements of biomass from space** (although limited to values of biomass less than ~100-120 tonnes/ha). In addition, lidar provides a means of measuring **forest height** from space. The space agencies **should promote a mission exploiting one or both of these technologies**. The potential of polarimetric interferometry as a means of measuring forest height from space should continue to be explored. The science community should be encouraged to develop further our understanding of the scope and limits of these technologies.

## *Recommendations to GTOS*

### **Regional campaigns**

There is an urgent need for GTOS, with guidance from TCO, to identify the major ongoing and planned regional observational campaigns relevant to the carbon cycle (e.g., Carbo-Europe, NACP, NEESPI, Boreas Machine) and negotiate with their coordinators in order to:

- ensure consistent data acquisitions and standard methods
- develop strategies to obtain, archive and maintain essential long-term measurements gained from these campaigns and extend their availability well beyond the lifetimes of the individual campaigns.

### **Data continuity, consistency and currency**

The continuity, consistency and currency of critical measurements (e.g. from meteorological stations, the flask network) needs to be ensured.

Methods for biomass inventories and reporting of their accuracy should be standardized (FAO).

## *Recommendations to TCO*

Priority areas where TCO should promote new data products fall into two categories:

### **1. Products that are achievable without major new developments**

#### *(a) Space data*

- Harmonization of fire data
- Refinement of the Vegetation Continuous Fields land cover product
- Consolidation, harmonization and regular updating of the static Land Cover products
- Improved Land Cover Change products
- Delineation of wetlands (assuming an L-band SAR satellite, notably the NASDA PALSAR sensor to launched in 2004)

#### *(b) Ground data*

- standardization of ancillary data around flux sites

### **2. Products requiring major efforts**

- biomass measurements from key regions of high biomass using airborne sensors (VHF, lidar)

- tower CO<sub>2</sub> measurements in under-sampled eco-types.

## *Recommendations to data providers*

### **Uncertainty issues**

The need to bound and reduce the uncertainty in carbon flux estimates was a recurring theme throughout the workshop, with implications for both data provision and modelling. **Explicitly calculated observation errors** should always be reported with observations relating to the spatial distribution of natural and human dominated terrestrial land surface pools and fluxes. This will improve atmospheric inversions of GHG fluxes and is essential for verifying and attributing greenhouse gas fluxes at regional to global scales. This led to three recommendations:

- Establish, in consultation with the modelling community, protocols and methodologies for routine reporting of errors and uncertainties in datasets.
- Promote the assembly of datasets which report natural and human dominated fluxes together with their errors and uncertainties in order to establish proof of concept in model-data fusion (e.g. CDIAC, UK, USA).
- Provide details on allometry with inventories (IUFRO).

## *Recommendations to the research community*

### **Proof of concept studies**

- Develop a project to demonstrate how error estimates and uncertainties in distributed land-surface and remote sensing datasets can be used to improve atmospheric inversions.
- Test operational upscaling from flux tower to a 50 km grid (through a Fluxnet/Bigfoot meeting).

### **Workshops**

Two workshops were proposed:

- Characterizing uncertainty in unmodelled fluxes, e.g. fossil fuel use, to be attached to the CarboEurope schedule.
- Biogeochemical Data Assimilation, to be organised by TCO/GCP.

### **Methodology development**

- Improve the understanding of the contribution of lateral flows and alternative pathways of carbon (e.g. Volatile Organic Compounds, Dissolved Organic Carbon in drainage) to the carbon balance.
- Quantify the impact of initial conditions, e.g. land-use history, on carbon calculations and suggest a response.
- Analyse how field campaigns and flux tower & trace gas concentration network designs can optimally reduce uncertainties, and conduct cost-benefit analyses for these designs.

- Develop methodology to improve computational efficiency of numerical error analyses (e.g. emulation methods).

### *Summary of the meeting presentations*

The meeting commenced with overviews of international planning for carbon observations, together with the perspectives and needs perceived by the Agencies. Presentations from GTOS-TCO, IGCO, GCP, the EU, NSF, ESA, NASA and NASDA made it abundantly clear that very many programmes bearing on our understanding of the Earth's carbon cycle are currently being formulated, but that the different remits and allegiances of the lead organisations create some difficulty in ensuring that these developments are coherent.

### *International planning for carbon observations*

IGCO and the GCP have the widest remit to coordinate carbon-related observations and science, with GTOS-TCO focussing on land observations.

