Integrated Global Carbon Observing system Implementation Plan. Draft 1.0

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Draft only, do not cite.

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Executive summary

Understanding the global carbon cycle and predicting its evolution under future climate scenarios is one of the biggest challenges facing science today. The uncertainty in the present state of the carbon cycle is a leading contributor to the uncertainty in climate predictions due to the feedbacks between climate change and the carbon reservoirs. And a key reason for our lack of understanding of the global carbon cycle is a lack of global observations. An increased, improved and coordinated observing system for observing the carbon cycle is vital.

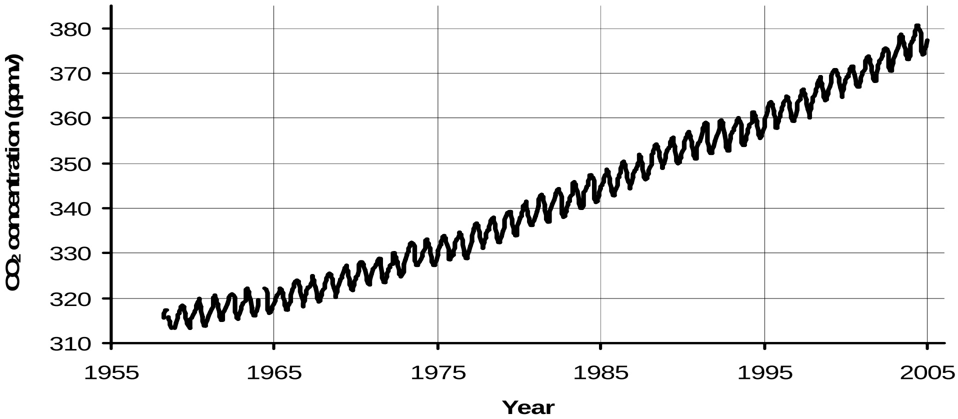

Figure 1 Mauna Loa CO_2 record from the Scripps and NOAA/CMDL laboratories. This was one of the first observations of the global carbon cycle, and is valuable due to its continuous high quality.

This Implementation Plan sets out a large number of actions (over 100) that need to be taken to expand the current observing system such that a fully integrated observation system of the core variables is achieved. Some actions are already being carried out, while others are still to be addressed. Completing the plan will involve thousands of scientists, agency representatives, technicians, and policy makers. The goal of the IGCO is to provide a central communication point to facilitate the flow of information from the data providers to the data users and to summarise the current state-of-the-art and the way forward.

The list of observations that are covered in this plan are shown in Table 2. The observations have been broken down into Atmospheric, Oceanic and Terrestrial, along with sections on the fossil fuel emissions, the role of modelling, and of data management. Within each of the atmosphere, ocean and terrestrial domains, the in situ and remote sensing systems are presented separately. There exist many overlaps between these sections and wherever possible links to the other relevant sections have been made.

The following two chapters (Introduction and Strategic Approach to Implementation) detail the rationale behind having a carbon observation plan and how the plan will work. The interactions with existing groups (such as IGOS partners and themes, GEO and other existing research and observational systems) are described. The remainder of the document list and details each of the action items.

It is anticipated that this document will become a live document, continuously updated and available online. As action items are achieved, the following steps will become clear, necessitating new actions and new directions. The IGCO will be a service provider to the carbon community, facilitating the flow of information.

1 Introduction

1.1 What is this document and what is its rationale?

This document provides the plan for implementing a coordinated observing system of the global carbon cycle. This document is a follow up of the carbon observing strategy developed by the Carbon Theme Team of IGOS-P (Integrated Global Observing Strategy Partners).

The Integrated Global Carbon Observations (IGCO) team was established in 2001 with the mission to develop a flexible and robust strategy for deploying global systematic observations of the carbon cycle. The IGCO published in 2004 the Carbon Theme Report which sets forth the strategic goals and the key elements of such a future coordinated global carbon observing system. The global carbon observing system is envisioned to combine in-situ and remotely sensed systematic observations in order measure carbon fluxes and pools globally, with sufficient spatial and temporal resolution to uncover the controlling processes. The present situation is that most of the major elements of the integrated carbon observing system already exist, but mostly operate on a research basis, and their long term continuity is not guaranteed. In synergy with carbon cycle research programmes, this 10 year implementation plan thus aims to firmly establish the necessary long term "backbone" carbon observations and associated modelling activities that are needed to quantify and understand the ongoing perturbations of the carbon cycle. Such a global carbon observing system is expected to become in the future an essential component of a broader Earth observing system.

The format and style of this document is heavily borrowed from that of the Global Climate Observing System Implementation Plan (http://www.oco.noaa.gov/docs/gcos_plan.pdf). We acknowledge the work of Prof Mason and all the GCOS Science Panel Chairs and other contributing authors in creating that document.

1.2 Why do integrated global carbon observations?

The carbon cycle is central to the Earth System, being inextricably coupled with climate, the water cycle, nutrient cycles and life on earth. It has been subject to large perturbations through the combustion of fossil fuels throughout the industrial age, with major consequences for global and regional climates through enhanced greenhouse warming. To manage and mitigate these consequences, systematic, sustained observation of the carbon cycle is critical (Dilling et al, 2003).

Integrated global carbon observation has two main objectives, one scientific and the other policy-oriented:

- To provide the long-term observations required to improve understanding of the present state and future behaviour of the global carbon cycle, particularly the factors that control the global atmospheric CO_2 level.
- To monitor and assess the effectiveness of carbon sequestration and/or emission reduction activities on global atmospheric CO_2 levels, including attribution of sources and sinks by region and sector.

The benefits of an integrated global carbon observation system stem in part from the need to understand and manage the risks associated with vulnerabilities in the earth system, and especially the carbon cycle, under climate change. There is a risk that as the carbon cycle responds to global warming and other manifestations of climate change, positive feedbacks (such as releases of carbon from soils and permafrost) will accelerate the rate of warming (Cox et al., 2000, Friedlingstein et al. 2003). The uncertainties associated with these feedbacks are comparable with those for different emissions scenarios (ref IPCC, Edmonds chapter in Field and Raupach book). A key contribution of an integrated global carbon observation system is to reduce the uncertainties associated with these feedbacks, and the investment in such a system will repaid many times over through its contribution to reducing these uncertainties and targeting more effectively the magnitude and timing of global mitigation efforts.

An integrated global carbon observation system is a key contribution to the Group on Earth Observations (GEO) and the Global Earth Observation System of Systems (GEOSS), as called for in recent Earth Observation Summits. Because of the connection between the carbon cycle and other components of the Earth System, the IGCO supports GEO and GEOSS goals not only in climate but also in managing and understanding the water cycle, improving weather prediction, monitoring and managing terrestrial ecosystems, and supporting agricultural sustainability.

1.3 What is the integrated global carbon observation system?

An integrated global carbon observing system will routinely quantify and assess the global distribution of carbon and its exchange between the Earth's surface and the atmosphere, and measure at regular intervals the changes of key carbon stocks, along with observations that help elucidate underlying biogeochemical processes. The system will integrate across the three major reservoirs of the carbon cycle: ocean, land, and atmosphere. It will combine data and models for the different reservoirs, wherein information from one reservoir places valuable constraints on the workings of all others.

The global carbon cycle is forced by a disparate set of human and natural drivers. Its response can be observed via a similarly large set of signatures such as material and energy flows (e.g. fluxes to the atmosphere), changes in various stocks (e.g. dissolved inorganic carbon in the ocean) and changes in structure (e.g. changes in land cover in response to climate). These inputs and responses must be measured with sufficient spatial and temporal resolution to characterize the current state and evolution of the system.

The measurements should adhere to a number of principles, as we have chosen to adopt the GCOS Climate Monitoring Principals which are detailed in the GCOS Implementation Plan. These principals are in line with the Data and Information System and Services Principals of IGOS-P outlined in the IGOS Partner Process Paper (2000). We summarize the pertinent ones here:

- Consistency: Much of the critical information on the carbon cycle is inferred from spatial or temporal differences in a quantity (e.g. atmospheric concentration gradients). Measurements must be consistent to avoid biasing such inferences.
- Continuity: For many quantities, the temporal evolution is more important than absolute magnitude. Also, the variability of the carbon cycle is a key indicator of its sensitivity. This implies a demand for continuity of measurement with well-planned transitions from one platform or technique to another.
- Coverage: Few regions of the world are not potential sources or sinks of carbon. Many important regions are not currently covered by measurements. Programmes that can fill these gaps warrant special attention.

- Quality: Measurements must be of sufficient quality to further the science or policy goals. This demands not only their accuracy and precision but proper characterization of their errors.
- Redundancy: No single approach will guarantee a reliable measurement. Where possible, at least two independent measurements of comparable quantities should be available.
- Optimality: Where possible, measurements should be tested in data utility studies to assess their contribution to scientific or policy goals.

Similar principles, applied specifically to carbon observations, were developed by Raupach et al. 2005).

1.4 Who will do it?

1.4.1 Operational and Research Satellite Agencies

The IGCO implementation plan relies heavily on the support of both operational and research satellite agencies for essential global observations of

- atmospheric composition, dynamics and thermodynamics,
- the land surface biosphere (including biomass burning), land hydrosphere and cryosphere,
- ocean dynamics, thermodynamics, composition, biosphere and cryosphere;

In addition, the satellite agencies will provide observations essential for mapping purposes and for essential geophysical quantities such as the geoid.

The space-based observations required by the plan will be provided partly by operational missions and partly by research missions. It is expected that the spirit of the agreement between WMO and space agencies on data access for meteorological purposes to both operational and research missions can be extended to the data needed for the IGCO implementation plan.

Moreover, in the course of the IGCO implementation, the responsibility for several key categories of space observations and data products will move from research to operational agencies. The difficulties of such transitions (National Academy Press, 2000) are acknowledged, and we note that a sufficiently long timescale is required to allow the planning for groups and individuals to adapt. In such transitions it will be important for IGCO that forward and backward compatibility of data products will be achieved wherever possible; relevant examples include information on greenhouse gases, aerosols, vegetation, biomass and biomass burning.

1.4.2 Operational and in situ agencies, networks and programs

The IGCO implementation plan relies equally heavily on the support by a multitude of research and operational agencies providing in situ observation from five primary categories. These include:

- direct in situ atmospheric measurements providing the large scale CO_2 concentration distribution from which the underlying spatio-temporal source fluxes can be determined using inverse modelling of atmospheric transport;
- direct surface-atmosphere carbon flux measurements over land by the eddy covariance measurement technique and over oceans using observations of the air-sea partial pressure difference;

- observations on land and in the ocean of carbon pool size and pool size changes, such as inventories of forest biomass, soil carbon and dissolved carbon in the ocean,
- compilations of data from statistical information, such as geographically explicit emissions from fossil fuels use statistics, and carbon flows by trade which are needed to establish the full carbon balance of any given geographical region;
- auxiliary in situ data that are needed to understand in detail the processes controlling the various physical, chemical and biological processes underlying carbon flows into and out of the different reservoirs.

In situ observations currently are performed by international and national agencies and to a considerable extent by individual research institutions. Because of this they often lack continuity and coherence. Recently, integrated regional carbon studies have started to provide the integration of several types of observations, but in general these lack a long-term observation perspective. Implementing a global observing system of systematic in situ observations necessitates a transition from the present patchy research mode to operational mode. Main challenges in this transition arise from co-ordination of the diverse types of observations and data streams, the spatial completion of in situ networks and maintenance of a long-term support for these measurements.

1.5 Relationship to other global observation programs

The implementation plan of the IGCO theme is closely related to and benefits from a number of already existing plans. Among them, the Terrestrial Carbon Observation (TCO) initiative, a component of the Global Terrestrial Observing System (GTOS), which has developed an extensive framework and implementation strategy for a comprehensive terrestrial and atmospheric carbon cycle observing system.

The plan rests similarly upon a strong base for ocean carbon observations, and benefits from the strategy developed for the Global Ocean Observation System (GOOS) for a global ocean carbon observation system and its connectivity to the atmosphere (Doney and Hood, 2002). Ocean carbon surveys will be conducted as part of the 10-year repeat hydrographic transects being coordinated by CLIVAR (Climate Variability and Predictability, a project of the WCRP), theOceanSITES time series observatory network, and the cooperative network of carbon measurements from Volunteer Observing Ships. The International Ocean Carbon Coordination Project, an initiative of the IOC-SCOR CO_2 Panel and the Global Carbon Project, provides essential coordination for all large-scale ocean carbon observation activities.

Essential non-carbon measurements for the global carbon observing system such as climate variables (atmospheric temperature, precipitation and moisture fields, sea surface temperature etc) will be provided and coordinated by the GCOS.

In addition to the existing global-scale but compartmentalized observation strategies, there are a number of important regional and national observation systems and strategies that will contribute valuable components to the strategy for developing a carbon observing system. At present, however, they still operate in a fragmentary fashion and their full potential can only be realised through the development of an internationally integrated observational strategy.

This plan is not a new carbon cycle research agenda which has been largely developed and coordinated by the GCP, a joint project of the International Geosphere-Biosphere Pogramme (IGBP), the International Human Dimensions Programme (IHDP), WCRP, and Diversitas under the Earth System Science Partnership (ESSP). However, both the IGCO and the GCP have carefully aligned the needs for operational observations and research that are required to collectively address fundamental science questions and policy needs. Thus, both efforts are complementary and well coordinated.

1.6 What is the audience for this document?

This document is intended to be an aid in establishing the steps and priorities necessary to achieve an integrated global carbon observing network. As such, the intended audience is the groups that instigate and fund observing networks, which aid the coordination of such networks, and the scientists and technicians that will produce the data, the modellers that will make use of the data, and finally the policy makers that will make use of the final products.

- IGOS-P
- GAW, GCOS, GTOS and GOOS
- GEO/GEOSS
- Operational agencies (e.g. weather services)
- Funding agencies (national and international)
- Research community
- United Nations Framework Convention on Climate Change (UNFCCC)
- Intergovernmental Panel on Climate Change (IPCC)

1.7 How to use this document

This Implementation Plan is the continuation of the process commenced by the creation of the Carbon theme of IGOS and the writing and publishing of the carbon theme report. The report is available online at http://ioc.unesco.org/igospartners/Carbon.htm. The report contains much of the scientific reasoning behind the strategy presented here, and should be used in conjunction with this document.

The IGCO IP is a series of action items that, once achieved will provide the community with a coordinated and integrated observing system of the carbon cycle. Each of the action items is briefly described and is given a priority, a cost estimate and a timeframe. These classifications are necessarily vague so as to avoid the plan becoming outdated if one or more actions prove more difficult to achieve than originally thought. Each item has been assigned an approximate cost, a time frame and any products that will be created as a result.

Cost indictor		Timeframe	
Low	Up to $100K	Short term	1-2 years
Medium	100K-500K	Medium	2-5 years
High	500K and above	Long	5-10 years

Table 1: Action item definitions

Where appropriate, each action item is cross referenced to action items in other reports such as the GCOS implementation plan, the ocean, water cycle and atmospheric chemistry theme reports of the IGOS, and the TCO implementation plan.

The document is separated into sections by reservoir, and within each reservoir the in situ and remote sensing issues are outlined. The four reservoirs are the atmosphere, ocean, terrestrial and fossil domains. Following these is a section on modelling the carbon cycle and the synergy between process models and the data that drives them. Finally the issue of data management and stewardship is detailed.

The action items are labelled:

- S - strategic implementation actions
- AI - in situ atmospheric
- AR - atmospheric remote sensing
- OI - ocean in situ
- OR - ocean remote sensing
- TI - terrestrial in situ
- TR - terrestrial remote sensing
- F - fossil reservoir
- M - integrated modelling
- D - Data management

An appendix lists all the action items sorted by time frame. This list will be made available on line and will be updated as time progresses.

2 Strategic Approach to Implementation

2.1 Basis

In 1999 IGBP, GOOS, GTOS, GCOS, NASA, CNES, NASDA, CEOS, UNEP, FAO and WMO/GAW initiated the IGCO, which was subsequently approved in 2000 by IGOS-P, with a Carbon Theme Report submitted to IGOS in 2003 and published in 2004. The IGOS theme process does not specifically require an Implementation Plan, but a list of action items will facilitate achieving the goals set out in the theme report. In November 2004, IGOS-P requested that such an implementation plan be written.

Other important documents have outlined the need for an improved carbon observing system. The Second Report on the Adequacy of the Global Observing Systems for Climate in Support of the UNFCCC specifically mentions greenhouse gas concentrations under item AF18, which recommends the expansion of the GAW network and the advancement of satellite measurements of green house gases (GHGs). The report also covers ocean carbon under item OF12, while the terrestrial carbon domain is covered in items TF11 to 15, with the recommended continuation and improvement fields such as fAPAR, LAI, area burnt, and terrestrial flux measurements. Accordingly, the GCOS Implementation includes CO_2, CH_4, ocean surface pCO_2 and subsurface dissolved inorganic carbon and related carbon biogeochemical compounds, fAPAR, LAI, biomass and fire disturbance.

Based on the boxes 1, 2 and 3 of the Carbon Theme Report, the following list of key carbon cycle variables has been compiled:

Domain		Variables
Atmospheric	Core	CO_2, CO and CH_4 columns from remote sensing CO_2, CO and CH_4 concentrations; in situ, surface and aircraft profiles
	Ancillary	Climate variables, i.e. surface and upper air temperature, precipitation, wind speed, cloud and moisture fields

Terrestrial	Core	Eddy covariance tower fluxes Forest inventories Soil carbon inventories Land cover Fire and other disturbance maps Leaf area index Vegetation architecture fAPAR
	Ancillary	Albedo Soil moisture Soil temperature Canopy temperature Nutrients
Oceanic	Core	pCO_2 Dissolved and particulate inorganic, and organic carbon Ocean colour
	Ancillary	Ocean circulation Air sea gas transfer
Fossil		Fossil fuel emission maps

Table 2: Essential Global Carbon Cycle variables and fields

This document does not stand alone, and is a cross section through many other coordination projects, in particular the GCOS, GOOS and GTOS. Wherever possible the documents below have been cross referenced here.

Document	Date	Where to find it
Themes Concept for IGOS	1999	http://www.eohandbook.com/igosp/docsIGOS.htm
IGOS Partnership Process Paper	2004	http://www.eohandbook.com/igosp/docsIGOS.htm
IGOS Carbon Theme Report	2004	http://www.eohandbook.com/igosp/Carbon.htm
Implementation Plan for the Terrestrial and Atmospheric Carbon Observation (TCO) Initiative	2003	http://www.fao.org/gtos/TCO.html
A Global Ocean Carbon Observing System (GOOS report 118)	2002	http://ioc.unesco.org/goos/docs/doclist.htm
The Global Carbon Project (GCP) Framework and Implementation Plan	2003	http://www.globalcarbonproject.org/products.htm
Global Climate Observing System (GCOS) Implementation Plan	2004	http://www.wmo.ch/web/gcos/Implementation_Plan_(GCOS).pdf

Strategy for the Implementation of the Global Atmosphere Watch (GAW) Program	2001	http://www.wmo.ch/web/arep/reports/gaw142.pdf
CarboEurope 5 year Implementation Plan	2003	http://www.globalcarbonproject.org/carbon_portal/nat_reg_contributions.htm
North American Carbon Plan (NACP) Implementation Plan	2002	http://www.globalcarbonproject.org/carbon_portal/nat_reg_contributions.htm
US Carbon Cycle Science Program	2004	http://www.carboncyclescience.gov/
IGOS Ocean theme report	2001	http://www.eohandbook.com/igosp/Ocean.htm
IGOS Atmospheric Chemistry (IGACO) theme report	2004	http://www.eohandbook.com/igosp/Atmosphere.htm

Table 3: List of implementation plans and other documents to be used in conjunction with this implementation plan.

2.2 Links between data collecting agencies and data users, and data users end products

The carbon cycle is a global phenomenon and acts in the atmosphere, ocean, terrestrial biosphere and the fossil reservoir. As such, coordination between the various data collecting agencies is required. As data users move into using full carbon cycle models, as opposed to modelling each reservoir separately, data products that integrate across the reservoirs are required. Significant inter-annual variability exists in the fluxes between the reservoirs and therefore it is important that data for the same periods are available from each reservoir.

Action S 1

Action:	Identify data users and their needs, and the products they are expected to produce
Who:	IGCO partners
Time-frame:	Short term and ongoing
Product:	List of groups using data and the products they create
Cost:	Low

Action S 2

Action:	Improved coordination among existing international programmes and components, particularly GCP, TCOS, IOC and IGCO
Who:	IGCO partners
Time-frame:	Short term
Product:	Representation of these organisations in the IGCO implementation team
Cost:	Low

Several remote sensing agencies already have instruments in orbit that can sense greenhouse gases, and the next generation of CO_2 specific instruments will be launched soon. It is important that the activities of the agencies is coordinated so that maximum information can be retrieved, that the records are continuous, and that validation against surface based observation can be optimised.

Action S 3

Action:	Involvement of operational satellite agencies such as NOAA, EUMETSAT
Who:	IGCO partners, space agencies
Time-frame:	Short term
Product:	Representation of space agencies in the IGCO implementation team
Cost:	Low

Regional carbon studies such as the NACP and CarboEurope are carrying out studies to intensively observe the carbon cycle over domains of 10s to 100s of kilometres. While the data products will be specific to each region, the processes of scaling up and modelling the carbon cycle processes are similar and as such coordination of the efforts of the regional studies is important to best advance their understanding.

Action S 4

Action:	Convergence of current regional studies through joint workshops (i.e. CarboEurope and NACP, CarboOceans and OCCC) to a coordinated programme within the framework f the GCP
Who:	IGCO partners and regional programs
Time-frame:	Medium term
Product:	Progress of workshops and meetings
Cost:	Medium

The process of ingesting vast quantities of data into models is not new, and is done every day as part of the weather forecast process. The expertise and tools of the weather forecasting will need to be utilised to efficiently create a data assimilation system.

Action S 5

Action:	Improved links between the carbon cycle research community and traditional weather forecasting centres
Who:	IGCO partners and weather prediction centres, i.e. ECMWF, NCEP)
Time-frame:	Short term
Product:	Communication between IGCO partners and NWP centers.
Cost:	Low

2.3 Planning and reporting

The bulk of the work required to produce an integrated carbon cycle observing system will be carried out by the agencies, institutions and organisations already in place. However to facilitate the coordination of the efforts an IGCO office is required. A relatively small group of people is required to monitor the progress of the partners, to improve communication between partners, search for funding opportunities for international efforts, and, when and where possible to organise meetings and workshops to specifically tackle emerging issues.

Action S 6

Action:	Establish an IGCO office to oversee the implementation of the carbon plan
Who:	IGCO partners, GEO
Time-frame:	Short term
Product:	Appointment of staff
Cost:	Low – Medium

Communication of information such as the progress of action items, organisation of meeting and general carbon cycle news is best served with an up to date webpage. The webpage could serve as a portal to all the relevant global databases and research programs. IGCO will compile a list of email addresses for the global community to keep them up to date with IGCO activities, producing a newsletter 3 or 4 times a year.

Action S 7

Action:	Establish an IGCO web page and email lists
Who:	IGCO office
Time-frame:	Short term
Product:	Webpage
Cost:	Low

As time passes, some action items will be achieved, others will prove more difficult than expected, and breakthroughs in the science of observing the carbon cycle will mean that a continual update of the IP will be required. We anticipate a full update of the IP each two years and a continuous update of the action items on the IGCO web pages.

Action S 8

Action:	Rolling review of the IGCO implementation plan
Who:	IGCO office
Time-frame:	Medium to long term
Product:	Revised IP
Cost:	Low

2.4 Cross cutting issues and integrated products

This document is divided by reservoir and by in situ and remote sensing, but there are cross cutting issues where either more than one reservoir is involved, or both in situ and remote sensing measurements are used. Primarily this occurs at the reservoir boundaries, and when in situ measurements are used as ground truths for remote sensing products.

Air sea interface

Currently measurements of pCO_2 and the flux of carbon between the atmosphere and ocean do not require high precision atmospheric CO_2 concentration measurements. However, from an atmospheric inversion point of view, if ships measuring pCO_2 could also measure atmospheric CO_2 at high enough precision this could act as a valuable constraint on the ocean fluxes. See Action OI 2 and Action OI 3.

Land/atmosphere interface

Similar to the previous paragraph, for terrestrial eddy covariance fluxes atmospheric concentrations are also taken but are not calibrated accuracy as the precision is not required, just the temporal variability. Again, if the standard of these atmospheric observations was increased to meet the WMO/GAW standards the use to atmospheric modellers could be potentially very high. See Action TI 4.

Land/ocean/atmosphere interface

The coastal areas where river run off meets the marine environment are an area requiring multidiscipline coordinated observations. The river runoff contains substantial amounts of carbon, while the nutrient rich coastal waters have both complex physical and biological behaviour. See Action TI 14, Action OI 11 and Action OI 12.

Data assimilation tools
While this document is not about carbon cycle models, the observations are often going to be used in models. As the models tend towards coupled data assimilation systems, observing systems from the in situ and remotes sensing approaches, and the atmospheric, oceanic and terrestrial domains will require coordination. See Action M 1.

In situ and remote sensing – validation and calibration.
An important cross cutting issue is that between the in situ and remote sensing approaches, whereby the in situ measurements are used as ground truths for the remote sensing products. Every remote sensing product requires in situ measurements to calibrate and validate the algorithms that interpret the reflectance values from the satellite sensors. A over arching goal of the IGCO is to facilitate interaction between the remote sensing and in situ communities to allow the establishment of coordinated in situ networks. See Action AI 2, Action AI 10, Action AI 11, and Action AR 2.

2.5 Interactions with IGOS themes ands partners

The nature of the carbon cycle is that the IGCO will interact with virtually every IGOS theme and partner. There are some strong links which we expand on here:

- GAW is taking the lead on the coordination of the in situ atmospheric networks, for CO2 and other carbon cycle gases (CO, CH_4).
- The global nature of the carbon cycle means remote sensing will become more and more important, so the coordinating role of CEOS will be vital.
- Many of the auxiliary measurements required for carbon cycle research (such as surface temperature, wind fields, precipitation, aerosol fields) are being coordinated by GCOS.
- GTOS and GOOS explicitly mention carbon in their plans – the IGCO integrates the carbon observations across the domains
- FAO has been actioned in various places relating to the carbon in soils and agriculture
- The carbon theme overlaps with the Atmospheric, Ocean, Coastal, Land and Water Cycle themes. Coordination with these and any new themes (especially energy) will be important

2.6 Interactions with GEO and GEOSS

The Group on Earth Observations (GEO) is currently writing a detailed implementation plans based on its 10 year plan summary (http://earthobservations.org/docs/10-Year%20Implementation%20Plan.pdf) for a Global Earth Observing System of Systems (GEOSS). IGCO is specifically mentioned in the GEO 2 year work plan and the GEOSS 10 year implementation plan, and has been active in the writing of the GEOSS implementation plan, contributing to the near term (2 year) goals. IGCO will continue to work with GEO to complete the mid- and long term goals, and eventually to aid GEO in the execution of the carbon aspects of its IP. If organised well, the GEOSS goals and IGCO goals should have a complete overlap such that the IGOS goals are a subset of the GEOSS goals.

Action S 9

Action:	Continued contribution to the writing of the GEOSS IP
Who:	IGCO and partners
Time-frame:	Short term
Product:	Carbon observations featuring in the GEOSS IP
Cost:	Low

Action S 10

Action:	Assisting the GEOSS with the execution of their IP
Who:	IGCO and partners
Time-frame:	Short term
Product	Carbon observations featuring in the GEOSS IP
Cost:	Low

3 Atmospheric Implementation Plan

3.1 In situ atmospheric CO_2 measurements

The in situ atmospheric measurements of CO_2 have formed the backbone of modern global carbon cycle research, starting with the stations at Mauna Loa (Figure 1) and South Pole started in 1958 (the International Global Geophysical Year) by C. D. Keeling which are still operating today. From these two stations alone one can deduce the seasonal cycle and increasing trend, as well as the inter-annual variability with correlates with the Southern Oscillation Index. The increasing north-south gradient can also be observed to be increasing due to the increasing fossil fuel source mainly locating in the Northern Hemisphere. A primary goal of the IGCO is to promote and facilitate the establishment of long-term funding commitment at the national level to ensure the continuation of these and other vital atmospheric stations.

Action AI 1

Action:	Ensure the long-term continuity of the already established atmospheric CO_2 monitoring stations
Who:	GAW/WMO, national CO_2 networks and national funding agencies
Time-frame:	Short term and ongoing
Product	Essential long records of atmospheric CO_2
Cost:	Medium

As well as well as the direct interpretation of atmospheric measurements to estimate surface fluxes of CO2, the atmospheric network will also serve as a calibration tool for the remote sensing instruments on the OCO and GOSAT missions due for launch in 2008. Any design of the atmospheric network must be coordinated with the needs of the remote sensing community.

Action AI 2

Action:	Facilitate communication between the in situ and remote sensing communities
Who:	IGCO, CEOS, GAW and other IGOS partners
Time-frame:	Short term
Product	Coordinated design systems
Cost:	Low

As the network has expanded (Figure 2) more details of the latitudinal gradients have been discovered, and in conjunction with ocean pCO_2 observations has led to the strong evidence of a large sink of CO_2 in the Northern Hemisphere mid-latitudes. Using transport models and inversions of the atmospheric data to determine the longitudinal distribution of the sources and sinks of CO_2 has produced a broad range of results, partly due to the sparse distribution of monitoring stations. A denser network of stations is required to better resolve the spatial distribution of source and sinks. There are gaps in the current network, notably over the tropical and Southern Hemisphere continents, Northern Eurasia and the Southern Ocean.

The existing components of atmospheric carbon observations are:

- Flask sampling sites numbering approximately 100 with weekly sampling frequency. In most cases, multiple species are determined from flask air samples (e.g., $^{13}C\text{-}CO_2$, $^{18}O\text{-}CO_2$, O_2:N_2, CH_4, N_2O, SF_6, CO).

- Continuous stations of in situ CO_2 monitoring, including several marine atmosphere baseline stations (e.g., Mauna Loa), continental mountain stations, and more recently several tall towers in the interior of continents. About 10 of the in situ CO_2 stations out of a total of 20 around the globe have long records spanning over the past 20 years.
- Aircraft vertical profiles at about 10 sites around the globe (e.g., North America, Europe, Siberia, South Pacific) which deliver information on the vertical structure of tracers, related to source distributions of CO_2 and to atmospheric mixing. This includes a long term commercial aircraft sampling programme in Japan between Tokyo and other major cities.
- Periodical sampling analysis of the stratospheric CO_2 and other gases (CH_4, N_2O, CO, O_2/N_2, H_2, $\delta^{13}C$ and $\delta^{18}O$ in CO_2, $\delta^{13}C$ and $\delta\Delta$ in CH_4 is done periodically in Japan and Antarctica (Tohoku Univ.).

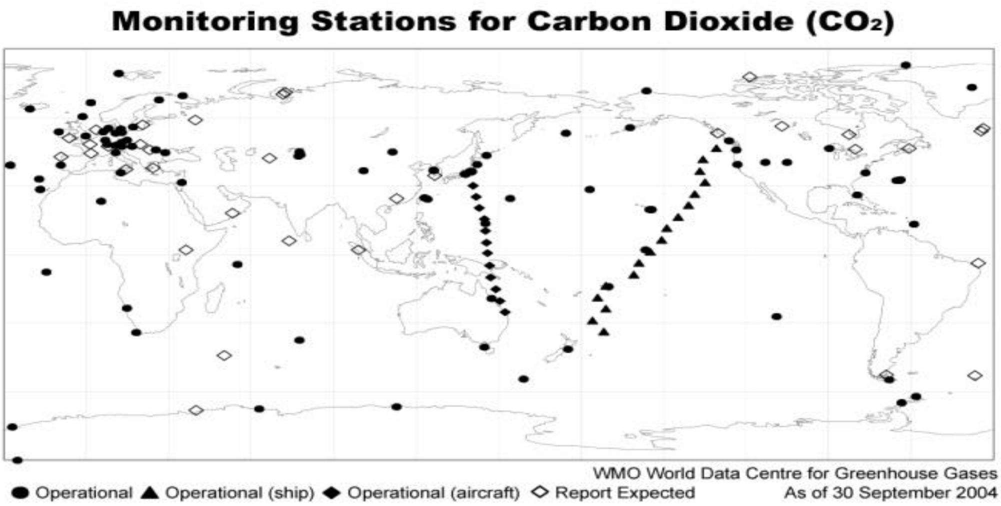

Figure 2 Current configuration of the comprehensive WMO GAW network for CO_2-based data contained at the WDC for Greenhouse Gases in Japan. The network for CH_4 is almost identical (Source: WDC-GG). Other ship and aircraft observations are being added in 2

Action AI 3

Action:	Identify key gaps in monitoring network
Who:	GAW in collaboration with modelling groups (see modelling sections below)
Time-frame:	Short term
Product	Estimates of error reduction for new stations
Cost:	Low

Action AI 4

Action:	Increase atmospheric measurement networks, building on global and regional networks
Who:	All national CO_2 monitoring programs i.e. NOAA/CMDL, CSIRO, LSCE, MPI, NIES etc
Time-frame:	Medium term
Product	More atmospheric stations (target of 50% increase in number of stations)
Cost:	Moderate-High

It is vital that the individual national networks are combined to form an inter-calibrated and fully coordinated global network. This work is being led by the Global Atmospheric Watch (GAW) of the WMO. GAW oversees the measurement guidelines, data quality objectives, and submission of data to the World Data Centre for Greenhouse Gases (WDC-GG) in Japan. GAW is leading the effort to coordinate the combination of in situ flask, continuous and aircraft sampling programs (Table 4) to make the best possible use of the data.

Product	Global networks	Network status	Links with other integration products
Flask samples	GAW	Operational for 15 years	IGACO
Continuous measurements	GAW	Partial network operational last 20 years	IGACO
Continuous measurements on tall towers	NOAA/CMDL	Small network mostly in North America	
Routine Airborne in situ and flask sampling	NOAA/CMDL etc	Partial network North America	Regional programmes GAW
	NIES/MRI/JAL	Tokyo to Sydney (flaks sampling) and other major cities (in situ analysis)	WDCGG
Campaigns	PEM ACE ALGAGE Etc	Opportunity basis	

Table 4: Atmospheric in situ measurements

Action AI 5

Action:	Put in place calibration standards and protocols to enable combining of networks
Who:	GAW Central Calibration Laboratory @NOAA/CMDL and GAW Greenhouse Gas Scientific Advisory Group (Meeting Regularly with CO_2 Measurements Experts).
Time-frame:	Medium term
Product	Standards documentation
Cost:	Moderate

Action AI 6

Action:	Continue to submit data to the World Data Center for Greenhouse Gases (WDCGG), improve the accessibility to the data by the data users and promote the use of the dataset by the global community
Who:	GAW and national networks, the WDCGG and the global research community
Time-frame:	Short term and ongoing
Product	Complete data set well used by the community
Cost:	Moderate

As well as maintaining the raw data sets, it is important that data experts produce data products that a tailored to certain research sectors' needs. The GLOBALVIEW data product is a good example of this.

Action AI 7

Action:	Develop an Integrated Data Analysis Centre (WIDAC) for CO_2 and other greenhouse gases.
Who:	WMO GAW and its WDC-GG in consultation with the Research Community supporting GLOBALVIEW
Time-frame:	Medium term
Product	Establishment of data analysis centre
Cost:	Medium

As well as the absolute concentrations of CO_2, the relative abundances of its isotopes have also provided insight into the allocation of the sink of anthropogenic CO_2 between the terrestrial and ocean domains. As for the CO_2 concentrations it is important to maintain long-term records of isotopic abundances, combine networks and inter-calibrate, and maintain data availability through the WDCGG.

Action AI 8

Action:	Continue and increase the CO_2 isotope records at the monitoring stations, calibrate networks and archive the data.
Who:	GAW and national networks, the WDCGG and the global research community
Time-frame:	Short term and ongoing
Product	Complete isotope data set well used by the community
Cost:	Moderate

As can be seen from Table 4, very tall towers and aircraft profiles are becoming an important part of the in situ network. Vertical profiles are invaluable for understanding the large scale distribution of fluxes, evaluating the atmospheric transport models, and very importantly serve as a validation tool for the remote sensing measurements of CO_2. As well as the vertical profiles, several commercial aircraft have been fitted out with in situ continuous instrumentation to measure CO_2. In conjunction with the surface network, is likely to prove to be very useful. Vertical profiles will be especially useful for the calibration and validation of remote sensing products from the OCO and GOSAT missions.