#### **Integrated Global Carbon Observation - IGCO**

The IGCO is primarily concerned with measurements, and focuses on a core set of observations that can be made operational, together with development of new technologies to fill important gaps in observational capabilities. Specific goals are:

- to develop a flexible, robust strategy for gaining global systematic observations of the carbon cycle over the next decade;
- to provide the long-term observations needed to understand the present state and future behaviour of the global carbon cycle, particularly those factors controlling the global atmospheric CO<sub>2</sub> level;
- to monitor and assess the effectiveness of carbon sequestration and/or emission reduction activities on global atmospheric CO<sub>2</sub> levels, including attribution of sources and sinks by region and sector.

#### **Global Carbon Project - GCP**

The GCP has a stronger research brief, whose objective is to develop comprehensive, policy-relevant understanding of the global carbon cycle, encompassing its natural and human dimensions and their interactions. A central element of the GCP programme is Model-Data Fusion, which can be defined as the introduction of observations into a modelling framework, to provide:

- Optimal fit between data and model;
- Optimal estimates of model parameters;
- Uncertainties on parameters and model output;
- Model testing.

This involves the development of effective ways to combine observations and models so as to gain insight into coupling and feedback within the carbon cycle system. Models coupling the biophysical and human dimensions are also needed, with the ultimate aim of managing the carbon cycle.

## Terrestrial Carbon Observations - TCO

The TCO is a coordinated international response to scientific and policy needs for reliable, systematic, consistent and comparable information on:

- the spatial and temporal distribution of terrestrial C sources and sinks;
- the role of terrestrial sinks and sources in the global C cycle.

The TCO is expected to provide/support:

- Methods and data required for full carbon accounting (i.e. all ecosystem sources and sinks).
- Spatial carbon flux products and data sets usable at the national level.
- Use of the best current observation and modeling methods, resulting in harmonized data products.
- Capacity building for national data collection, assessments, modeling efforts and product generation.
- Data meeting the needs of both atmospheric inversion and ecosystem models.

An issue for all these panels is how to work constructively with existing and planned agency and regional programmes.

### *Carbon plans within national organizations and agencies*

The U.S. Carbon Cycle Science Plan maps fairly directly onto that of the IGCO-GCP, comprising a strong observational component whose outputs can be integrated into models. International collaboration is seen as important, particularly for:

- linking the North American Carbon Program (NACP) and the Carbo-Europe consortium to characterize Northern Hemisphere carbon sources and sinks;
- coordinating ocean carbon measurements;
- cooperating in establishing common policies and procedures for data access and data release to the public.

The EU's approach to carbon cycle research is indirect and based on the needs of the UNFCCC, the Kyoto Protocol and the European Climate Change Programme (whose purpose is to help identify the most environmentally friendly and cost-effective measures enabling the EU to meet its Kyoto target). Nonetheless, it supports a major terrestrial carbon research programme (Carbo-Europe).

The space agencies' contributions to carbon research are driven by different remits. NASA has its own carbon science focus area, which forms part of the U.S. Carbon Cycle Science Plan. ESA has no in-house carbon science programmes, but provides data relevant to carbon cycle research mainly under the Geosphere-Biosphere Theme of its Living Planet programme. Under the Kyoto & Carbon Initiative, NASDA has defined a plan for systematic large-scale observations by the ALOS satellite (to be launched in 2004). These observations are geared to the needs of terrestrial carbon studies, and will be supported by derived information on forest and land cover, incremental change in biomass (regenerating and planted forest) and wetlands at regional scale.



## *The priority datasets*

One of the major tasks for the TCO and GCP is to ensure that agencies recognize the priority IGCO datasets and that progress is made towards securing these data and their continuity. This has at least two facets:

- Provision of global datasets, many of which are satellite based;
- Taking full advantage of regional datasets and studies to construct near-global products.

There is substantial agreement amongst all programmes concerned with the terrestrial carbon cycle about the core measurements needed:

### **(a) *Space based observations over land***

- Land cover, Land cover change;
- Disturbances (especially fire frequency and extent);
- Fraction of absorbed photo-synthetically active radiation (fAPAR) and related biophysical parameters (including LAI and phenology);
- Biomass.

### **(b) *In situ observations related to processes***

- Soil characteristics;
- Soil moisture;
- Phenology;
- Nutrient distributions;
- Respiration terms measured at eddy flux towers;
- Species composition of ecosystems;
- Atmospheric tracers ( $O_2:N_2$ ;  $^{13}C-CO_2$ ; CO; aerosols).