Action AI 9

Action:	Increase network of continuous sampling on tall towers
Who:	GAW/WMO and national CO_2 monitoring programs i.e. NOAA/CMDL, CSIRO, LSCE, MPI etc
Time-frame:	Medium term
Product	Good coverage over the continental interiors
Cost:	Moderate-High

Action AI 10

Action:	Increase number of regular aircraft profile networks
Who:	All national CO_2 monitoring programs i.e. NOAA/CMDL, CSIRO, LSCE, MPI, NIES etc
Time-frame:	Medium term
Product	Sufficient full tropospheric vertical profiles to characterise the variability to both understand the surface fluxes and to validate remote sensing measurements
Cost:	Moderate-High

Action AI 11

Action:	Deployment of in situ CO_2 analysis equipment on passenger aircraft (Boeing 777 and 747)
Who:	NIES/JAL
Time-frame:	Medium term
Product	Frequent full tropospheric vertical profiles
Cost:	Medium-high

There exists at present a network of eddy covariance flux towers (see section 5.1.1) which measure atmospheric CO_2 concentrations continuously. For the eddy covariance technique the absolute concentrations of CO_2 are not necessary, just the temporal variability. However, the quality of the CO_2 measurements could be increased to meet the WMO standards with a moderate amount of effort. The resulting dataset could be extremely useful. This action will require cooperation of both FluxNet and GAW, and is a cross-cutting issue. See Action TI 2.

3.2 Sensor development

A key area of research required to expand the current network of atmospheric CO_2 concentrations and create the possibility of inclusion of CO_2 in the operational network is the development of new technology to reduce the cost and technical expertise required to make accurate CO_2 measurements. IGCO supports the current efforts and encourages the national funding agencies to contribute more resources to this aim.

Action AI 12

Action:	Development of inexpensive, easy to use and accurate sensors to measure CO_2 continuously in situ
Who:	Instrument research community
Time-frame:	Medium - long-term
Product	Cheap CO_2 sensor
Cost:	Moderate

3.3 Other in situ trace gases

There are other important trace gases that need to be considered in the planning of an integrated global carbon observing system; the other carbon containing greenhouse gases, and the tracers that a useful for understanding the processes that govern the transfer of carbon between the reservoirs. Methane and carbon monoxide play important roles in the carbon cycle, and they oxidise in the atmosphere to produce CO_2 and are therefore a on-surface source of CO_2 and require special attention. CFCs, SF_6 and radon are useful tracers for the validation and development of atmospheric transport models which are necessary to perform atmospheric inversions.

3.3.1 Links to IGACO (chemistry integration plan)

It is important that the IGCO coordinates with the Integrated Global Atmospheric Chemistry Observation theme of IGOS to ensure that the reactive atmospheric species measurement networks fill the needs of the global carbon cycle research community.

Product	Contributing networks	Tracer type	Network status
Methane	GAW surface continuous monitoring network.	Greenhouse gas	Operational; Partial network; Operational data

	GAW surface flask sampling network. AGAGE, SOGE and University of California at Irvine, USA. Airborne sampling.		management. Operational; Partial network; Operational data management. Operational; Partial network; Operational data management. Limited operational aircraft vertical profiling initiated.
222Rn	GAW	Transport validation	
CFCs	GAW &AGAGE	GG & transport validation	
SF6		Fossil fuel proxy	
CO	GAW surface network NDSC sites operating FTIR instruments Airborne sampling.	Biomass burning proxy	Operational; Partial network; Operational data management. NDSC network has limited spatial coverage. Available for selected routes through MOZAIC and CARIBIC programmes; Limited operational aircraft vertical profiling initiated.

Table 5: Other trace gas measurements useful for carbon cycle research

Action AI 13

Action:	Continue to review and remedy shortcomings in the global network for non- CO_2 greenhouse gases
Who:	IGACO & GAW
Time-frame:	On-going
Responsibility PI:	Scientific Advisory Group on Greenhouse Gases (Chair E. Dlougogenky) & Chief Environment Division WMO coordinating GAW (L. Barrie)
Cost:	

Action AI 14

Action:	Ensure multi-species approach such that flasks are analysed for many gases
Who:	GAW and networks
Time-frame:	Ongoing
Product	Data series of gases other than CO_2
Cost:	Medium

Action AI 15

Action:	Ensure in situ measurements of reactive species such as CO and ^{222}Rn are carried out at observing sites
Who:	GAW for CO: GAW and IAEA for ^{222}Rn (see Paris June 2003 Workshop Report GAW Publications List On website
Time-frame:	Ongoing
Product	CO and ^{222}Rn data sets
Cost:	Medium

3.4 Auxiliary atmospheric data

As well as atmospheric composition concentrations, studies of the carbon cycle require other atmospheric fields such as temperature, moisture fields, aerosols, wind velocity and cloud cover (Table 2). The observation of these fields is coordinated by the Global Climate Observing System, and the specific actions required are in the GCOS Implementation Plan. It is important the IGCO coordinates with GCOS to ensure that the fields required for modelling of the global carbon cycle are indeed covered by the GCOS strategy.

Action AI 16 See also GCOS IP sections 4.1 and 4.2

Action:	Coordinate efforts with the GCOS to ensure appropriate data sets of variables necessary for tracer transport and process based studies are maintained
Who:	IGCO partners, GCOS, operational forecasting centres
Time-frame:	Short term and ongoing
Product	Data sets
Cost:	Low

Action AI 17

Action:	Coordinate efforts with the GCOS to ensure appropriate data sets of variables necessary for remote sensing tracer concentrations retrievals are maintained
Who:	IGCO, GCOS and operational forecasting centres
Time-frame:	Short term and ongoing
Product	Data sets
Cost:	Low

3.5 Remote sensing of the atmospheric CO_2 column

Remote sensing of the composition of greenhouse gases in the atmosphere is a relatively new science, but is proving to hold the potential of revolutionising the approach to carbon cycle science. It will be vital that the way forward to achieving useful retrievals of CO_2 as well as CO and CH_4 be coordinated between the remote sensing agencies, the in situ measurement community, and the data users.

Action AR 1

Action:	Coordinate with in situ networks of atmospheric CO_2 to provide appropriate calibration and validation data sets
Who:	IGCO, CEOS, GAW, NIES
Time-frame:	Short term and ongoing
Product	Coordinated data sets

Cost:	Medium

Remote sensing of the CO_2 column is referenced in the GCOS IP under actions A25, A26, A27 and A28.

Table 9.1 of the Carbon Theme report contains details of remote sensing products relevant to carbon cycle research.

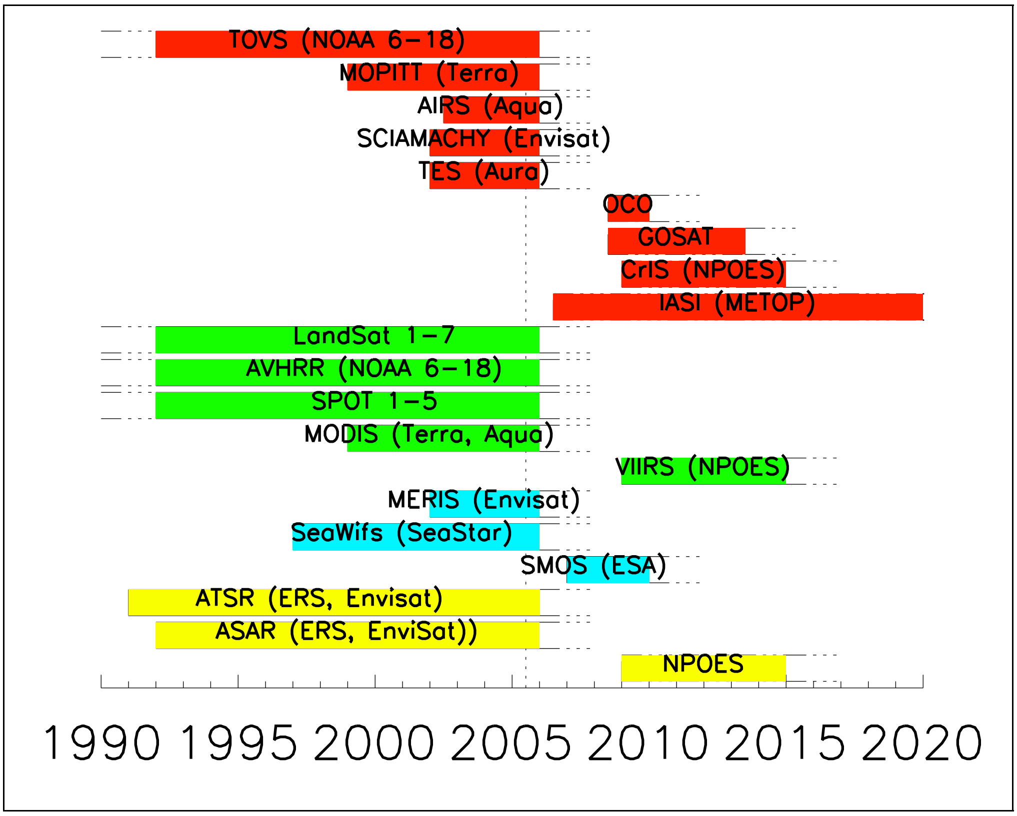

Figure 3 Timeline of selection of various satellites that contribute data to the global carbon cycle problem. This highlights the problems of long-term continuity; and also the large amounts of data that will ne available in the near future.

3.5.1 Target (from IGCO Report)

'The measurements need to be at 0.3% (1 ppm) precision or better for significant improvements in our knowledge of sources and sinks' (Carbon theme report, section 5.2.1, based on Rayner and O'Brien 2000). The spatial resolution implied is 1000x1000 km with a monthly temporal resolution.

3.5.2 Current capability

It is possible to recover mid-troposphere layer CO_2 content with TOVS and AIRS at a spatial resolution of 50 km. However, spatial and temporal averaging to 10 degrees and on the order of two weeks is required to make a usable product (precision of 2.5 ppm) for attribution of sources and sinks. TOVS and AIRS have the capability to measure CO_2 in both the daytime and nighttime orbital pass. Sciamachy utilizes the 1.6 μm and 2.0 μm bands in the daytime orbital pass; however the 2.0 μm band currently is degraded by icing. Currently, the precision of Sciamachy is about 10 ppm.

Action AR 2

Action:	Establish and validate internationally accepted algorithm(s) for operational

	CO_2 retrieval and establish an operational processing capability.
Who:	Research and NWP Community
Time-frame:	Short term
Product	Validation by aircraft measurements and modelling
Cost:	Low (requires coordination of data provision from other existing sampling programmes)

Action AR 3

Action:	Develop an analysis capability to interpret the mid-troposphere measurements in terms of sources, sinks, atmospheric transport and other atmospheric attributes.
Who:	NWP Community (ECMWF, NASA/NOAA)
Time-frame:	1-3 years
Product	Rapid assessments will avoid high reanalysis costs
Cost:	Economical if accomplished within existing programmatic schedules (for AIRS)

Action AR 4

Action:	Conduct re-analysis of the NOAA_TOVS HiRs data following pioneer work by Chedin et al.
Who:	NOAA?
Time-frame:	Medium
Product	Upper troposphere CO_2 concentrations
Cost:	Low

Action AR 5

Action:	Expand efforts to retrieve CO_2 distributions from existing satellites (e.g. AIRS, SCIAMACHY, IASI and TES
Who:	Space agencies
Time-frame:	Short term
Product	Improved retrievals from remote sensing
Cost:	Medium

3.5.3 Secured Future

IASI (Metop) and CrIS (NPP, NPOESS) will provide continuity and with similar capability as the current status of AIRS. These two instruments are onboard operational meteorological satellites that will provide continuity of observations up to 2015-2020. An international agreement exists for data sharing through the Initial Joint Polar Systems (IJPS) agreement between USA and Europe. GOSAT has a complimentary set of LWIR(mid-troposphere) and SWIR (total column) with a nominal lifetime of 5 years. SWIR covers wide spectral range and the effect of path radiance from cirrus cloud can be corrected. OCO is a research mission that will provide higher spectral and spatial resolutions for daytime orbital passes (same orbit as AIRS) over a nominal 2-year lifetime. GOSAT is an operational mission with an expected lifetime of 5 years. The success criteria for GOSAT is a 4 ppm precision for daytime observations; however, the expectation is that it will have a precision similar to OCO. OCO and GOSAT are thus expected to estimate CO_2 column concentration with high accuracy. However, to reduce CO_2 surface-atmosphere flux estimation error will require assimilation of such satellite-based remote sensing data and in-situ data in models.

Action AR 6

Action:	The capabilities of GOSAT and OCO to be explored through international cooperation between the principal research groups supported by the responsible space agencies. GOSAT science team is supported by MOE.
Who:	JAXA/MOE/NIES, NASA/NOAA, principal research groups
Time-frame:	Medium
Product	International preparatory programme and data sharing agreement
Cost:	Low-medium (funding for 4-5 research groups)

Interpretation of the vast quantities of remote sensing data that will become available as the next generation of composition instruments come on line will require a high powered and sophisticated data assimilation effort.

Action AR 7

Action:	Development of assimilation and transport models to be able to ingest the volume of all satellite CO_2 measurements
Who:	Space agencies, atmospheric modelling community, operational weather centres
Time-frame:	Short term-medium
Product	Demonstrated ability to handle the volume of satellite data prior to launch
Cost:	Economical

Action AR 8

Action:	Coordinated international assessment of the value of OCO and GOSAT in improving the skill for estimates of CO_2 sources and sinks
Who:	Research Community, NASA/NOAA, NIES, ESA
Time-frame:	Medium to long term
Product	International evaluation of CO_2 sources and sinks
Cost:	Moderate (requires coordinated funding opportunities by space agencies)

3.5.4 Next Generation

There is significant inter-annual variability in the sources and sinks particularly across an ENSO cycle and continuity of OCO/GOSAT-like observations across at least one full cycle is highly desirable. This implies the need to continue OCO operation beyond its nominal 2-year lifetime (if possible) and that the Space Agencies should plan for equivalent follow-on missions.

Action AR 9

Action:	Funding for continued operation of OCO beyond its nominal lifetime
Who:	NASA
Time-frame:	Long term
Product	Continued operation
Cost:	High (satellite and ground segment operation)

The appropriate next step after OCO is an active mission that focuses upon the measurement of column CO_2 without diurnal, seasonal, latitudinal, or surface restrictions. This mission could be accomplished with the measurement technique known as Integrated Path Differential Absorption (IPDA) or Laser Absorption Spectroscopy (LAS). The technique makes use of either pulsed or continuous wave laser transmitters to provide CO_2 total column observation via measurement of the backscatter from ‘ hard’ targets (sea, land surfaces, thick clouds), on and off an absorption line. IPDA/LAS differs from Differential Absorption LIDAR (DIAL) in that DIAL operates by measuring the weak backscattered signal from molecules and atmospheric aerosols while IPDA/LAS exploits the much stronger return from hard targets, with implications on the required emitted energy and receiving telescope aperture compared to a DIAL system. Continuous Wave (CW) IPDA/LAS systems enables exploitation of investment by the commercial telecom industry that operate through clean, well-isolated CO_2 absorption lines but are limited by the need for auxiliary data required to determine the altitude of the scattering surface and to correct for the presence of aerosols and/or optically thin clouds. Pulsed systems can overcome the limitation of CW ones through their range resolving capability that allows to determine with the required accuracy the altitude of the scattering surface and to discriminate the hard target return signal from those generated by aerosols and clouds.

Action AR 10

Action:	Follow-on mission for OCO/GOSAT
Who:	Space Agencies
Time-frame:	Long-term
Product	Launch of new sensor as part of payload
Cost:	High (design, build, launch, operate)

Action AR 11

Action:	Continued programme in sensor development focusing on DIAL and/or LAS technique
Who:	Space Agencies
Time-frame:	5-10 years
Product	Credible tested and space hardened sensor design to meet IGCO identified requirement
Cost:	High

Action AR 12

Action:	Establish a strategic plan for a global CO_2 satellite observation system combining existing OCO mission and future GOSAT mission and European projects
Who:	Space agencies/GOSAT:NIES,JAXA,MOE
Time-frame:	Short term
Product	Writing of a plan
Cost:	Low

3.6 Remote sensing of the methane column

3.6.1 Target

Space observation of column atmospheric CH_4 (1%, 20ppb)

3.6.2 Current or already funded

Sciamachy and MOPITT utilize the 2.28 μm to compute the total methane column during daytime. Initial reports for Sciamachy show an accuracy of 2.5% with a weighting function that is partially sensitive to the boundary layer. MOPITT has not reported methane products due to instrument and algorithm difficulties; however, expectations are that these products will be made available prior to the end of the mission. AIRS, IASI and CrIS have a capability to determine CH_4 to a precision of 2% in the mid-troposphere in both the daytime and nighttime orbits; however, there is no sensitivity to the boundary layer. Plans exist both in the USA and Europe to convert AIRS research products to an IASI operational product within the next 2 years. NOAA is currently considering methane as a 'NOAA-unique' product stream for CrIS (no funding mechanism in place). The recovery of methane information from CrIS would be desirable. GOSAT will provide methane observations during daytime using the SWIR channel (at 1.7µm, 0.2cm-1 resolution) in the 2008-2012 time-frame with an expected precision of 1% on a spatial resolution of 10 degrees intervals in longitude.

Action AR 13

Action:	Advancement of chemical tracer transport models and inversion techniques to handle reactive gases.
Who:	Modelling community
Time-frame:	Medium term
Product	Source estimates of CH_4
Cost:	Low-medium

Action AR 14

Action:	Continued retrieval and analysis of column CH_4 from current sensors
Who:	Space agencies
Time-frame:	Short term-medium
Product	Data sets of CH_4
Cost:	Low-medium

Action AR 15

Action:	Strategic plan to coordinate retrievals of CH_4 from future missions such as GOSAT and CrIS
Who:	NIES (GOSAT), CEOS and space agencies
Time-frame:	Short term
Product	Plan
Cost:	Low

3.6.3 Secured future

Sciamachy, MOPITT, and GOSAT products are available until the end of mission. AIRS products will be migrated, as discussed, to IASI and CrIS for the next 20+ years.

3.6.4 Next Generation

No additional missions are planned at this time. Follow on missions for MOPITT, Sciamachy, and GOSAT are not planned at this time although two atmospheric composition satellite families are being studied by ESA.

Action AR 16

Action:	Strategic plan to ensure the continuity of CH_4 column measurements.
Who:	Space agencies
Time-frame:	Short term
Product	Plan
Cost:	Medium

Action AR 17

Action:	Studies to explore the potential of new technology for application of CH_4 retrievals
Who:	Space agency instrument experts
Time-frame:	Medium term
Product	Technical reports
Cost:	Low

3.7 Remote sensing of the CO column

CO is a relatively minor component of the carbon cycle, however as a trace gas it is useful as a tracer of both biomass burning and fossil fuel combustion.

3.7.1 Target

Space observation of atmospheric CO profile (10%, 10ppb)

3.7.2 Current or already funded

MOPITT, AIRS and IASI have a capability to determine CO profiles during the daytime and night time orbits with an accuracy of ≈15% in the mid-troposphere. Sciamachy retrieves total column CO using the 2.365 μm band with a accuracy of ≈15-20% in daytime with significantly more weight in the lower boundary than the thermal instruments. Agreement between Sciamachy/MOPITT and AIRS/MOPITT retrievals are in progress and the initial comparisons look good. Plans exist both in the USA and Europe to convert AIRS research products to an IASI operational product within the next 2 years. The current design of CrIS has an unacceptable performance with respect to CO. However, NOAA is currently exploring a minor instrument re-design to improve CO capabilities. The recovery of CO information from CrIS would be desirable. GOSAT is exploring an option to add a CO band; however funding and schedule limitations make this addition unlikely at this time.

3.7.3 Secured Future

MOPITT products are available until the NASA/Terra mission is concluded. AIRS products will be migrated, as discussed, to IASI and CrIS for the next 20+ years.

3.7.4 Next Generation

No new missions are planned at this time. Follow on missions for MOPITT and Sciamachy are not planned at this time, although two atmospheric composition satellite families are being studied by ESA.

Action AR 18

Action:	Develop strategic plan to ensure the continuity of CO retrievals
Who:	Space agencies
Time-frame:	Short term
Product	Plan
Cost:	Low

Action AR 19

Action:	Ensure that future planned missions will acquire CO retrievals with the

	appropriate accuracy
Who:	Space Agencies
Time-frame:	Medium term
Product	Strategic plan for CO retrievals
Cost:	Medium-high

Action AR 20

Action:	Develop multi tracer inversion techniques using CO_2, CH_4 and CO to utilise properties of CH_4 and CO for differentiating types of C sources and sink to aid the remote sensing community with planning missions
Who:	Modelling community
Time-frame:	Medium term
Product	Data assimilation/inversion tools
Cost:	Medium

4 Ocean

Recent results from the international survey of ocean carbon performed in the 1990s suggest that the ocean has been a sink for about 48 percent of the total fossil-fuel emissions since the beginning of the industrial revolution (Sabine et al., 2004). However, the methods for estimating anthropogenic CO_2 uptake have large uncertainties, and predictive models about future ocean and land sinks of CO_2 differ considerably. These models cannot be improved without a more fundamental understanding of the processes controlling the ocean carbon cycle. This is no longer simply an academic issue, but one with economic and policy implications. Disagreements in predictions of sink behaviour will impact baseline targets for future CO_2 emissions reductions. At sequestration cost targets of 10 – 35 US dollars per ton, the model discrepancies in the amount of CO_2 that will be taken up by the ocean in the future leads to a cost discrepancy of several trillion US dollars. Reducing this uncertainty is crucial and requires improved understanding of the full ocean carbon cycle.

Repeat occupation of hydrographic surveys and fixed time-series stations are the only direct means of observing changes in the ocean CO_2 pool over decadal timescales. Regional air-sea flux patterns are less easily observed, and there is disagreement among atmospheric inversions, ocean surface pCO_2 flux estimates and ocean numerical models, particularly for the North Atlantic and Southern Ocean. The inventory and temporal and spatial gradients of ocean carbon are largely controlled by biogeochemical processes, many of which are not fully understood, and require concurrent measurements of carbon system variables, nutrients, oxygen, and trace metals, as well as an improved understanding of ecosystem dynamics. Ocean carbon exhibits significant variability on time-scales ranging from sub-diurnal to decadal. Much of the inter-annual variability is driven by large-scale ocean-atmosphere patterns, and is expressed on regional rather than basin-to-global scales. This requires a carefully planned comprehensive observing effort to appropriately observe processes over such a range of time and space resolutions. In the future, pphysical uptake of anthropogenic carbon by the ocean is expected to decline because of surface warming, increased vertical stratification, and slowed thermohaline circulation. However, in coupled simulations with simple biogeochemical models, the physical effects are partly compensated by increased uptake from changes in the strength of the natural biological carbon pump. In many regions, the biological pump can have a stronger control on the distribution of CO_2 than the solubility pump, and present models predict that without a biological pump, the atmospheric CO_2 concentration would rise to levels of ~680ppm. Further, growing evidence suggests that the lower pH and carbonate ion concentrations that will occur in a high CO_2 world will have profound impact on calcifying organisms (e.g., corals, coccolithophores) and biogeochemical cycles. This highlights the interdisciplinary nature of the problem, and uncertainties in predictions of the future behaviour of the ocean carbon sink cannot be reduced until we take a comprehensive global approach to observations and process studies.

At present, a number of relevant ocean research programs are either recently underway or are developing with start dates in 2005 and 2006 at the national, regional; and global level (e.g. Surface Ocean Lower Atmospheric Study (SOLAS), Integrated Marine Biogeochemistry and Ecosystem Research Project (IMBER), CLIVAR/ CO_2 Repeat Survey, Ocean Carbon and Climate Change (OCCC) (Doney at al 2004), CarboOcean). The majority of ocean carbon observations and process studies will be implemented through these programs, with coordination and communication between them facilitated by dedicated coordination projects at the international level. The more robust large-scale observations are being integrated into the global observing systems for climate with a view to sustaining these activities beyond the lifetime of the individual research programs.

4.1 In situ ocean measurements

The existing components and development requirements of an in situ ocean carbon cycle observing system are: surface pCO_2, full column sampling on repeat hydrographic surveys, and time series. Future observing networks will include pCO_2 sensors on drifting buoys such as the current Argo float network.

4.1.1 Basin-scale surface observations of atmospheric and oceanic pCO_2 and related parameters on research ships, ships of opportunity, and drifting buoys.

Goal: to understand basin and global-scale variability of surface pCO_2 and air-sea flux on seasonal and inter-annual timescales, to understand the climate sensitivity of air-sea fluxes, and to quantify annual basin-scale fluxes to +/-0.2 Pg C/yr.

Approximately 45 programs currently collect surface CO_2 data from a variety of platforms. Regional datasets have been collected for the North Pacific, North Atlantic and equatorial Pacific. Global data "climatologies" of monthly air-sea flux maps have been generated using the available pCO_2 data. These programs, however, are largely uncoordinated and the current observation coverage is not adequate to meet science goals.

Action OI 1 **See also GCOS action O17**

Action:	Develop an internationally-agreed implementation strategy for the development of a coordinated system of observations of surface pCO_2 and related chemical, biological and physical properties with the required coverage.
Who:	National, regional, and international research programs with coordination and project office support by the International Ocean Carbon Coordination Project and the GCOS-GOOS-WCRP Ocean Observations Panel for Climate.
Time-frame:	Regional activities to begin in 2005; Internationally agreed implementation strategy for regional coordination and global coverage to begin mid 2006.
Product:	Regular pCO_2 flux maps produced beginning in 2006; reduced uncertainty of future air-sea flux behaviour.
Cost:	High

Ships measuring pCO_2 generally also measure atmospheric CO_2, but at low precision as the required accuracy is low for the air-sea CO_2 flux calculation. However, the value of high precision measurements to atmospheric inversion modellers has the potential of being high, especially in poorly sampled regions where the horizontal gradients are small; i.e. in the Southern Ocean. Several options are currently available at various degrees of precision and cost.

Action OI 2

Action:	Feasibility study to estimate the value of high precision atmospheric CO_2 measurements on board underway ships
Who:	IOCCP and atmospheric measurement and modelling community.
Time-frame:	Short term
Product:	Continuous atmospheric CO_2 datasets from ships
Cost:	Low-medium

Action OI 3

Action:	Install high precision continuous atmospheric sensors aboard ships carrying out pCO2 campaigns
Who:	IOCCP and atmospheric measurement community
Time-frame:	Medium term
Product:	Continuous atmospheric CO2 datasets from ships
Cost:	Medium-High

4.1.2 Large-scale ocean inventories from hydrographic survey with full water column sampling of carbon system parameters.

Goal: *To assess the basin-scale decadal evolution and transport of anthropogenic CO_2 in the oceans to +/- 20 percent, and other related parameters including nutrients, oxygen, dissolved organic matter, and trace metals.*

Global ocean surveys have been carried out on approximately 10 years time scales since the 1980s; e.g., Geochemical Sections in the Ocean (GEOSEC), Transient Tracers in the Ocean (TTO), the World Ocean Circulation Experiment (WOCE)/ Joint Global Ocean Flux Study (JGOFS), and the current repeat hydrographic survey of the WCRP Climate Variability and Predictability (CLIVAR) project. Global syntheses of these data have been completed to document changes in uptake, transport, and storage of CO_2 in the oceans. These surveys are developed and implemented by research programs, and the survey lines and variables measured vary between the programs. In order to make consistent assessments of the evolution of CO_2 uptake and storage, these surveys and variables must be standardized and the observing effort sustained. A particular emphasis must be placed on integrating critical biogeochemical variables (e.g., carbonate system variables, nutrients, oxygen, dissolved organic matter, and trace metals) into the systematic survey.

Action OI 4 **See also GCOS O25**

Action:	Develop an internationally-agreed strategy for a core network of lines and core and ancillary variables. Perform the systematic global full-depth water column sampling every 10 years.
Who:	National and international programs in cooperation with CLIVAR, IOCCP, and OOPC.
Time-frame:	Draft strategy building on necessary global syntheses and observation system experiments to begin late 2005; survey implementation and syntheses on-going.
Product:	Percentage coverage of agreed sections with required variables measured.
Cost:	Medium

Action OI 5

Action:	Develop and promote the use of sensors of O2, nutrients and carbon species in automated ARGO floats
Who:	National and international programs in cooperation with CLIVAR, IOCCP, and OOPC.
Time-frame:	Short term and ongoing
Product:	Expanded suite of carbon related measurements from automated floats
Cost:	Medium

Action OI 6

Action:	International coordination to sustain the production of and promote use of standard ocean reference materials. This includes variables for which reference materials are currently available (e.g., dissolved inorganic carbon; alkalinity) and the development of new reference materials and standards (e.g., nutrients, dissolved organic matter, trace metals)
Who:	Ocean research community and reference material providers
Time-frame:	Short term
Product:	Reference standards
Cost:	Low

4.1.3 Moored and shipboard time series measurements of the ocean carbon cycle components.

Goal: *To understand and quantify natural seasonal to interannual variability and secular trends of ocean carbon, ecosystem structure, primary and export production, and subsurface carbon dynamics; and to improve understanding of the physical, chemical, and biological controls on present and future marine ecosystem and ocean carbon dynamics ,including biogeochemical responses to and feedbacks on climate change.*

There are presently about 10 time series stations measuring carbon cycle variables, and an international coordination project, OceanSITES, developing a global coordinated network of approximately 30 ocean time series stations. Carbon and biogeochemical measurements will be fully integrated into this network as it develops, with particular emphasis on nutrients and oxygen time series. In addition, some stations include sediment traps and sea-floor studies to investigate the transfer of carbon from the surface waters to deeper and longer-term storage compartments in the ocean. The global, regional, and national research programs that will begin in 2005 (e.g., US Ocean Carbon and Climate Change Program, E.U. Carboocean Project, SCOR-IGBP SOLAS and IMBER projects) will implement process studies employing time series stations and mesocosm experiments to specifically address science objectives.

Action OI 7 **See also GCOS action O28**

Action:	Coordination of developing OceanSITES network with process study needs and plans of national, regional, and international research programs; special attention to integration of variables needed for ocean colour ground-truthing into appropriate stations.
Who:	National, regional, and international research programs with international coordination aid provided by IOCCP and IOCCG.
Time-frame:	Process studies developed and implemented beginning 2005; OceanSITES strategy developed end 2005 and start of networked pilot project by end 2005.
Product:	Number of stations measuring carbon and biogeochemical variables in a coordinated network or process study.
Cost:	Medium

Action OI 8

Action:	Time-series of atmospheric deposition of iron/dust, nutrients, etc.; either islands or moorings
Who:	Ocean research community
Time-frame:	Medium
Product	Data sets

Cost:	Medium

4.1.4 *Pilot studies of autonomous biogeochemical sensors*

New in situ and shipboard sensors are rapidly improving our ability to make nearly continuous measurements of surface and subsurface ocean biogeochemical properties (e.g., fluorescence, particulate organic and inorganic matter, oxygen, nutrients, carbonate system parameters, video plankton recorders). Such sensors can be deployed on ships of opportunity (e.g., commercial VOS, research ships, Antarctic resupply ships), autonomous platforms (e.g., profiling floats, drifters, gliders), and cabled observatories. These new technologies will greatly expand ocean observational capabilities, but work is still need to transition these instruments from research to operational mode. Important issues include instrument stability, calibration, biofouling, platform integration, data retrieval and management. In addition, better coordination with other scientific/operational agencies is required to facilitate the inclusion of biogeochemical sensors within quasi-operational ocean climate observational networks (e.g., Argo profiling Floats; OceanSITES moorings, etc.).

Action OI 9 **See also GCOS O30**

Action:	meetings between CLIVAR/ARGO/Ocean Carbon Community
Who:	IOCCG
Time-frame:	Short term
Product:	Meeting reports, publications
Cost:	Low

Action OI 10

Action:	Expanded pilot studies for BGC sensors on Argo floats and glider survey tracks
Who:	Research community
Time-frame:	Medium term
Product	Prototype BGC sensors
Cost:	Medium

4.1.5 *Coastal zone time series stations on the continental shelf.*

Goal: *To quantify coastal ocean and continental margin air-sea CO_2 fluxes, land-ocean and coastal-to-open ocean carbon exchange, and biogeochemical cycling affecting carbon transport and transformations.*

Carbon system variables are measured as part of many national research programmes. Several global research programs have a focus on coastal issues that include carbon (e.g., the Land-Ocean Interactions in the Coastal Zone (LOICZ) project and IMBER), and several regional research initiatives are being developed to coordinate regional studies. At present, however, coastal observations are not sufficiently coordinated at the international level to establish a global observation network.

Action OI 11

Action:	Develop compilation of coastal carbon activities and plans; integrate activities with open-ocean network.
Who:	LOICZ and IMBER, with input from national and regional research programs, with international coordination aid provided by IOCCP.
Time-frame:	Compilation of activities to be produced by end 2005; initiation of

	integration activities beginning 2006.
Product:	Number of coastal stations measuring carbon and other critical variables in a coordinated network or process study.
CI:	Low

Action OI 12

Action:	Develop systematic monitoring capability for quantifying the river and groundwater inputs of biogeochemical species to the coastal ocean
Who:	Terrestrial and ocean research communities
Time-frame:	Medium term
Product:	Data sets on river discharge and carbon content
Cost:	Medium

4.1.6 Air-sea gas exchange

Goal: *To reduce uncertainty in gas exchange parameterisations that hinder ability to calculate CO_2 fluxes from air-sea pCO_2 differences.*

Algorithms relating gas transfer velocity to wind speed have been developed through a combination of laboratory data and field data. Existing field data, however, are insufficient to constrain gas transfer velocity over the range, time and space scales of physical forcing conditions. Recent advances include direct flux measurement techniques and airside gradient and covariance measurements, allowing for the direct measurement of fluxes in the field. Process studies are required to develop improved algorithms relating directly-measured flux to measurements characterizing the near surface turbulence that drives transfer velocity.

Action OI 13

Action:	Implement targeted process studies to elucidate relationships between directly measured flux, physical forcing, and near surface turbulence.
Who:	SOLAS, CLIVAR, national and regional research programs.
Time-frame:	Field programs of research programs to begin in 2005.
Product	Algorithm development and evaluation
Cost:	Medium

Action OI 14

Action:	Set up air-sea gas flux time series site (eddy-correlation) on a fixed platform; the long time-series site could then become the focus of process studies
Who:	Ocean research community
Time-frame:	Short term
Product:	Data series of ocean CO_2 flux
Cost:	Medium

4.1.7 Auxiliary Ocean observations

As for the atmosphere there are many fields that are required for ocean carbon research such as surface winds, temperature, salinity and currents. These fields are covered in the GCOS strategy, in sections 5.1 and 5.2. It is important the IGCO coordinates with GCOS to ensure that the fields meet the requirements of the ocean carbon community.

Action OI 15

Action:	Coordinate auxiliary ocean observation strategy with GCOS
Who:	GCOS and IGCO.
Time-frame:	Short term
Product	Documentation detailing ocean requirements
Cost:	Low

4.2 Ocean remote sensing

4.2.1 Ocean-Colour remote sensing.

Goal: *To quantify upper ocean biomass and ocean primary productivity and to provide a synoptic link between the ocean ecosystem and physical drivers.*

Satellites provide global coverage of surface ocean colour, and the International Ocean-Colour Coordination Group (IOCCG) estimates that current planned satellite missions are adequate to meet requirements for the medium-term. The linkage between ocean colour and ecosystem variables, including chlorophyll-a, remains weak, however, and enhanced *in situ* sampling of ocean colour, biooptical properties (e.g., backscatter, CDOM), and ecosystem variables from time series stations, autonomous platforms, and VOS networks is required to further develop and evaluate algorithms.

Action OR 1

Action:	Implement plans for a sustained and continuous deployment of satellite sensors and research and analysis; integrate in situ needs into VOS carbon network and OceanSITES timeseries network.
Who:	Satellite operators through the IGOS-P (CEOS) and in consultation with the International Ocean-Colour Coordination Group.
Time-frame:	Ocean-Colour sensor missions continued beyond medium term (approx 2009)
Product	Global coverage with consistent sensors; number of in situ stations providing regular ground-truthing data.
Cost:	Medium-high.

5 Terrestrial

The terrestrial biosphere presents a particularly difficult problem for the global carbon observing system: as opposed to the atmosphere and oceans, the terrestrial biosphere is extremely heterogeneous, and involves a complex web of processes that are difficult to model numerically, and it operates on timescales of sub-hourly to hundreds or even thousands of years. Current remote sensing technologies provide excellent spatial coverage of some features such as the leaf area index (LAI) and greenness of the vegetation (NDVI), but remote sensing cannot see below the surface where around half of the terrestrial carbon resides. It is for these reasons that the so called 'missing sink' has remained elusive despite around 15 years of research. A substantial effort is require to measure and understand the terrestrial processes and their carbon dynamics.