### **(c) *Atmospheric and weather data***

- Historical and current measurements of precipitation, solar radiation, temperature, vapour pressure;
- Atmospheric composition, with space-based measurements of atmospheric column content  $CO_2$  as a major new component.

### **(d) *Ancillary measurements***

- Hydrology;
- Large scale biomass and soil carbon inventories;
- Landform, topography.

In addition, three messages recurred repeatedly in the meeting:

- **Long time series** are essential to extract process information;
- The **history of disturbance and land use management** has very significant long-term effects and information on it is very important;
- **Characterizing uncertainty** in the measurements and quantifying the effect on carbon calculations in the model-data fusion process is of paramount importance.

## Global datasets

At the global scale, particularly for use with models, data are needed on a consistent earth grid (typically  $\frac{1}{2}^\circ$  degree latitude-longitude or finer). In some cases (e.g. for constructing spatio-temporal models for fire), long time sequences are required.

Numerous gridded datasets exist but with various problems:

- Lack of continuity and absence of long temporal records;
- Inadequate calibration;
- Lack of methods for comparing and combining measurements of the same quantity from different sensors;
- Algorithm inconsistency;
- Lack of information on accuracy;
- Data are often spread across many providers, with no single meta-database and access route.

The last point led to two related recommendations:

- Consolidate existing grid sources through a centralized meta-database or ‘one stop shop’ (ORNL Mercury, FAO, GOFD);
- Define procedures to keep information on global gridded products up to date.

Critical reviews of the global products were provided, aiming at displaying their accessibility, their characteristics (how often data are collected, temporal and spatial coverage and gaps, how quickly they become available, immediate requirements for data to become more useful), their quality, limitations and scope for improvement, together with issues of uncertainty associated with the data.

### (a) *Land cover, land cover change*

Many static depictions of global land cover/land use at scales of 1 km or coarser are available. These are mainly satellite-based (AVHRR, MODIS, SPOT VEGETATION), but there are important datasets giving historical agricultural land use (e.g., Ramankutty and Foley, 1999). The accuracy and comparability of these products is unknown, and their accuracy almost certainly varies with region. The 500m MODIS Vegetation Continuous Fields product is likely to become influential as it is well matched to the needs of biospheric models, and **developments in this product to finer levels of classification should be encouraged.**

The static products are not well-suited for land cover change. However, the *Millennium Ecosystem Assessment* aims to map, at a global scale, areas which have experienced rapid land-cover change during the last twenty years, by integrating existing data sets, including remote sensing, expert opinion and model output.

There are very large differences in the estimates of total area of tropical deforestation by JRC, FAO & UMD ( $8.3 \pm 2.6$ ,  $12.0$  and  $5.6 \pm 2.7 \times 10^6$  ha yr<sup>-1</sup> respectively). In addition, satellite-based estimates of the carbon flux from tropical deforestation and regrowth for the 1980s and 1990s are substantially lower than estimates based on national statistics. **Resolving these discrepancies is a serious challenge.**

Other major challenges include:

- Integrating land cover, biomass, fire, and biophysical parameter data to reduce uncertainties in carbon flux estimates (data-data fusion);
- Matching observations and data sets to the scales at which land cover change actually occurs;
- Mapping land cover dynamics as opposed to changes between static states;
- Data fusion with ecosystem models to assess land use fluxes and links with climate variability, fertilization, etc.

### **(b) Fire**

Both active areas and burnt area can be measured from space and are indicators of GHG emissions, land cover change and vegetation dynamics. However, estimates of greenhouse gas emissions from fire events are highly uncertain because of uncertainties in estimates of burned areas and fuel loads. To achieve the best results a multi-sensor, multi-resolution approach needs to be adopted. For savannah/boreal forest ecosystems, burnt-area products calibrated by high resolution data can be used to estimate the area burnt.

The relation between burning and land use change varies with the region. Using Global Fire products, land use/land cover change can be highlighted in forest ecosystems using active fire data with broad land cover maps, but not in savannah ecosystems.

Two specific areas of development were identified:

- Efforts must be made to harmonise the existing range of disparate 1 km fire products.
- The potential of the new generation of geostationary satellites for producing fire products needs to be explored.