The existing components of today's terrestrial carbon observations are:

- Eddy covariance flux networks of about 300 towers.
- Surveys of carbon pool size and flows between compartments such as leaf, branch, stem, root and soil.
- Forest biomass inventories that exist for most developed countries include a very large number of sampling locations, but many forest areas have little or no inventory data.
- Soil surveys at regional, national and global scale.
- Networks and transects for ecological studies and phenological observations.
- Satellite remote sensing (land cover and land cover changes induced by land use practices, vegetation phenology and biophysical properties, fires, radiation).

This section of the IGCO IP draws on The Implementation Plan for the Terrestrial and Atmospheric Carbon Observation (TCO) Initiative, which sets out the goal of 10^6 km^2 resolution fluxes with an accuracy of 20%.

5.1 Terrestrial In situ measurements

5.1.1 Land-atmosphere exchanges of CO_2, heat, and water measured via eddy covariance flux networks

The current FluxNet network consists of approximately 300 sites covering many biome types. One of the biggest problems with the network is continuity, with stations often only spanning short periods (less than required to understand effects of climatic variability). A concerted effort is required to expand the number of high quality continuous towers, and to ensure that the coverage is global with all biome types represented.

The current FluxNet network has a bias towards towers in mature forests, however a significant portion of the worlds terrestrial areas have recently been disturbed by fire, land clearing, insect damage and wind throw. As the vegetation regenerates the carbon dynamics varying as respiration and photosynthesis processes vary in domination until the system reaches equilibrium. It is essential that the understanding of the carbon dynamics of regeneration is improved, especially under a changing climate.

FluxNet Component	Website
FluxNet	http://www.fluxnet.ornl.gov/fluxnet/index.cfm
AmeriFlux	http://public.ornl.gov/ameriflux/
CarboEurope	http://www.carboeurope.org/
AsiaFlux	http://www-cger2.nies.go.jp/asiaflux/main.html

KoFlux	http://koflux.org/koflux/home/index.html
OzFlux	http://www.dar.csiro.au/lai/ozflux/
Fluxnet-Canada	http://www.fluxnet-canada.ca/
ChinaFlux	http://www.chinaflux.org/Observation/index.html.

Table 6 Summary of FluxNet components and links to their websites.

Action TI 1

Action:	Facilitate discussion on network design to improve network representation and continuity.
Who:	Flux tower and ecosystem scientists, coordinated by FluxNet
Time-frame:	Short term
Product	Strategy for network expansion
Cost:	Low

Action TI 2

Action:	Expansion of the current FluxNet network to cover major biomes and different stages of disturbance/recovery
Who:	Flux tower and ecosystem scientists, FluxNet and GTOS
Time-frame:	Medium to long-term
Product	Full-coverage of the different disturbance/recovery regime and management intensity in each major biome
Cost:	High

At present the data products available on the FluxNet website represent around 30% of the total of the FluxNet sites, and the most recent data presented is at least 5 years old. There is a need to increase the availability of the flux data and the speed of this availability. At the same time, the data managers and data users must correctly cite the authors of the data sets so that the scientific importance of the data can be shown through its usage.

Action TI 3

Action:	Improvement of data availability on the FluxNet website, and the strong adherence to the policy of citing the authors of the data sets by data users.
Who:	FluxNet, data providers and data users
Time-frame:	Short term and ongoing
Product	80% of station data available within 2 years of measurements being made
Cost:	Low

As part of the process of producing eddy covariance method fluxes, measurements of atmospheric concentration are required. Only the relative variability is required and as such the measurements are not calibrated against standard gases. Extension of high-quality, calibrated continuous CO_2 measurements across the continents by augmenting measurements at flux towers should be a very high priority and can be achieved at modest cost at each site (although the cumulative cost will be high). This will require cooperation between atmospheric measurement groups and flux scientists within each national program, and can be coordinated by international efforts such as FluxNet and GAW.

Action TI 4

Action:	Develop measurements of calibrated atmospheric CO_2 on eddy covariance towers

Who:	Cooperative efforts by atmospheric and flux scientists, coordinated jointly by FluxNet and WMO/GAW
Time-frame:	Short term and ongoing
Product	50 sites with documented calibration statistics within 5 years
Cost:	Medium-high

Eddy covariance flux stations measure exchanges of heat, water, carbon, and momentum between the surface and atmosphere. It is imperative that other physical measurements be made at these sites to allow linkage of ecosystem processes (e.g., transpirations, photosynthesis, respiration, soil hydrology) with atmospheric CO_2. FluxNet protocols should be sufficient to document hydrologic and meteorological drivers and responses to ecosystem carbon exchanges. These other observations are: air temperature, humidity, wind speed, soil moisture and temperature, direct & diffuse incoming shortwave radiation and incoming longwave radiation, precipitation and snow characteristics.

Further ancillary measurements to support upscaling from eddy covariance data include litterfall, litter quality, biomass, soil carbon, rooting profiles, allometry, and similar ecological observations. These data should be included at every flux tower site, and an effort should be made to quantify the representativeness of these data within the larger landscape and region. The cost of increasing observations at each site is moderate, and cumulative over the network is high.

Action TI 5

Action:	Increase ancillary data for physical and ecological characterisation of fluxes collected at FluxNet sites.
Who:	FluxNet and terrestrial carbon science community
Time-frame:	Medium term
Product	Larger, comprehensive carbon data sets
Cost:	High

5.1.2 Development of improved and less expensive eddy covariance instrumentation

Eddy covariance measurements are expensive and labour intensive. There is a need for advances in instrument technology to reduce the difficulty and expense of flux towers. A possible way forward is to convince private industry that there is a market for such a system and have them develop the sensors with the assistance of the research community.

Action TI 6

Action:	Develop new instruments to measure fluxes of CO_2 and energy budgets.
Who:	Research community and FluxNet, instrumentation scientists and technicians, private industry.
Time-frame:	Medium term
Product	Cheap, reliable and easy to use CO_2 flux sensors
Cost:	Medium-high

5.1.3 Biomass inventories of Forests and Other Wooded Lands

Due to the economic value of timber, many countries maintain in situ measurement datasets of above ground wood quantities. These data can provide estimates of total forest sinks or sources, rates of deforestation or growth and losses due to disturbance and harvesting.

However, the methods used to collect the data, and even the types of data collected vary from country to country. The data is not collected with carbon as a specific goal and conversion factors must be used to convert wood figures to carbon. And, because of the economic value of the data, often it is not available to the scientific community.

A large, global effort is required to collate the available forest inventory data, attempt to gain access to currently unavailable data, understand the data in terms of carbon storage, and to expand the inventories into countries which currently do not maintain forest inventories.

The forest inventories will also be valuable as 'ground truths' for remote sensing products which in turn will allow upscaling of the inventory data to regions which are data poor. (see section 5.2.5).

Action TI 7

Action:	Collect global data sets of past forest inventories
Who:	FAO and IGCO
Time-frame:	Short term
Product	Data sets available on line
Cost:	Medium

Appropriate spatial and temporal resolution (1° x 1° and higher where available) estimates of biomass are desired, with a standard methodology for provision of biomass values to populate the grid cells. The requested information should include, generated from the source data;

- minimum, maximum, mean, median, standard deviation, estimation protocol, number of points included.
- Biomass by root, folia, stem, and branch components.
- Time period represented by the biomass estimates.

Action TI 8

Action:	Define methodology so that biomass inventories in forest and other wooded lands can be updated with appropriate spatial and temporal resolution
Who:	FAO and IGCO
Time-frame:	Medium term
Product	Define methods to produce spatial products, obtain agreement on standards and protocols
Cost:	Medium

Action TI 9

Action:	Expand forest inventories to improve global coverage
Who:	FAO and IGCO
Time-frame:	Medium-long term
Product	Global forest inventory coverage with 1°x1° coverage and 5 year temporal resolution
Cost:	High

Biomass is a measurement that is becoming available from remote sensing platforms, and an important integration activity is to have the in situ inventory agencies work together with the remote sensing agencies to allow validation and upscaling of the in situ measurements based on the remote sensing products (see actions TR6, TR7, TR8 and TR9)

5.1.4 *Soil carbon inventories (including in frozen soils)*

Unlike the regular inventory intervals of most forest inventories, soils inventories are rarely repeated on a regular basis. Currently the FAO/UNESCO soil map of the world (based on soil surveys carried out during 1960s; FAO, 1995) remains the main global inventory of soil information to date. The IGBP Global Soil Data Task (GSDT) and the World Inventory of Soil Emission Potential (WISE) share much of the information contained in the FAO soil map. The variables available include carbon and nitrogen content, bulk density, texture (% sand, silt, and clay), depth, water retention, pH and several others of lesser interest to the carbon cycle. The pedon database size and geographic distribution are inadequate for a robust product at regional scales and for smaller areas.

On the regional scale, the USDA Soil Conservation Service has a very large pedon database (>22000 records) in the public domain. The data quality is high and consistent, but the overwhelming majority of records are for the USA. They also have produced several global products (including soil carbon), based on the reclassification of the FAO Soil Map into the USDA soil taxonomy. Some data sets have resulted from individual research efforts (e.g., the Zobler dataset, Emanuel and Post datasets; both are available through ORNL). The global coverage is patchy and the internal methodological consistency is unclear. Soil carbon content and texture classes are available.

The intensive monitoring plot network of UN/ECE offers ground based measurements of soil carbon in European forests with the aim of repeated surveys every 5-10 years in the Intensive monitoring plots, the database include the organic layer and the mineral soil to a depth of 80 cm (in some countries restricted to only 0-40 cm) for the intensive monitoring plots plus a detail profile information. In addition, for around 6000 level I plots soil carbon is available only to a depth of 20 cm with no clear aim of repetition. Several European countries made soil carbon assessments based on Level I Forest Soil Inventory (Baritz and Strich 2000).

The International Soil Science Society has been promoting a much-improved approach to mapping of the world's soils, known as the Soil and Terrain Database (SOTER) project. The principal implementing agency is ISRIC, in collaboration with FAO and national governments. The coverage, originally intended to be at 1:1 Million but now mostly at 1:5 Million, is proceeding slowly but steadily. About half of the world has been remapped in a way that permits much more reliable association of soil attributes (such as carbon content and texture) to locations, in principle down to a resolution of approximately 5 km. Much of the world will probably have been mapped by 2008, but some areas (for example, tropical Africa) may not benefit from remapping in that timeframe.

Action TI 10

Action:	Characterize and catalogue the available soil carbon inventories, with descriptions of the variables, spatial coverage and methodologies employed
Who:	FAO, SOTER and IGCO
Time-frame:	Short term
Product	List on the IGCO database
Cost:	Low

Action TI 11

Action:	Develop a methodology for combining the various soil carbon data set,
Who:	FAO, SOTER and IGCO
Time-frame:	Short term

Product	Database resulting from the combination of past data sets
Cost:	Low-medium

Action TI 12

Action:	Develop a common global methodology for the sampling of soil carbon
Who:	FAO, SOTER and IGCO
Time-frame:	Medium term
Product	Documentation detailing methodology
Cost:	Low-medium

Action TI 13

Action:	Expand the spatial and temporal coverage of soil carbon inventories
Who:	FAO, SOTER and IGCO
Time-frame:	Medium to long term
Product	Extensive soil carbon database (goal of 2°x2° global resolution with 10 year repeat frequency)
Cost:	High

5.1.5 Fluvial transport of carbon

Approximately 0.8 Pg C yr^{-1} is transported to the oceans by the world's rivers. This is made up from runoff through soils, direct mixing from atmospheric CO_2, and erosion of rocks. As well as the carbon that reaches the ocean, a portion of the carbon input to the rivers is deposited before reaching the ocean, especially behind man-made dams. It is important to properly quantify these estimates as it constitutes a redirection of a substantial portion of the net terrestrial sink. There is currently a large quantity of existing data on discharge and water quality from around the world, but protocols are national and incompatible. Global Runoff Data Centre (GRDC) has proposed a global standard for hydrological data and metadata, which may serve as a basis, using existing ISO standards and the evolving WMO Metadata Standard. GEMS/Water maintains a global database of water quality parameter and has adopted the proposed GRDC standard.

Action TI 14

Action:	Workshop to develop and promote standards and protocols, with the aim of developing a global database of dissolved and particulate carbon in rivers
Who:	WMO Hydrology and Water Resources Programme, collaborate with GEMS/Water & GRDC
Time-frame:	Short term
Product	Protocol for converting existing hydrologic data to carbon transport basis
Cost:	Low

5.1.6 Carbon storage in anthropogenic pools, i.e. wood products and lateral movement of stocks

The process of harvesting food, wood and fibre crops results in carbon storage and a horizontal shift in carbon stocks, and therefore a shift in the location of the return of the carbon to the atmosphere relative to its sink. To be sure that inventories, process based models and atmospheric inversions are compatible, these stocks and lateral fluxes must be considered.

Currently large quantities of economic data exists regarding the production and transport of food and fibre crops, however much work is required to assemble and process the data into useful carbon stores and fluxes.

Action TI 15

Action:	Organise workshop to define requirements for anthropogenic carbon storage data sets
Who:	FAO, IGCO
Time-frame:	Short term
Product:	Protocol for definitions of carbon stores and lateral flux data sets
Cost:	Medium

Action TI 16

Action:	Following the protocol in action TI 15, collect and interpret anthropogenic carbon stores and transport data
Who:	FAO, IGCO
Time-frame:	Medium term
Product:	Anthropogenic carbon stores and lateral flux data sets
Cost:	Medium

5.2 Terrestrial remote sensing

5.2.1 Land cover and land cover change

To achieve the objectives of monitoring land cover changes (at 5 year time interval, 1 km spatial resolution) requires the establishment of methodological standards for the generation of land cover information from satellite observations, the commitment to produce regular global products following such a standard, to commit to making available sensor systems capable of providing long term data supplies and to establish a baseline inter-comparison of existing and upcoming products. This last issue is very important with regard to land cover change, since the capabilities of individual satellite sensors and algorithms differ to the extent that a change can be an artefact of the senor system/algorithm. It is therefore vital that there is an active high spatial resolution monitoring network tailored to the regions of algorithm /sensor discrepancy but also to internationally accepted regions where rapid change is known to be taking place. These high spatial resolution data will provide the necessary validation products for the 1-km data.

Current capability

- IGBP Discover/UMD (University of Maryland) Land Cover – produced from AVHRR LAC (Advanced Very High Resolution Spectrometer Local Area Coverage) data collected in 1992-93. The classifications adopted were both globally applied resulting in two independent products with dissimilarities.
- GLC'2000 (Global Landcover Classification) produced from 1 km VEGETATION S1 and some Along Track Scanning Radiometer 2 (ATSR) data over the period December 1999-December 2000. The data exist as a series of regional blocks with their own classifications generated by regional experts and then as a global product merged by the same groups coordinated by the European Commission Joint Research Centre. This product was produced on behalf of FAO and UNEP and respects the classification logic of the FAO's Land Cover Classification System (LCCS). It is no considered a repeatable exercise.

- Moderate Resolution Imaging Spectroradiometer (MODIS) product from Boston University contains land cover type and land cover change parameters, produced at 1-km resolution on a **quarterly** basis beginning 18 months following launch of the Terra and Aqua platforms. The land cover parameter identifies 17 categories of land cover following the IGBP global vegetation database. The additional land cover change parameter quantifies subtle and progressive land-surface transformations as well as major rapid changes.

Next generation:
The ESA GLOBCOVER initiative is to develop a service that will produce a global land-cover map for the year 2005, using as its main source of data the fine resolution (300m) mode data to be acquired by the Medium Resolution Imaging Spectrometer Instrument (MERIS). This new product is intended to update and to complement the other existing comparable global products, such as the global land cover map at 1 km resolution for the year 2000 (GLC-2000) produced by the Joint Research Centre (JRC). The thematic legend of the final product is intended to be compatible with the FAO LCCS. The service will be developed in such a way that any further update of the global land cover map will be at recurrent cost.

Action TR 1

Action:	Develop algorithms to map the global distribution and temporal variability of land cover using a standard methodology and produce the these maps at repeated intervals
Who:	Space Agencies
Time-frame:	Short-term and ongoing
Product	Land cover change products
CI:	Medium

Action TR 2

Action:	Conduct cross-comparison exercise on existing land cover products to confirm similarities and highlight discrepancies. Establish translation methodology and tables
Who:	CEOS, GTOS, GOFC-GOLD
Time-frame:	Medium
Product	Common methodologies
Cost:	Medium

5.2.2 Fire distribution and burned areas

Fire and burned area distributions are currently under-represented and present a gap in IGCO. Active fire distribution on a daily basis requires the coordination of multiple sensors and, ultimately, the design and launch of dedicated sensors. There exists a dichotomy in system design for fire detection between having a polar orbiting system or a geostationary system. The principal issues are that a polar orbiting sensor will only be able to record a snapshot of active fire, at the time of overpass, conditioned by the presence of cloud, smoke and vegetation, while geostationary systems while having the higher temporal resolution are conditioned by spatial resolution which is variable. The currently available data is of limited duration and relatively incomplete, with the longest temporal record being the ESA ATSR-2/AATSR World Fire Atlas from 1996-present. MODIS is now producing data from the two platforms Terra and Aqua (from 2001), TRMM (Tropical Rainfall Measuring Mission) for the tropical zone from 1998 and some data have been produced with AVHRR (World Fire Web).

With respect to the current available products and systems, all are produced, with the exception of MODIS, from satellite sensors not originally designed with fire detection in mind. Inter-comparison is also extremely difficult given the different overpass times and sensor and algorithm capabilities. In order to reach a daily distribution of fire a synthesis/integration activity is required to pull together, into a single product, the available observations from AVHRR, ATSR-2/AATSR, TRMM and MODIS. Efforts on the geostationary side from GOES and MSG require inclusion.

Burned area on a monthly basis at a global level only exists in the form of two demonstrator products: GBA-2000 (Global Burnt Area) and GLOBSCAR that were developed independently for the year 2000. These demonstrators are currently being revisited in the ESA GLOBCARBON project to produce, for the period 1998-2003 initially, burned area on a monthly basis constrained by active fire information.