### **(c) Seasonal growth cycle (LAI, Growth Season Duration)**

Limited globally validated growth cycle or LAI products are available. These are derived from a variety of sensors and cover different periods: AVHRR, ATSR-2/VEGETATION/AATSR (GLOBCARBON), MODIS/MISR from 2000 and MERIS fAPAR from 2002.

### **(d) Biomass**

Currently there are no reliable global gridded datasets of above ground biomass and the available data are almost entirely provided by inventory methods, which are of differing quality, gathered at different periods and only provide regional values. Biomass maps at a scale of 50m for central Siberia have been produced from space using SAR interferometry in the FP5 SIBERIA project, but the required space system is no longer in orbit. The best hopes for a global capability in the next decade involve long wavelength SAR (a P band mission proposal, BIOMASCA, is being developed for ESA/NASA; this should be able to produce global maps of biomass up to values around 100 tonnes/ha) and/or Vegetation Canopy Lidar (which can measure forest height). Polarimetric InSAR is being intensively investigated as a longer term technology for measuring forest height. Ways to significantly improve our current capabilities include:

- Harmonize and intensify *in situ* measurements and standardize accuracy reporting.
- Make use of present EO technology (e.g. L band radar) to monitor post disturbance biomass.
- Strongly encourage the space agencies to launch a P band satellite.
- Use airborne surveys by VHF SAR, lidar or interferometric SAR to measure biomass in key regions of high biomass (beyond the values feasible with spaceborne SARs).

### **(e) Soils**

Knowledge of soil resources, particularly soil organic carbon, soil total nitrogen, water holding capacity and soil thermal properties, is fundamental to constructing realistic models of the terrestrial carbon and hydrological cycles. Soil C stocks and fluxes are globally important in terms of the terrestrial carbon cycle and many soil C pools are vulnerable to global change. However, changes in pools are slow and difficult to detect and existing inventories contain significant errors.

All currently available global soil maps are based on the FAO 1:15 M soil map of the world, formulated in the 1970s. Improved global maps will be provided by ISLSCP-II and SOTER 1:5M maps, which are in preparation. SOTER, in particular, promises to become the most important public domain source of digital soils data: South America, parts of Africa and Asia are already available and the rest should come online within the next five years.

### **(f) Climate**

Several global model-based climates are available (e.g. HadCM2, ECHAM4, CGCM1, GFDL-R15, CSIRO-Mk2, NCAR-DOE, CCSR). In some cases model calculations exist in a re-analysed form which is constrained by observations. There is also a range of gridded observational datasets covering different periods, principally:

- ISLSCP-I (1987-88) and II (1982-90) with grid scale of 1° (and ¼° and ½° in ISLSCP-II);
- Leemans and Cramer (1931-60 at ½°);
- New et al. 1999, 2000 (1961-1990 mean, 1901-1995 monthly grids at ½°).

Major issues are **distribution, continuity and currency**, with the latter being a particular issue for re-analysed data.

### **(g) Topography**

Readily available global topographic datasets include

- GLOBE ([www.ngdc.noaa.gov/seg/topo/globe.shtml](http://www.ngdc.noaa.gov/seg/topo/globe.shtml)), elevations regularly spaced at 30 arc-seconds, variable accuracy, but at best ±18m vertically.
- ACE ([www.cse.dmu.ac.uk/geomatics/ace/index.html](http://www.cse.dmu.ac.uk/geomatics/ace/index.html)), with 30 arc-second spacing, derive with aid of space altimeter data and provides data quality information.

The SRTM DEM (<http://seamless.usgs.gov/>, <http://www.jpl.nasa.gov/srtm/>) is an interferometric product which will provide a DEM between 60° N and S with elevations at 1 x 1 arc-second and vertical accuracy of ±16 meters. It is currently being processed one continent at a time.

### **(h) CO<sub>2</sub> column content from space**

A major new technology likely to revolutionize our knowledge of the sources, distribution and variability of atmospheric is column content of CO<sub>2</sub> measured from space. The AIRS and Sciamachy instruments are already providing low resolution measurements, but the Orbital Carbon Observatory, due to launch in 2007, will bring much higher resolution, together with better sampling in space and time. This mission's projected 2-year lifetime is insufficient to measure trends (for example, it will not measure across an El Nino/La Nina cycle) but will prove the concept as well as providing unprecedented data.

## Regional programmes

Regional carbon programmes formed a specific theme of the meeting for three main reasons:

- Regional programmes provide crucial demonstrators of methods for analysing the terrestrial carbon cycle.
- Construction of a global carbon observation system will rely in part on making best use of planned or existing regional programmes.
- Most of the inventory work needed for a global system is carried out at national scale for UNFCCC reporting.

Now is a particularly important time, since several major regional carbon programmes are just being initiated or are planned for the near future. In order that these programmes can be best combined within a global carbon observing system, issues of compatibility, consistency and data sharing between programmes must be tackled immediately.

Programmes in Amazonia, Australia, Canada, USA, Europe, Indonesia and Siberia/Eurasia were presented. They each had quite distinctive characters, as described below. Not represented at the meeting were important programmes in China and Japan, or the LBA project in Amazonia.

### Amazonia

In **Amazonia**, the RAINFOR project aims to establish if *old-growth* Amazonian forests are changing over time (in structure, biomass, composition and dynamics). It uses a systematically monitored network of previously established sample plots, and is developing a standardised pan-Amazonian dataset of soil physics and nutrient status based on common sampling protocols and lab analyses. The network is cheap and easy to maintain, with extensive spatial coverage allowing insight into processes. It also provides relatively long-term data allowing the relationship between the carbon cycle and biodiversity to be examined. Against this, only above-ground live biomass is usually measured and the small (1 hectare) plot size makes investigation of natural dynamics difficult to study from these data.

### Australia

**Australia** provides an important illustration of the application of a '*multiple constraints*' approach to modeling net carbon fluxes across the Australian continent. It tries to maximize the information from 'ecological' observations when using inverse methods to estimate carbon-climate model parameters. Key points made in this presentation were that for model-data fusion the forward model must accurately represent processes **at the scale of interest**, the model state equations and observations must **share parameters** with the same **definitions** and parameters must be defined on the **same scale**.

### Canada

In **Canada**, terrestrial carbon studies are of considerable policy and scientific interest, with reporting, mitigation, Kyoto Protocol mechanisms/economic opportunities, Kyoto Protocol 2, impacts and adaptation as the main drivers. Most research so far is based on inventory or bottom-up modeling at universities and government laboratories, coordinated through various mechanisms. Heavy use is made of remote sensing. Carbon-related research is increasing in scope and intensity, and there is increasing interest in fusing top-down and bottom-up approaches. The Canadian community is likely to participate in continent-wide research projects, whose extent depends on compatibility with research funding.

## Europe

For **Europe**, the FP5 and FP6 Carbo-Europe projects aim to provide the ecosystem and atmospheric measurements and data assimilation needed to understand carbon budgets at local, regional and continental scales. The main linked themes are:

- Ecosystem carbon budgets and driving forces;
- A continental atmospheric observing system;
- The regional carbon budget and its driving forces;
- Integration of scales and carbon data assimilation methods.

Within Carbo-Europe, the Carbon Assimilation and Modelling of the European Land Surface (CAMELS) project is intended to develop a prototype operational Carbon Cycle Data Assimilation System using a multiple constraint approach. Ecophysiological models will be used with a variety of inputs (net ecosystem carbon fluxes from eddy covariance towers, changes in carbon pools from land carbon inventories, biophysical parameters from remote sensing) in order to distinguish contributions to the land carbon sink (as required by the Kyoto Protocol). These models will be constrained by large-scale atmospheric measurements (including satellite-derived CO<sub>2</sub> column content) to provide best estimates and error bars at regional and national scales.

## United States of America

For the **United States**, the North American Carbon Plan aims at improved, coordinated monitoring of the atmospheric, land and ocean domains for North America and the adjacent oceans, complemented by a new generation of process models and a comprehensive framework for model-data fusion. In a five-year time frame, it aims to deliver information on North American carbon sources and sinks, and quantify the contributing processes. Its implementation involves four elements:

- Enhanced observation networks;
- Pilot field programmes;
- Improved land surface products;
- Improved assimilated meteorological products and developments in 4DDA.

It has much in common with Carbo-Europe, and it is clear that there would be considerable gain by coordination and integration (also with programmes elsewhere).