Action TR 3

Action:	Develop algorithms to map the global fire distribution burned area (using i.e. Landsat, SPOT, ALOS, NPOESS)
Who:	Space Agencies
Time-frame:	Short-term and ongoing
Product	Fire distribution and burned area maps
Cost:	Medium

5.2.3 LAI and fAPAR

Only a few global LAI and fAPAR products are currently available. In the near future the ESA GLOBCARBON project will be making available data from 1998-2003 at a resolution of 10km and upwards through the combination of VEGETATION, ATSR-2/AATSR and MERIS data following the methodology developed at the University of Toronto, Canada. In addition data are being produced with VEGETATION, MERIS, MSG and AVHRR through the EC Framework 5 Cyclopes project. These products are all at a resolution of 1 km and coarser and a temporal resolution of between 2 weeks and a month. There is a need to conduct cross-comparisons and synthesis activities to make the data record as long as possible and to conduct coordinated validation efforts to ensure precision and accuracy are key features. However, the current validation network needs strengthening spatially and temporally to allow this to be undertaken and the results used to improve the products. Higher spatial resolution products are currently not envisaged given the paucity of data, except as a means of validation.

Action TR 4

Action:	Inter-compare and generate syntheses from the current products of global distribution and temporal variability of leaf area index
Who:	Space Agencies
Time-frame:	Medium
Product	LAI products
Cost:	Medium

5.2.4 Phenology

Knowledge of seasonal growth characteristics such as growing season duration, timing (onset and end) are important constraints on defining the period of carbon sequestration. Typically growing season extent is defined thermally, using a standard 5°C cut-off in air temperature. While this is reasonable for cold northern climates it is not relevant to tropical or sub-tropical climes where growing season is dictated by water availability and high temperature. In addition, the onset of both 'green-up' and 'senescence' is dictated by the reactions of individual species within plant assemblages.

Observations with satellites have shown the ability to detect 'green-up' and 'brown-down' in boreal and temperate ecosystems. For boreal systems, a crucial consideration is the effect of snow on the detection of phenological signals in spring. In particular, both snowmelt and budburst cause changes with the same sign in commonly-used spectral indices, such as NDVI and NDSI (for which both phenomena cause an increase and decrease respectively). However, the NDWI, which can be derived from the spectral bands available from the SPOT-VEGETATION satellite, shows a decrease with snowmelt, followed by an increase with green-up; hence the green-up date can be much more reliably detected. The SPOT-VEGETATION data can also be used to calibrate the green-up recovery from NDVI, allowing phenology to be recovered from the long time-series provided by the NOAA AVHRR satellites. This allows the analysis of trends and spatial variability across the whole global zone since the early eighties, and the relation to climate signals to be established. These data have been used to calibrate climate-based boreal green-up date algorithms, with very good results when tested against ground data; they also indicate where such algorithms fail (current indications are that this is where the chilling requirement for bud-burst becomes relevant). In contrast, algorithms to detect boreal senescence currently exhibit considerable uncertainty in the senescence date, but this is not as critical as bud-burst as regards its effect on Net Primary Production over the year.

As the above illustrates, it is important for the space and ground-based observation communities to agree on definitions of terms, such as growing season, leaf-on, leaf-off and budburst, that have meaning in ecological, carbon and remote sensing terms. For example, leaf-on has been determined using a variety of algorithms and on diverse remote sensing data streams, such as Leaf Area Index in GLOBCARBON and Spectral Indices (NDWI, NDSI, NDVI) in SIBERIA-II. All such approaches depend on the predominant vegetation exhibiting change as a function of active growth and this change being detectable in the presence of confusing factors (such as snowmelt). Sensitivity analysis of space-based methods is therefore required and development of strategies to use data from multiple sources (this is already underway in the use of SPOT-VEGETATION data to calibrate AVHRR). In addition, space-based inferences on the dates of important phenological events and the length of the growing season, whose inter-annual variation is on the order of days, need to be compared with reliable ground-based observations across arrange of forest types and regions. This should be supported by extended ground-based instrumentation (e.g., spectral sensors mounted on flux towers) and greater sharing of information.

Improvements in phenological information from space do not require new instrumentation, although the importance of having the correct spectral bands to detect green-up in boreal forests has been illustrated by SPOT-VEGETATION. The main progress is likely to be gained by combination and comparison of data sets, improved sets of ground measurements, both ecological and from ground-based spectral sensors, in order to establish better-founded link between the satellite signal and its phenological interpretation, and the formation and dissemination of standardised, complete datasets at a wide range of ground locations.

Action TR 5

Action:	Calibration and cross-comparison of methods from ground-based meteorology, ground-based plant observations and space including coordination and data compilation
Who:	CEOS WGCV, Research Community, Space Agencies producing products.
Time-frame:	Short
PI:	Common agreement on the definition of e.g. ‘green-up’ and ‘brown-down’, common methodological standards.
CI:	Low

Action TR 6

Action:	Rigorous sensitivity analysis of the space-based observations over a long temporal sequence including data from multiple satellites (AVHRR, VEGETATION, ATSR, MODIS).
Who:	Space agencies producing products, research community
Time-frame:	Short
PI:	Availability of processed data on phenology and globally distributed and documented ground-based observations for validation purposes.
CI:	Medium

5.2.5 Biomass

Current capability

Current remote sensing applications (LAI and C-band radar) are unable to provide accurate estimates of above ground biomass. A significant step forward is likely if the launch (expected late 2005) of the JAXA ALOS-PALSAR L-band radar is successful. Data from the earlier NASDA JERS L-band satellite, supported by numerous airborne studies, have indicated that L-band radar provides a more robust measurement of biomass than C-band, albeit still limited to 50-70 t/ha. Under their Kyoto and Carbon Initiative, JAXA will carry out systematic coverage of all the world’s forests, and an international supporting team will assess whether biomass, within the restricted range noted above, can reliably be derived from these data. The initial studies will be regional, but if the methodology can be demonstrated to yield accurate results, it will be applied to the global dataset to provide global gridded data.

The restriction of biomass recovery to at most 70 t/ha means that only the biomass of young or low productivity forest can be mapped by ALOS-PALSAR. The former will give some information on the age structure in plantation forests. ALOS-PALSAR should also be able to map biomass changes in young regrowing forest in the tropics, because of their rapid rate of growth.

Action TR 7

Action:	Support global availability of ALOS biomass data, after validation
Who:	JAXA K & C group for methods and validation, but then extra support needed
Time-frame:	Medium
Product :	ALOS data product
Cost :	Medium-high

Next generation

Three technologies show promise as a means to derive improved biomass information from space. One of these is long wavelength radar. At present, the lowest frequency we can use for spaceborne SAR is P-band (wavelength ~68 cm); this opportunity arose for the first time in June 2003 when the ITU allocated a 6 MHz bandwidth (432-438 MHz) as a secondary allocation for remote sensing. Numerous airborne studies have shown that P-band backscatter is sensitive to forest biomass up to a saturation level of 100 to 150 t/ha. This makes it suitable to map the biomass of most of the boreal forest and a large part of the temperate forests, but not the biomass levels found in the tropics. The two other technologies aim to measure forest height, from which biomass maps may be constructed if suitable local or regional allometric relationships between biomass and height are available. The first is lidar. Airborne lidar systems have demonstrated the capability to measure forest vertical structure, but no spaceborne mission has yet been implemented. Since such a lidar will produce spaced samples along transects, generating spatially explicit maps will need some means of extending the measurements spatially, for example using radar imagery. The second technology to retrieve forest height is L-band SAR polarimetric interferometry, which has recently been developed and explored with airborne systems. Proposals for missions using all three technologies have been submitted to the 2005 ESA Call for Ideas, but at time of writing it is not known if any of them will be selected for further development. If one of them does become a selected mission as a result of this ESA call, it is unlikely that it will be in orbit before 2013. It should be noted that a Vegetation Canopy Lidar (VCL) was previously selected by NASA but has not gone forward. The possibilities for complementary missions under the NASA ESSP are not known at present.

Action TR 8

Action:	If biomass mission selected for development by ESA or NASA, involvement in assessing the limits of the technology, including theoretical studies and the design and support of airborne campaigns, with associated well-documented ground data.
Who:	IGCO community
Time-frame:	Medium to long
PI:	Strategy for implementation of biomass monitoring from space
CI:	Medium to high (airborne campaigns are expensive)

6 Fossil fuel reservoir

Since the beginning of the industrial era the functioning of the global carbon cycle has been perturbed by the rapid and increasing release of carbon from the inactive pool of geologic deposits of fossil fuel. Since 1750 an estimated 277 billion tons of C (through 2000) have been released to the atmosphere as CO_2 from the combustion of coal, petroleum, and natural gas. Another 6 billion tons have been released from calcining limestone to manufacture cement. It is these two fluxes that have driven unprecedented growth in the concentration of atmospheric CO_2 and it is the continuation of these two fluxes that raises concern about the continuing perturbation of the global carbon cycle.

Understanding the behaviour of the global carbon cycle requires an accurate understanding of the magnitude of the fossil-fuel flux. Understanding the details and mechanisms of the global carbon cycle will require that we measure not only the global, annual total of emissions from fossil fuels, but that we have data on the distribution of this flux on the same temporal and spatial scales as for the other processes we hope to understand. This implies the short-term objective of characterizing emissions at the scales of months and 100 km over the land.

Action F 1

Action:	Organise workshop to define requirements geo-referenced information for creating high resolution fossil fuel maps
Who:	Marland/Andres/IGCO
Time-frame:	Short term
Product	Improved fossil fuel maps, i.e. seasonal cycle
Cost:	Low

Data on the use of fossil fuels is generally accumulated by questionnaires to fuel producers, traders, and users. The data are typically collected by some political jurisdiction and most data collected to date are at the scale of countries and years. Because of the importance of energy in the global economy and because most fossil fuels are traded in formal markets; there is considerable data on the production, trade, and consumption of fossil fuels. International compilations of energy data are maintained by the United Nations Statistics Office (UNSO) and by the International Energy Agency (IEA). The UNSO maintains data for all countries and the IEA maintains data for at least all countries that play a significant role in the production, trade, or consumption of petroleum or petroleum products; some 140 countries. These two agencies cooperate in the distribution of their questionnaires and share the energy data retrieved. Data on global energy production and use are also collected by organizations such as the US Department of Energy and the British Petroleum Company. These primary data sets are at the scales of countries and years, although both the UNSO and IEA do retain some monthly data. Many developed countries have at least a portion of their energy data at a monthly scale and in some cases the data are collected for major political subdivisions of the countries, e.g. for states or provinces. The US Department of Energy, for example, publishes data on national energy consumption by month and by state, but not state data by month.

Data sets estimating CO_2 emissions from fossil fuel by country and year are maintained by the IEA (based on the IEA energy data set), by the Carbon Dioxide Information Analysis Center (CDIAC) (based on the UNSO energy data set), and by RIVM in The Netherlands (based on the IEA energy data set). Marland et al. (1999) have published a detailed comparison of the

CO_2 emissions estimates produced by CDIAC and by RIVM and the agreement is quite good for most countries. In 1984 Marland and Rotty estimated that the global total values had an uncertainty of 6 to 10%, depending on whether or not the data for the 3 primary fuels are independent of each other. Estimates for individual countries can have much larger uncertainty, especially for developing countries with weak systems of data collection and management. In fact, the UNSO finds that in a typical year only on the order of 1/3 of African countries respond to their annual questionnaire, and they are obligated to rely on within-country reports and international energy companies to piece together national summaries. Negative values for emissions of CO_2 have been reported for a country when, for example, small differences in large numbers result in reported exports exceeding reported production and calculated internal consumption ends up as a small negative value. The comparison between CDIAC and RIVM values found that the largest percentage differences were among some developing countries, but the largest absolute differences were among some of the countries with the best data systems. The two estimates for the US differed by only 0.9%, but in absolute terms this difference was larger than the total of emissions from 147 of the 195 countries considered.

An effort currently underway by Andres and his students and Marland aims to produce estimates of global CO_2 emissions by month and by state for the larger countries. The initial objective is to accumulate appropriate data for the 21 countries that are collectively responsible for over 80% of global total emissions. Blasing et al., 2005a and 2005b have papers describing US emissions by state and by month and additions by Andres, Losey, and Gregg will soon result in a data set for North America (US, Canada, and Mexico) by month and state. The US monthly data go back to 1981 but some of the requisite, monthly time series are very short. In many cases monthly data on fuel consumption are not available at all and proxy data will be used to estimate the pattern of fossil-fuel use. Losey et al. (in preparation), for example were unable to find monthly data on coal consumption in Brazil and used data on steel production to estimate coal consumption since the iron and steel industry is responsible for 80% of coal consumption in the country.

Action F 2

Action:	Production of fossil carbon emission maps with monthly temporal resolution and by state or country.
Who:	Marland/Andres
Time-frame:	Short term
Product	Dataset
Cost:	Medium

Proxy data will probably play a major role in many CO_2 emissions estimates. Andres et al. (1996) published estimates of CO_2 emissions on a 1 degree by 1 degree latitude/longitude grid using population density as a proxy. Andres et al. estimated emissions for each country and then used population density data to distribute those emissions within each country. By this method, emissions totals were constrained within the respective countries, but the underlying assumption was that emissions per capita were constant within each country. The state-by-state US data set of Blasing et al. (2004b) reveals some of the weakness in this assumption, per capita emissions vary by a factor of 10 between Wyoming and California. The Andres et al. data set was also unable to distribute the emissions from fuels used in international commerce, e.g from ships at sea and from international airline flights. Formal energy statistics generally account for these bunker fuels at the point of their last sale.

CO_2 emissions by sector or activity, that will be important in evaluating mitigation efforts, are reported by the IEA and are required in the national reports of all developed countries in compliance with their commitments under the UN Framework Convention on Climate Change. The Intergovernmental Panel on Climate Change has published guidelines for countries to use in these reports (the Guidelines are currently in the process of updating) and this helps to improve completeness and comparability among the reports. These reports provide considerable sectoral detail but are national and annual in scope.

At the annual, global level, the largest source of uncertainty in CO_2 emissions estimates is the energy data itself. The UN Statistics Office is under-funded and under-staffed. The IEA seems to be better off in both respects but does not cover all countries and is reliant on UN questionnaires for some of its data. Many countries do not report at all. Data at finer spatial and temporal scales are spotty in both time and space. Some monthly and state data do exist.

There is now some data from monitoring large point sources at the point of emissions. This requires monitoring both the concentration of CO_2 in the stack gases and the flow rate of the hot gases. Globally roughly 1/3 of emissions are at large point sources and are thus potentially susceptible to this kind of monitoring. Another roughly 1/3 of global emissions are from transportation systems and in current estimates the emissions get tabulated at the point of the last fuel transaction. As the spatial scale decreases it will become increasingly important to distinguish where the fuel is burned as distinguished from where it was last purchased. Similarly, most fuel is not combusted near the time of its last sale but will be distributed over time. Distinguishing the exact time of combustion will also become more important as the temporal scale of emissions estimates shrinks.

Action F 3

Action:	GEOSS to recommend fossil fuel emissions reporting to UNFCC by month and state/prefecture level rather than annual as current practice
Who:	GEO
Time-frame:	Short term
Product	
Cost:	Low

Action F 4

Action:	Monthly emissions at political unit level to be disaggregated in space and time according to separate empirical functions appropriate for: • Transportation (including diurnal and day-of-week cycles) • Electricity generation (including time of day and energy demand functions according to weather) • Industrial sector • Residential heating with demand curves related to weather Use “City Lights” (DMSP) data to spatialize, and compare to combustion tracers to evaluate products.
Who:	Fossil emissions research community
Time-frame:	Medium-long
Product	Target should be global grids at hourly temporal scales at spatial resolution sufficient to resolve boundaries urban areas
Cost:	Medium-high

7 Integrated modelling

This implementation plan concerns observing strategies for understanding the global carbon budget, and not the development of models per se. It is clear, however, that models are required to interpret the information contained in such data, and so it is important that a strong link between observationalists and modellers is facilitated so that the models use the data in the correct fashion, and that both the requirements and the findings of the models are communicated to the observationlists.

The models in question are required to have specific properties to make best use of available observations:

- They must be comprehensive, able to simulate processes that give rise to a given observation.
- They must be global since the earth's fluid reservoirs transport and hence integrate constituents.
- They must be capable of optimally incorporating observations, that is they must be coupled to a data assimilation system.

7.1 Integrated systems

As we develop a fully integrated global carbon observation system, an important question will be which observation(s) we should add to the system, extend coverage or improve accuracy for, such that we best reduce the uncertainty in our understanding of the carbon fluxes and pools. The field could be a direct measure of carbon, either in a reservoir or a flux, but could also be a climate or state variable such as soil moisture, cloud cover or ocean nutrients, or possibly physical properties such as turn-over rates in soil carbon pools or ocean mixing from the surface to deeper levels.

This question can be addressed with a fully coupled process based model of the global carbon cycle. The details of building of such a model are outside the scope of an observation plan, but we strongly encourage such an activity.

Action M 1

Action:	Build an integrated experimental design tool so that observationalists and planners can analyze the impact and potential value of future measurements
Who:	Data assimilation and process modelling communities
Time-frame:	Medium term
Product	Coupled process models with assimilation capability
Cost:	High

7.2 Atmosphere

Atmospheric inversions have provided some vital information about the carbon cycle, notably pointing to the existence of a large Northern Hemisphere terrestrial sink. As the community attempts to resolve the surface sources and sinks at higher spatial resolutions additional data aside from the ‘baseline’ clean air CO_2 network are required. The use of such data (continuous continental data, aircraft profiles, future satellite missions) will require significant effort such that the mismatch between what the models can reproduce and the data are minimised.

Action M 2

Action:	Hold an international workshop to form a new protocol for reporting and selecting atmospheric composition data for use in inversions. This is necessary as we move to use more informative but difficult parts of the measured data we previously neglected
Who:	Atmospheric transport research community (TransCom & GCP), and atmospheric observation community (WMO/GAW, national networks)
Time-frame:	Short term
Product	Protocol for pre-processing data for inversions
Cost:	Low

A key tool for estimating carbon fluxes with inversions of atmospheric concentration data are the atmospheric transport models, and the TransCom experiment (sponsored by the GCP) has demonstrated the impact of transport model error on the uncertainty in the inversion results. As satellite concentration data becomes available, the vast increase in data coverage is likely to increase the relative importance of the transport model error, but this is currently poorly understood.