## Northern Eurasia

**Northern Eurasia** is a first order hotspot of climate change, in which a range of critical carbon processes is being driven by climate warming. Many studies, providing a wealth of data, have focused on this region, including:

- IGBP Northern Eurasia High Latitude Transects;
- National Programmes: “Global Change of Environment and Climate” and “Russian Forests”;
- EU funded projects: CARBOEUROPE, TCOS SIBERIA, SIBERIA and SIBERIA-II;
- The Terrestrial Biota Full Greenhouse Gases Accounting for Russia (IIASA and Russian Institutions);
- Projects funded by Japan (West Siberia, Russian Far East);
- Projects funded by USA (European North-West, Central Siberia, Russian Far East).

**Integration of these data and coordination of research remain unsolved problems.** Two important projects are under development which will attempt to provide a way forward:

- Boreas-Machine, to be submitted to the EU FP6 Programme.

- The NASA-led Northern Eurasia Earth Science Partnership Initiative (NEESPI).

## **Indonesia**

**Indonesia** is of major importance in global carbon studies, since it contains the major tropical deposits of peat (which are very vulnerable under human interference, particularly fire and disturbances to the hydrological network). In addition, deforestation is proceeding at a frightening pace. Two major projects are underway, led by the BOS Foundation and Wageningen University, to map the peat and to provide three-monthly web-based information on forest status. **These initiatives need to be coordinated with the other major projects in tropical forest monitoring.**

## **Ocean observations**

**Ocean observations** are important to close the carbon budget at the continental scale and hence constrain terrestrial carbon sinks. The EU FP5 project: Carbon variability studies from ships of opportunity (Cavassoo) aims to provide the necessary information on variable ocean basin sinks in the Northern hemisphere oceans. It will improve understanding of the processes giving rise to the ocean carbon sink (seasonality, inter-annual variability and long-term trend) and improve our ability to predict its future size. Together with atmospheric inversions, it will better constrain calculations of the terrestrial sinks for CO<sub>2</sub> in Europe-Asia and North America, providing more accurate estimates of these on a year-by-year basis.

## Appendix I Meeting agenda

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Tuesday, June 3, Start 9:00, Finish 17:30

### **9:00 – 9:10 Opening: Welcome and Logistics**

Shaun Quegan and Mike Raupach

### **9:10 – 9:40 Overview of International Planning for Carbon Observations and Research (10' talks)**

**Chairman for session: Ian Woodward**

9:10 GTOS-TCO – Shaun Quegan

9:20 IGCO – Philippe Ciais

9:30 GCP – Mike Raupach

### **9:40 – 11:40 Agency Perspective and Needs (15' + 5' questions)**

9:40 – 10:00 UNFCCC (Guenther Seufert)

10:00 – 10:20 NSF representative (Rachael Craig)

10:20 – 10:40 ESA representative (Steve Plummer)

#### **10:40 – 11:00 Coffee**

11:00 – 11:20 NASA representative (Bill Emanuel)

11:20 – 11:40 NASDA representative (Ake Rosenqvist)

### **11:40 – 12:05 Interactions between models and data (including data uncertainty issues) (20' + 5' questions) Dave Schimel (presented by Dennis Ojima)**

### **12:05 – 12:30 Determining Terrestrial Carbon, Water and Energy Fluxes: Models, Data and Policy Implications (20' + 5' questions) Mike Raupach**

#### **12:30 – 13:30 Lunch**

### **13:30 – 17:00 Data Assimilation: Demonstration Projects (20' + 5' questions)**

**Chairman for session: Shaun Quegan**

*Biogeochemical Processes Focus:*

13:30 – 13:55 Dennis Ojima

13:55 – 14:20 Ian Woodward (model testing)

*Atmospheric Focus:*

14:20 – 14:45 Peter Rayner

14:45 – 15:10 Peter Cox (CAMELS)

#### **15:10 – 15:40 Tea**

15:40 – 16:05 Martin Heimann (Integration component of CarboEurope)

*Operational Weather Forecasting:*



16:05 – 16:30 Richard Engelen

16:30 – 17:00 Open Discussion (30')

17:00 – 17:30 Initialization of Working Groups: Mike Raupach / Shaun Quegan

Wednesday, June 4. Start 8:45, Finish 18:30

### **9:00 – 11:00 Global Observations: (15" + 5' questions)**

**Chairman: Richard Harding**

8:45 – 9:05 Overview on "What is available": Stephen Plummer

#### **Critical reviews on IGCO priority topics**

These talks will discuss how good the datasets are, their limitations, and ways to improve them:

- (i) **uncertainties** of the data
- (ii) **characteristics** of the data (how often data are collected, temporal and spatial cover and gaps, how quickly the data become available, immediate requirements for data to become more useful).

9:05 – 9:25 Land Use/Cover Change: Ruth DeFries

9:25 – 9:45 Biomass: Thuy Le Toan / Shaun Quegan

9:45 – 10:05 Land Cover and Fire: Frederic Achard

10:05 – 10:25 Soil Carbon: Phil Ineson

10:25 – 10:45 Open Discussion

#### **10:45 – 11:15 Coffee**

### **11:20 – 13:00 Regional Observations (projects) 1: (15" + 5' questions)**

**Chairman: Guenther Seufert**

Short talks discussing the type of C relevant data being measured at the regional level with an emphasis on how good the datasets are, their limitations, and ways to improve them:

- (i) **characteristics (specifications)** of the data (how often data are collected, temporal and special cover and gaps, how quickly the data become available, immediate requirements for data to become more useful).
- (ii) **uncertainties** and other limitations of the major data sets obtained in the projects
- (iii) **requirements** and **needs** to improve collection and make data more useful (including new product development and delivery)
- (iv) what important/critical **data are missing** for your region (in order to do complete full accounting and/or to apply a data assimilation scheme). Specifically, what one or two pieces of data that you don't have which would make the most difference for a full carbon accounting of the region?
- (v) What are the key issues/barriers in linking your regional findings to the global carbon cycle (i.e., how can your methodology be scaled up to continent and globe)?

11:20 – 11:40 Tropical forest inventories: Yadvinder Malhi

11:40 – 12:00 Australia: Damian Barrett

12:00 – 12:20 Canada: Josef Cihlar

12:20 – 12:40 USA (NACP): Rachael Craig

12:40 – 13:00 The OCO mission: Philippe Ciais

#### **13:00 – 14:00 Lunch**

### **14:00 – 15:40 Regional Observations 2: (15" + 5' questions)**

**Chairman: Dick Olson**

14:00 – 14:20 Europe (AEROCARB regional atmospheric measurement network): Philippe Ciais  
14:20 – 14:40 Euroflux (eddy flux tower network): John Grace  
14:40 – 15:00 Russia: Anatoly Shvidenko  
15:00 – 15:30 Siberia II/Boreas Machine: Thuy Le Toan / Chris Schmillius  
**15:30 – 16:00 Tea**  
16:00 – 17:30 Break-out groups 1  
17:30 – 18:30 Posters session

Thursday, June 5 Start 8:30, Finish 17:00

**8:30 – 10:00 Break-out groups 2**

**10:00 – 11:00 Initial feedback from break-out groups**

**Chairman: Mike Raupach**

**11:00 – 11:20 Coffee**

**Miscellaneous important topics (15' + 5' questions)**

11:20 -11:40 Indonesia: Dirk Hoekman (presented by Shaun Quegan)

11:40 – 12:00 CO<sub>2</sub> from space: Alain Chedin

12:00 – 12:20 Constraining the terrestrial C budget using ocean observations: Andy Watson

12:20 – 12:40 Global Soil Datasets: Bob Scholes

**12:40 – 14:00 Lunch**

**14:00 – 17:00 Break-out groups**

Friday, June 6 Start 9:00, Finish 13:00

**9:00 –10:30 Break-out groups**

Finalisation of findings, conclusions and recommendations

**10:30 – 11:00 Coffee**

**11:00 – 12:30 Plenary session**

Reports from groups

Timetable for write-ups, manuscripts, special issue/feature, and GTOS and GCP meeting reports.

**13:00 End of Workshop**

**Products:**

1. GTOS and GCP report (focus on observation outputs), acting as Executive Summary for report to IGOS-P (with components on space observations, in situ networks, research, and regional/global NWP centres)
2. A special issue (if we have up to 10 papers) or special feature (up to 5 papers), and a number of multi-author papers resulting from the break-out groups.
3. Proposal for a number of potential projects to be pursued after the meeting with links to specific leadership, groups/centers, and funding opportunities.

## Appendix II Working Sessions

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### *Meeting Objectives*

*Broad goal of the workshop:* to increase the reliability and availability of estimates of terrestrial C sources, sinks and processes, regionally and globally, through syntheses of observations and models.

*Specific aims:*

- To reflect the state and direction of the science of terrestrial carbon observation and model-data fusion (TCO-MDF);
- To advance this science by learning from each other through the workshop;
- To develop specific new projects, or enhance existing projects, which are crucial to advancing observations, models or appropriate model-data fusion methodologies.