Action M 3

Action:	Initiate project to investigate model error when inverting satellite concentration data. this could start with the high-quality methane datasets
Who:	TransCom via the GCP
Time-frame:	Medium term
Product	Publications describing model error contributions to uncertainty in inversions of satellite data
Cost:	Medium

We also need a series of tracer measurements to help constrain the transport characteristics of models. This is a major subdiscipline in oceanography but has received less attention in the atmospheric sciences. It also appears that the behaviour of models in transporting passive tracers in the troposphere is difficult to infer from their dynamical behaviour. We therefore encourage enhanced research into modelling transport of passive tracers and, in particular studies to define tracer measurements that provide the best constrain on tracer transport characteristics. Total action is medium term medium cost, the resulting observational programme is another matter altogether. A short-term action is to hold a workshop so that modellers understand the set of available observations and the various cost-benefit trade-offs of these measurements. IGBP atmosphere is probably the group to lead this.

Action M 4

Action:	Workshop between modellers and observationlists to discuss tracer properties
Who:	IGBP atmosphere
Time-frame:	Short term
Product	Publications on ideal tracer properties for evaluating transport models
Cost:	Low

Action M 5

Action:	Measure tracers in the atmosphere valuable for transport model validation
Who:	GAW
Time-frame:	Medium/long term
Product	Tracer data sets

Cost:	Medium/high

An extremely useful tool to assist the communication between modellers and observationlists would be an online conclusive inventory of the model fields required, including trace gas concentrations, temperature, wind fields, water vapour and cloud fields, surface fluxes of heat, moisture and trace gases. Compiling the list itself will be a non trivial task as different models tend to use different subsets of the full list. The pseudo data set will be accessible via a live access server such that a direct comparison between an observation and the model prediction can be easily made.

Action M 6

Action:	Produce a state-of-art model atmosphere with 4d fields of all relevant variables for comparison with observations, coupled to with a live access server
Who:	TransCom or C4MIP
Time-frame:	short term
Product	Pseudo data set with live access
Cost:	Medium

As the increase in volume of atmospheric composition data accelerates with the availability of satellite data, our ability to ingest and analyse the data must also grow. This problem is already addressed in the metrological domain which combines in situ and remote sensing data of vast quantities for weather forecasting. The same tools could and should be applied for the assimilation of atmospheric composition data. The assimilation system could either be a stand alone system specifically for the carbon cycle, or could be incorporated into an existing system at a national/international weather forecasting centre. The process should also benefit the weather forecasting as the concentration data can be used as an independent validation of the calculated atmospheric mixing.

Action M 7

Action:	Build an atmospheric data assimilation system for the inversion of all atmospheric composition data
Who:	National and International weather services + NASA. National agencies may also offer this as a large project
Time-frame:	Medium term
Product	Assimilation system
Cost:	High

7.3 Ocean

Many of the atmospheric issues described above also apply to the ocean domain, and several of the action items are similar.

Action M 8

Action:	Generate a 4d field of all relevant variables for comparison with observations. Couple this with a live access server. Preferably use more than one model, Fields should include fluxes to atmosphere
Who:	either PCMDI or OCMIP
Time-frame:	Medium term
Product	Pseudo data set with live access

Cost:	Medium

Action M 9

Action:	A series of workshops with observationalists and modellers to define observational operators and error specifications for ocean measurements. This should also include remote sensing
Who:	IOCCP or GCP
Time-frame:	Short term
Product	Publications detailing data requirements for ocean models.
Cost:	Low

7.4 Terrestrial

Much of the variability in the atmospheric observations of CO_2 on scales of hours to months is due to processes over land, either burning fossil fuel, terrestrial biosphere exchange by photosynthesis and respiration, and by disturbance (especially fire). The continued development of models to simulate the behaviour of these processes and to facilitate comparison with observations is key to our understanding of the global carbon cycle and to be able to estimate the future terrestrial biosphere emissions.

As for the atmosphere and ocean domains described above, the terrestrial modelling domain has similar objectives to achieve to improve the ability to absorb and interpret the large quantities of data available now and in the future.

Action M 10

Action:	Produce a model 4d archive of all relevant variables for comparison with observations. Couple this to a live access server
Who:	IGBP terrestrial
Time-frame:	Short term
Product	Pseudo data set with live access
Cost:	Medium

Action M 11

Action:	Hold a series of workshops with observationalists and modellers to define the observational operator and error specification for terrestrial data assimilation
Who:	GCP
Time-frame:	Short term
Product	Publications detailing data requirements for terrestrial carbon models
Cost:	Medium

Fire is a key disturbance process on land that contributes around 2 - 4 Pg of carbon to the atmosphere each year, and is an important factor shaping the carbon budget on land via its affect on vegetation type, mass, and age class distribution.

Action M 12

Action:	Hold a full conference on the remote sensing and modelling of fire
Who:	IGCO, GCP and fire research community
Time-frame:	Medium term
Product	Publications on understanding fire impacts on the carbon cycle
Cost:	Medium (2007 GCP meeting planned)

The human impact on the terrestrial biosphere is enormous. Through logging and agriculture we have substantial control over vast amounts of carbon.
Considerable data is available, such as forest inventories and crop volumes are available, as well as the climate variables that drive the growth of managed ecosystems. Continued development of managed terrestrial ecosystems and the use of and comparison of observations is to be facilitated.

Action M 13

Action:	Hold a full conference on the remote sensing and modelling of land management
Who:	GCP, IGCO and land use and land use change research community
Time-frame:	Medium term
Product	Publications
Cost:	Medium

A key step in any modelling process is the preparation of the data sets to drive the model. For the terrestrial biosphere this includes many fields from reanalysis products such as those from NCEP and ECMWF. However as these products are not specifically designed for terrestrial model input, considerable work is required to modify fields to suit the needs of the models. This is done differently by different groups and potentially leads to differences in the model results. An effort to form a high-quality near surface climatology for driving the models is required.

Action M 14

Action:	Form a high-quality near-surface climatology for driving terrestrial models.
Who:	IGCO and terrestrial modelling community
Time-frame:	Medium term
Product	Data set online.
Cost:	High

8 Data and Information Management

8.1 Introduction

The overall IGCO strategy of building a coordinated system of integrated global carbon cycle observations requires a highly integrated data and information management system. Key to the data and information management system is the ability to integrate carbon observations from a wide variety of platforms and techniques within a coherent modeling framework based on data assimilation and model-data fusion methods. To achieve these aims, IGCO needs a data management system that enables access, understanding, use, integration, and analysis of large volumes of diverse data at multiple scales. The end-to-end data management and analysis systems will deliver high quality products that will be freely accessible to the scientific, resource management, and policy communities around the world.

The challenge for the IGCO is to manage high quality, consistent, long-term data in a manner that directly supports the data assimilation models, while maintaining enough flexibility both to respond to new observations as our understanding of carbon cycle dynamics evolves and as new information technology approaches are developed. The state of the art is still relatively young, and progress is needed in order to support the data requirements of the Coordinated System of Integrated Global Carbon Cycle Observations. It is thus key to the success of IGCO data and information assimilation system to plan at an early stage improved data calibration, harmonization, and quality assurance procedures that will ensure that observations produced by different networks and observing systems covering differing spatial and temporal domains are fully compatible and readily integrated in data assimilation systems.

The following sections describe actions required to establish and operate the IGCO data system.

8.2 Priority data products and services

The integration of models and data requires establishment of both data requirements and modelling-assimilation strategies. Using inverse modelling and data assimilation to place constraints on the fluxes of CO_2 between the Earth's surface and the atmosphere requires reliable, quality assured, and well-calibrated measurements of key carbon stocks and fluxes. In addition there are a number of additional and ancillary observations that are crucial to the data assimilation and model-data fusion activities of IGCO.

The IGCO Theme document has identified priority data products and listed some improvements that need to be made in accuracy, precision, site placement (sample design), and spatial resolution. IGCO needs to expand this list to determine the data products and data management services and functions required to meet its goals. For example, IGCO will rely heavily on innovative new methods of data assimilation / model-data fusion. The specific functions required of the data management system to support data assimilation needs to be identified and plans made to provide that support.

Action D 1

Action:	Identify data management services and functions and priority data products, including socio-economic data and data for decision-support, required to address IGCO research questions and when those products and services are needed
Who:	IGCO
Time-frame:	Short term and ongoing

Product	List of data services on IGCO website
Cost:	Low

Many of the required data streams exist today and systems are in place for handling many of these individual data streams. The IGCO data and information management system should build on these existing systems to meet the needs of IGCO. Many of the required data streams exist today and systems are in place for handling these individual data streams. However, some of the data streams are not produced consistently at the time and space resolution needed for IGCO, and the data are not assembled into an integrated set for data fusion. The IGCO data and information management system should build on these existing systems to meet the needs of IGCO.

Action D 2

Action:	Identify national and international data centers that are currently producing data streams crucial to IGCO and develop memorandums of understanding (MOUs) to facilitate exchange of priority data products.
Who:	IGCO
Time-frame:	Short term
Product	MOUs
Cost:	Low

8.3 Data Management Working Group

Close coordination among data managers, those making the observations, modellers, and other data users is critical. To achieve its goals, IGCO requires integration and dialogue between the research teams and the data systems to both define and realize data product requirements.

IGCO needs to define a charter for the Data Management Working Group, which will facilitate data management, interface with observation activities, and modellers. The group will work closely with the scientific leadership of IGCO to ensure that the data system fulfills the data and information management needs of IGCO.

Action D 3

Action:	Establish a Data Management Working Group comprised of data producers, data users, and data system developers to provide coordination and integration of data management, observation activities, and modeling
Who:	IGCO
Time-frame:	Short term
Product	Working group
Cost:	Low

8.4 Data policy

Managing and integrating data for IGCO requires an overarching data policy that provides full and open access to global observational data in a timely manner. IGCO Data Policy will be derived from ICSU, WMO, and Diversitas's data policies and will be tailored to meet the specific needs to IGCO.

ICSU / CoData: http://www.codata.org/data_access/principles.html

WMO: http://www.meteo.fr/meteo/e_resol40.html

The IGCO Data Policy will provide a continuing commitment to the establishment, maintenance, description, accessibility and long-term availability of high-quality data and information.

Action D 4

Action:	Establish data policies that are based on full and open sharing of data products and that facilitate the generation, exchange, and archiving of carbon observations
Who:	IGCO, data centres, data producers and data users
Time-frame:	Short term
Product	Documentation detailing data policies
Cost:	Low-medium

8.5 Metadata standards

IGCO needs to promote interoperability principles and metadata standards to facilitate cooperation and effective use of collected data and information. Metadata enables users to discover data products and understand the content of those products. In addition systems and tools rely on consistent and interoperable metadata as a means to enable automatic processing, including analysis, visualization and subsetting.

IGCO should work with its members to promote the development and use of flexible, open and easy-to-use community standards for metadata. These standards should be interoperable and independent of specific hardware and software platforms. Guidelines for their use should be widely circulated and incorporated into data management training courses.

Action D 5

Action:	Promote the adoption and use of standards and procedures for metadata
Who:	Data centre managers and data providers
Time-frame:	In progress
Product	
Cost:	Low

8.6 Flow of data

One of the key requirements of IGCO is to have a data system that enables accessing multiple sources of constraining data, with vastly different spatial, temporal and process resolutions used in the modelling approach.

Action D 6

Action:	Ensure timely and efficient flow of essential carbon observation data and metadata to IGCO, including as needed, real time data transfer for key data streams.
Who:	Data providers
Time-frame:	In progress
Product:	
Cost:	

8.7 Quality assurance

Potential data sources can be assessed for the reduction in uncertainty they provide for model parameters. Importantly, this modelling approach requires the uncertainty characteristics of the data be an integral component of the data system.

Assimilation models that will integrate multiple data types will be more vulnerable to bias than inverse models that have largely relied on data from surface concentration networks. The space/time variations in biases from different measurements must be defined well before use in assimilation systems.

Action D 7

Action:	Implement quality assurance procedures and document the quality of data so that users know the data's limitations
Who:	IGCO, data centres, data producers
Time-frame:	In progress
Product	Up to date list of data sets with quality descriptions
Cost:	Low

IGCO needs to periodically take stock of the data and information by documenting its character and quality in ways that are responsive to the needs of its end users, now, for both basic and applied uses, and into the future as they provide the climate-quality, long-term records of Earth system change. As IGCO provides information for policy-makers (e.g., IPCC reports, the data products inputs to these analyses need to be evaluated and published in the peer reviewed literature or of some equivalent, documented quality.

Action D 8

Action:	Establish a process for preparing peer-reviewed data reports for documenting primary carbon observation data sets
Who:	IGCO
Time-frame:	In progress
Product	Documentation
Cost:	Low

8.8 Assembly of integrated / harmonized data products for data assimilation

The ultimate goal of the coordinated system of global carbon observations is to generate data products that are of value for the user communities. Raw observations are rarely adequate on their own. To create usable products, in situ measurements from a variety of sources need to be integrated with remote-sensing observations within a modelling framework. To achieve this, a major challenge is to collect, process and harmonise in situ data from diverse sources. At present problems with in situ data include, among others, inconsistent parameter definitions, differing data formats, incomplete data, differing spatial and temporal scales, and sampling bias in measurements.

Many core measurements of carbon pools and fluxes are entirely nationally based, so the harmonization of existing data and the standardization of methodologies is a central issue. Many other pool and flux measurements exist only in research mode (e.g., Global Carbon Project (GCP)), and considerable further development is required before they can be included in hind-casting, re-analysis, or carbon budget studies in the context of an operational system.

A challenge is to implement a data system that facilitates the combination of atmospheric observations with observations on the surface and subsurface, both on land and in the ocean (e.g., deployed on eddy covariance towers or onboard ships of opportunity), and to include ancillary observation of ecosystem condition. Atmospheric measurements need to be integrated with surface data into a single, internally consistent, coherent strategy.

Once the carbon observing system is in place, model-data fusion techniques will routinely assimilate data streams of carbon measurements to produce consistent and accurate estimates of global CO_2 flux fields with typical resolution of 10 km over land and 50 km over oceans with weekly frequency. These products will need to be indexed and made available for assessment, policy, and resource management.

The data integration function of IGCO should directly support merging, synthesis, and eventually the fusion of carbon observations within process oriented carbon models. It will require comprehensive advanced Carbon Cycle Data Assimilation Systems, that are expected to analyze large amount of data and diagnose on a routine basis carbon quantities, and provide error diagnostics.

Action D 9 **see also action M1**

Action:	Facilitate assembly of disparate data sets into integrated data products for data assimilation and synthesis and assessment activities
Who:	Data providers, modelling communities
Time-frame:	In progress
Product	Data sets
Cost:	Medium

Action D 10 **see also actions M6, M8, M10**

Action:	Organize series of workshops to define requirements and initiate collection of geo-referenced information required to meet the goals of IGCO
Who:	Modelling groups, data producers and data centres
Time-frame:	In progress
Product	Workshop documents
Cost:	Medium

Incorporate open source collaboration principles in system development efforts (portal design, data filters, format conversion, web mapping services, cross-platform compatibility).

Action D 11

Action:	Identify and select tools / services for data acquisition, visualization, and analysis, based on standards and open sources.
Who:	Data centre managers and carbon research community
Time-frame:	In progress
Product	Data tools and services
Cost:	Medium

8.9 Preservation of data.

IGCO should formulate a strategy for archive of data and products developed by IGCO activities. IGCO data products, including value-added products, need to be archived when the data sets are finalized. A data archive plan for IGCO data products is critical, because of the distributed nature of the data management system with individual agencies holding active data products. A data archive plan developed early in IGCO will prevent such loss of data.

Archiving procedures must take data security, integrity, and routine technological updating into account, and archives should support data discovery and access.

Many data products used for IGCO are currently being archived by agency or national data centers, and IGCO should not duplicate those efforts. IGCO should identify agency roles and responsibilities, commitment, and the issues/concerns of international collaborators associated with long-term data archival.

Action D 12

Action:	Ensure that IGCO data are preserved through establishment of long-term IGCO data archives, or establish MOUs with existing long-term archives to preserve IGCO data.
Who:	Data centres
Time-frame:	In progress
Product	Archives
Cost:	Medium

9 References

Baritz, R. and S. Strich. Forests and the National Greenhouse Gas Inventory of Germany. Biotechnol. Agron. Soc. Environ. 2000 4 (4), 267–271

Blasing, T. J., C. T. Broniak, and G. Marland, 2005a. The annual cycle of fossil-fuel carbon dioxide emissions in the USA. Tellus, 57B: 107-115.

Blasing, T. J., C. T. Broniak, and G. Marland, 2005b. State-by-State carbon emissions from fossil-fuel use in the United States 1960-2000. Mitigation and Adaptation Strategies for Global Change, in press.

Cihlar, J., Heimann, M., and Olson, R. (Eds.) 2002. In situ data for Terrestrial Carbon Observation (TCO). Report GTOS-31, report of In situ Meeting, 5-8 June 2001, Frascati, Italy. (Available from www.fao.org/gtos)

Cox, P. M., R. A. Betts, C. D. Jones, S. A. Spall, and I. J. Totterdell 2000, Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model, Nature, 408(6813), 750.

Dilling, L., S.C. Doney, J. Edmonds, K.R. Gurney, R. Harriss, D. Schimel, B. Stephens, G. Stokes, 2003: The role of carbon cycle observations and knowledge in carbon management, *Annual Review of Environment and Resources,* 28, 521-558, doi: 10.1146/annurev.energy.28.011503.163443.

Doney, S.C. and M. Hood, 2002: A Global Ocean Carbon Observation System, A Background Report, Global Ocean Observing System Report No. 118, UNESCO Intergovernmental Oceanographic Commission IOC/INF-1173, 55p.

Doney, S.C., R. Anderson, J. Bishop, K. Caldeira, C. Carlson, M.-E. Carr, R. Feely, M. Hood, C. Hopkinson, R. Jahnke, D. Karl, J. Kleypas, C. Lee, R. Letelier, C. McClain, C. Sabine, J. Sarmiento, B. Stephens, and R. Weller, 2004: Ocean Carbon and Climate Change (OCCC): An Implementation Strategy for U.S. Ocean Carbon Cycle Science, UCAR, Boulder, CO, 108pp.

Edmonds, J., Joos, F., Nakicenovic, N., Richels, R.G. and Sarmiento, J.L., 2004. Scenarios, targets, gaps and costs. In: The Global Carbon Cycle: Integrating Humans, Climate and the Natural World. (Eds: Field, C.B. and Raupach, M.R.). (Island Press, Washington). p. 77-102.

FAO, Global Forest Resources Assessment 2000: Main Report, FAO, 2001.
Olson J.S., Watts J.A. and Allison L.J. (1983) Carbon in Live Vegetation of Major World Ecosystems. Report ORNL-5862. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 164pp.

Friedlingstein, P., J. L. Dufresne, P. M. Cox, and P. Rayner, 2003, How positive is the feedback between climate change and the carbon cycle?, Tellus, Ser. B, 55(2), 692–700.