### *Products*

- A synthesis paper on “Terrestrial carbon observations and model-data fusion” in an appropriate journal;
- A report to GTOS, GCP and IGOS-P summarising the workshop content and the recommendations emerging from the Working Groups;
- Proposals for potential projects to be pursued collaboratively after the workshop.

### *Working Groups*

Working Groups discussed and provided recommendations on the following three topics:

**Group 1 Model-data fusion methodologies for terrestrial carbon observation and prediction.**

**Group 2: Towards operational terrestrial carbon observation and prediction: Data resources, opportunities and challenges.**

**Group 3: Strategies for defining and reducing uncertainty in terrestrial carbon observation and prediction.**

## Appendix III List of Participants

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List including contact details is available at: <http://www.fao.org/gtos/meetSHE.html>

Dr Frédéric Achard, Joint Research Centre of the European Commission, Italy  
Prof. Clive Anderson, CTCD, University of Sheffield, UK  
Dr Damien Barrett, CSIRO Plant Industry, Australia  
Mr Christian Beer, Friedrich-Schiller-University Jena, Germany  
Dr Alain Chedin, CNRS, France  
Dr Philippe Ciais, Commissariat à L'Energie Atomique, France  
Dr Josef Cihlar, Canada Centre for Remote Sensing, Canada  
Dr Stefano Conti, CTCD, University of Sheffield, UK  
Dr Robert Cook, Oak Ridge National Laboratory, USA  
Dr Peter Cox, Met Office, UK  
Dr Rachael Craig, National Science Foundation, USA  
Dr Ruth Defries, University of Maryland, USA  
Dr Mat Disney, CTCD, University College London, UK  
Dr Pierre Drezet, CTCD, University of Sheffield, UK  
Dr William Emanuel, U.S. National Aeronautics and Space Administration, USA  
Dr Richard Engelen, ECMWF, UK  
Prof. Julia Georgieva, National Institute of Meteorology and Hydrology, Bulgaria  
Prof. John Grace, CTCD, University of Edinburgh, UK  
Dr Richard Harding, Centre for Ecology and Hydrology, UK  
Prof. Martin Heimann, Max-Planck-Institut for Biogeochemistry, Germany  
Dr Andreas Heinemeyer, CTCD, University of York, UK  
Ms Jo House, Max Planck Institute for Biogeochemistry, UK  
Prof. Phil Ineson, CTCD, University of York, UK  
Dr Marc Kennedy, CTCD, University of Sheffield, UK  
Prof. Juergen Kesselmeier, Max Planck Institute for Chemistry, Germany  
Dr Sebastien Lafont, CTCD, Forest Research, UK  
Dr Thuy Le Toan, CESBIO, France  
Dr Mark Lomas, CTCD, University of Sheffield, UK  
Dr Yadvinder Malhi, University of Edinburgh, UK  
Dr Caroline Nichol, CTCD, University of Edinburgh, UK  
Dr Dennis Ojima, Colorado State University, USA  
Mr Richard Olson, Oak Ridge National Laboratory, USA

Dr Jennifer Pellenq, CTCD, University of Sheffield, UK  
Dr Ghislain Picard, CTCD, University of Sheffield, UK  
Dr Stephen Plummer, IGBP-ESA, Italy  
Dr Tristan Quaipe, CTCD, University College London, UK  
Prof. Shaun Quegan, CTCD, University of Sheffield, UK  
Dr Michael Raupach, CSIRO Land & Water, Australia  
Dr Peter Rayner, CSIRO, Australia  
Mr Stefan Reis, University of Stuttgart, Germany  
Dr Ake Rosenqvist, NASDA, Japan  
Prof. Chris Schmullius, Friedrich-Schiller University, Germany  
Dr Bob Scholes, CSIR Environmentek, South Africa  
Dr Géraud Servin, FAO of the UN, Italy  
Dr Reuben Sessa, FAO of the UN, Italy  
Dr Günther Seufert, European Commission Joint Research Centre, Italy  
Prof. Dr Anatoly Shvidenko, International Institute for Applied Systems Analysis, Austria  
Mr Paul Taylor, CTCD, Forest Research, UK  
Prof. Andrew Watson, University of East Anglia, UK  
Prof. Ian Woodward, CTCD, University of Sheffield, UK