Fung, I., S.C. Doney, K. Lindsay, and J. John, Evolution of carbon sinks in a changing climate, 2005: *Proc. Nat. Acad. Sci. (USA),* **102**, 11201-11206, doi:10.1073/pnas.0504949102.

Intergovernmental Panel on Climate Change, 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, edited by J. T. Houghton et al., 881 pp., Cambridge Univ. Press, New York.

Marland, G., A Brenkert, and J. Olivier, 1999. CO_2 from fossil fuel burning: a comparison of ORNL and EDGAR estimates of national emissions. Environmental Science and Policy 2: 265-273.

National Academy Press, From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death, 2000. *Commission on Geosciences, Environment and Resources* (CGER)..

National Research Council (NRC), 2002, Chemical Reference Materials: Setting the Standards for Ocean Science, Washington, D.C., National Academy Press, 130 pp.

Randerson, J. T., P. S. Kasibhatla, E. S. Kasischke, E. J. Hyer, L. Giglio, G. J. Collatz, and G. R. van der Werf, 2005. Global Fire Emissions Database (GFED), Version 1. Data set. Available on-line [http://daac.ornl.gov/] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A.

Raupach, M.R., Rayner, P.J., Barrett, D.J., DeFries, R.S., Heimann, M., Ojima, D.S., Quegan, S. and Schmullius, C.C., 2005. Model-data synthesis in terrestrial carbon observation: methods, data requirements and data uncertainty specifications. Global Change Biology 11, 378-397.

Rayner, P. J. and D. M. O'Brien, 2001. The utility of remotely sensed CO_2 concentration data in surface inversions. Geophys. Res. Lett., 28, 175-178.

World Resources Institute - PAGE, 2000 (http://earthtrends.wri.org/text/forests-grasslands-drylands/map-225.html).

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Appendix 2 Acronyms

AGAGE	Advanced Global Atmospheric Gases Experiment
AIRS	Atmospheric Infrared Sounder
ALSO	Advanced Land Observing Satellite
ATRS	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometry
BGC	Biogeochemistry
CDIAC	Carbon Dioxide Information Analysis Center
CDOM	Colored components of dissolved organic matter
CEOS	Committee on Earth Observation Satellites
CrIS	Cross-track Infrared Sounds
CLIVAR	Climate Variability and Predictability
CMDL	Climate Monitoring and Diagnostics Laboratory
CNES	Centre National d'Etudes Spatiales
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CW	Continuous Wave
DIAL	Differential Absorption LIDAR
ECMWF	European Centre for Medium-range Weather Forecasting
ENSO	El Niño Southern Oscillation
ESA	European Space Agency
ESRIN	European Space Research Institute
ESSP	Earth System Science Partnership
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAO	Food and Agriculture Organisation
fAPAR	fraction of Absorbed Photosynthetically Active Radiation
GAW	Global Atmosphere Watch
GCOS	Global Climate Observing System
GEMS	Global Environment Monitoring System
GEO	Group on Earth Observations
GEOSEC	Geochemical Sections in the Ocean
GEOSS	Global Earth Observation System of Systems
GCP	Global Carbon Project
GHG	Greenhouse Gas
GOES	Geostationary Operational Environmental Satellite Program
GOFC-GOLD	Global Observation of Forest and Land Cover Dynamics
GOOS	Global Ocean Observing System
GOSAT	Greenhouse gases Observing Satellite
GRDC	Global Runoff Data Centre
GSDT	Global Soil Data Task
GTOS	Global Terrestrial Observing System
HIRS	High Resolution Infrared Radiation Sounder
IASI	Infrared Atmospheric Sound Interferometer
ICSU	International Council for Science
IEA	International Energy Agency
IGACO	Integrated Global Atmospheric Chemistry Observations
IGBP	International Geosphere-Biosphere Programme
IGCO	Integrated Global Carbon Observations
IGOS	Integrated Global Observing Strategy

IGOS-P	Integrated Global Observing Strategy Partners
IHDP	International Human Dimensions Programme
IJPS	Initial Joint Polar Systems
IMBER	Integrated Marine Biogeochemistry and Ecosystem Research Project
IOC	Intergovernmental Oceanographic Commission
IOCCG	International Ocean Colour Coordinating Group
IOCCP	International Ocean Carbon Coordination Project
IP	Implementation Plan
IPCC	Intergovernmental Panel on Climate Change
IPCA	Integrated Path Differential Absorption
ISRIC	International Soil and Reference Information Centre
JAL	Japanese Airlines
JAXA	Japanese Aerospace Exploration Agency
JGOFS	Joint Global Ocean Flux Study
JRC	Joint Research Centre
LAC	Local Area Coverage
LAI	Lead Area Index
LAS	Laser Absorption Spectroscopy
LCCS	Land Cover Classification System
LIDAR	Light Detection and Ranging
LOICZ	Land-Ocean Interactions in the Coastal Zone
LSCE	Laboratoire des Sciences du Climat et de l'Environnment
LWIR	Longwave infrared
MERIS	Medium Resolution Imaging Spectrometer Instrument
MODIS	Moderate Resolution Imaging Spectroradiometer
MOE	Ministry of the Environment (Japan)
MOPITT	Measurements Of Pollution In The Troposphere
MOU	Memorandum of Understanding
MPI	Max Plank Institute
MSG	Meteosat Second Generation Satellite
NACP	North American Carbon Plan
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NCEP	National Centers for Environmental Prediction
NDSI	Normalized Difference Snow Index
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NIES	National Institute for Environmental Studies
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
NWP	Numerical Weather Prediction
OCCC	Ocean Carbon and Climate Change
OceanSITES	Ocean Sustained Interdisciplinary Timeseries Environment Observation system
OCMIP	Ocean Model Intercomparison Project
OCO	Orbiting Carbon Observatory
OOPC	Ocean Observations Panel for Climate
ORNL	Oak Ridge National Laboratory
PALSAR	Phased Array type L-band Synthetic Aperture Radar

PCMDI	Program fro Climate Model Diagnosis and Intercomparison
RIVM	National Institute for Public Health and the Environment (Netherlands)
SAR	Synthetic Aperture Radar
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Chartography
SCOR	Scientific Committee on Ocean Research
SIBERIA-I	SAR Imaging for Boreal Ecology and Radar Interferometery Applications
SOLAS	Surface Ocean Lower Atmospheric Study
SOTER	Soil and Terrain Database
SPOT	Satellite Probatoire d'Observation de la Terre
SWIR	Shortwave Infrared
TCO	Terrestrial Carbon Observations
TES	Tropospheric Emission Spectrometer
TIROS	Television Infrared Observation Satellite
TOVS	TIROS Operational Vertical Sounder
TRMM	Tropical Rainfall Measuring Mission
TTO	Transient Tracers in the Ocean
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNFCCC	United Nations Framework Convention on Climate Change
UNSO	United Nations Statistics Office
USDA	United Sates Department of Agriculture
VCL	Vegetation Canopy Lidar
VOS	Volunteer Observing Ships
WCRP	World Climate Research Programme
WDCGG	World Data Center for Greenhouse Gases
WGCV	Working Group on Calibration and Validation (CEOS)
WISE	World Inventory of Soil Emission Potential
WMO	World Meteorological Organisation
WOCE	World Ocean Circulation Experiment

Appendix 3 Summary of action items

Table 7 Short term action items

Action Item	Summary	Responsible parties
Action S 1	Identify data users and their needs, and the products they are expected to produce	IGCO partners
Action S 2	Improved coordination among existing international programmes and components, particularly GCP, TCOS, IOC and IGCO	IGCO partners
Action S 3	Involvement of operational satellite agencies such as NOAA, EUMETSAT	IGCO partners, space agencies
Action S 5	Improved links between the carbon cycle research community and traditional weather forecasting centres	IGCO partners and weather prediction centres, i.e. ECMWF, NCEP
Action S 6	Establish an IGCO office to oversee the implementation of the carbon plan	IGCO partners, GEO
Action S 7	Establish an IGCO web page and email lists	IGCO office
Action S 9	Continued contribution to the writing of the GEOSS IP	IGCO and partners
Action S 10	Assisting the GEOSS with the execution of their IP	IGCO and partners
Action AI 1	Ensure the long-term continuity of the already established atmospheric CO_2 monitoring stations	GAW/WMO, national CO_2 networks and national funding agencies
Action AI 2	Facilitate communication between the in situ and remote sensing communities	IGCO, CEOS, GAW and other IGOS partners
Action AI 3	Identify key gaps in monitoring network	GAW in collaboration with modelling groups
Action AI 6	Continue to submit data to the World Data Center for Greenhouse Gases (WDCGG), improve the accessibility to the data by the data users and promote the use of the dataset by the global community	GAW and national networks, the WDCGG and the global research community
Action AI 8	Continue and increase the CO_2 isotope records at the monitoring stations, calibrate networks and archive the data.	GAW and national networks, the WDCGG and the global research community
Action AI 13	Continue to review and remedy shortcomings in the global network for non- CO_2 greenhouse gases	Action AI 14
Action AI 14	Ensure multi-species approach such that flasks are analysed for many gases	GAW and networks
Action AI 15	Ensure in situ measurements of reactive species such as CO and ^{222}Rn are carried out at observing sites	GAW for CO: GAW and IAEA for ^{222}Rn
Action AI 16	Coordinate efforts with the GCOS to ensure appropriate data sets of variables necessary for tracer transport and process based studies are maintained	IGCO partners, GCOS, operational forecasting centres
Action AI 17	Coordinate efforts with the GCOS to ensure appropriate data sets of variables necessary for remote sensing tracer concentrations retrievals are maintained	IGCO, GCOS and operational forecasting centres
Action AR 1	Coordinate with in situ networks of atmospheric CO2 to provide appropriate calibration and validation data sets	IGCO, CEOS, GAW, NIES
Action AR 2	Establish and validate internationally accepted algorithm(s) for operational CO_2 retrieval and establish an operational processing capability.	Research and NWP Community
Action AR 3	Develop an analysis capability to interpret the mid-troposphere measurements in terms of sources, sinks, atmospheric transport and other atmospheric attributes.	NWP Community (ECMWF, NASA/NOAA)
Action AR 5	Expand efforts to retrieve CO_2 distributions from existing satellites (e.g. AIRS, SCIAMACHY, IASI and TES	Space agencies
Action AR 12	Establish a strategic plan for a global CO_2 satellite observation system combining existing OCO mission and future GOSAT mission and European projects	Space agencies/GOSAT:NIES,JAXA,MOE
Action AR 14	Continued retrieval and analysis of column CH_4 from current sensors	Space agencies
Action AR 15	Strategic plan to coordinate retrievals of CH_4 from future missions such as GOSAT and CrIS	NIES (GOSAT), CEOS and space agencies
Action AR 16	Strategic plan to ensure the continuity of CH_4 column measurements.	Space agencies

Action AR 17	Studies to explore the potential of new technology for application of CH_4 retrievals	Space agency instrument experts
Action AR 18	Develop strategic plan to ensure the continuity of CO retrievals	Space agencies
Action OI 1	Develop strategy for the development of a coordinated system of observations of surface pCO_2.	IOCCP
Action OI 2	Feasibility study to estimate the value of high precision atmospheric CO_2 measurements on board underway ships	IOCCP and atmospheric modelling community.
Action OI 4	Develop strategy for a core network of lines and core and ancillary variables..	National and international programs in cooperation with CLIVAR, IOCCP, and OOPC.
Action OI 5	Develop and promote the use of sensors of O2, nutrients and carbon species in automated ARGO floats	National and international programs in cooperation with CLIVAR, IOCCP, and OOPC.
Action OI 6	Define standard ocean reference materials.	Ocean research community and reference material providers
Action OI 7	Coordination of developing OceanSITES network with process study needs.	National, regional, and international research programs with international coordination aid provided by IOCCP and IOCCG.
Action OI 9	Meetings between CLIVAR/ARGO/Ocean Carbon Community	IOCCP
Action OI 11	Develop compilation of coastal carbon activities and plans; integrate activities with open-ocean network.	LOICZ and IMBER, with input from national and regional research programs, with international coordination aid provided by IOCCP.
Action OI 13	Implement targeted process studies to elucidate relationships between directly measured flux, physical forcing, and near surface turbulence.	SOLAS, CLIVAR, national and regional research programs.
Action OI 14	Set up air-sea gas flux time series site (eddy-correlation) on a fixed platform; the long time-series site could then become the focus of process studies	Ocean research community
Action OI 15	Coordinate auxiliary ocean observation strategy with GCOS	GCOS and IGCO.
Action TI 1	Facilitate discussion on network design to improve network representation and continuity.	Flux tower and ecosystem scientists, coordinated by FluxNet
Action TI 3	Improvement of data availability on the FluxNet website, and the strong adherence to the policy of citing the authors of the data sets by data users.	FluxNet, data providers and data users
Action TI 4	Develop measurements of calibrated atmospheric CO_2 on eddy covariance towers	Cooperative efforts by atmospheric and flux scientists, coordinated jointly by FluxNet and WMO/GAW
Action TI 7	Collect global data sets of past forest inventories	FAO and IGCO
Action TI 10	Characterize and catalogue the available soil carbon inventories, with descriptions of the variables, spatial coverage and methodologies employed	FAO, SOTER and IGCO
Action TI 11	Develop a methodology for combining the various soil carbon data set,	FAO, SOTER and IGCO
Action TI 14	Workshop to develop and promote standards and protocols, with the aim of developing a global database of dissolved and particulate carbon in rivers	WMO Hydrology and Water Resources Programme, collaborate with GEMS/Water & GRDC
Action TI 15	Organise workshop to define requirements for anthropogenic carbon storage data sets	FAO, IGCO
Action TR 1	Develop algorithms to map land cover using a and produce the these maps at repeated intervals	Space Agencies
Action TR 3	Develop algorithms to map the global fire distribution burned area	Space Agencies
Action TR 5	Calibration and cross-comparison of methods from ground-based meteorology, ground-based plant observations and space including coordination and data compilation	CEOS WGCV, Research Community, Space Agencies producing products.
Action TR 6	Rigorous sensitivity analysis of the space-based observations over a long temporal sequence including data from multiple satellites (AVHRR, VEGETATION, ATSR, MODIS).	Space agencies producing products, research community
Action F 1	Organise workshop to define requirements geo-referenced information for creating high resolution fossil fuel maps	Marland/Andres/IGCO
Action F 2	Production of fossil carbon emission maps with monthly temporal resolution and by state or country.	Marland/Andres

Action F 3	GEOSS to recommend fossil fuel emissions reporting to UNFCC by month and state/prefecture level	GEO
Action M 2	Hold an international workshop to form a new protocol for reporting and selecting atmospheric composition data for use in inversions.	TransCom & GCP, and atmospheric observation community (WMO/GAW, national networks)
Action M 4	Workshop between modellers and observationlists to discuss tracer properties	IGBP atmosphere
Action M 6	Produce a state-of-art model atmosphere with 4d fields of all relevant variables for comparison with observations, coupled to with a live access server	TransCom or C4MIP
Action M 9	A series of workshops with observationalists and modellers to define observational operators and error specifications for ocean measurements. This should also include remote sensing	IOCCP or GCP
Action M 10	Produce a model 4d archive of all relevant variables for comparison with observations. Couple this to a live access server	IGBP terrestrial
Action M 11	Hold a series of workshops with observationalists and modellers to define the observational operator and error specification for terrestrial data assimilation	GCP
Action D 1	Identify data management services and functions and priority data products, including socio-economic data and data for decision-support, required to address IGCO research questions and when those products and services are needed	IGCO
Action D 2	Identify national and international data centers that are currently producing data streams crucial to IGCO and develop memorandums of understanding (MOUs) to facilitate exchange of priority data products.	IGCO
Action D 3	Establish a Data Management Working Group comprised of data producers, data users, and data system developers to provide coordination and integration of data management, observation activities, and modeling	IGCO
Action D 4	Establish data policies that are based on full and open sharing of data products and that facilitate the generation, exchange, and archiving of carbon observations	IGCO, data centres, data producers and data users
Action D 5	Promote the adoption and use of standards and procedures for metadata	Data centre managers and data providers
Action D 6	Ensure timely and efficient flow of essential carbon observation data and metadata to IGCO, including as needed, real time data transfer for key data streams.	Data providers
Action D 7	Implement quality assurance procedures and document the quality of data so that users know the data's limitations	IGCO, data centres, data producers
Action D 8	Establish a process for preparing peer-reviewed data reports for documenting primary carbon observation data sets	IGCO
Action D 9	Facilitate assembly of disparate data sets into integrated data products for data assimilation and synthesis and assessment activities	Data providers, modelling communities
Action D 10	Organize series of workshops to define requirements and initiate collection of geo-referenced information required to meet the goals of IGCO	Modelling groups, data producers and data centres
Action D 11	Identify and select tools / services for data acquisition, visualization, and analysis, based on standards and open sources.	Data centre managers and carbon research community
Action D 12	Ensure that IGCO data are preserved through establishment of long-term IGCO data archives, or establish MOUs with existing long-term archives to preserve IGCO data.	Data centres

Table 8 Medium term action items

Action Item	Summary	Responsible parties
Action S 4	Convergence of current regional studies through joint workshops (i.e. CarboEurope and NACP, CarboOceans and OCCC) to a coordinated programme within the framework f the GCP	IGCO partners and regional programs
Action S 8	Rolling review of the IGCO implementation plan	IGCO office
Action AI 4	Increase atmospheric measurement networks, building on global and regional networks	All national CO_2 monitoring programs i.e. NOAA/CMDL, CSIRO, LSCE, MPI, NIES etc
Action AI 5	Put in place calibration standards and protocols to enable combining of networks	GAW Central Calibration Laboratory @NOAA/CMDL and GAW Greenhouse Gas Scientific Advisory Group
Action AI 7	Develop an Integrated Data Analysis Centre (WIDAC) for CO_2 and other greenhouse gases	WMO GAW and its WDC-GG in consultation with the Research Community supporting GLOBALVIEW
Action AI 9	Increase network of continuous sampling on tall towers	GAW/WMO and national CO_2 monitoring programs i.e. NOAA/CMDL, CSIRO, LSCE, MPI etc
Action AI 10	Increase number of regular aircraft profile networks	All national CO_2 monitoring programs i.e. NOAA/CMDL, CSIRO, LSCE, MPI, NIES etc
Action AI 11	Deployment of in situ CO_2 analysis equipment on passenger aircraft (Boeing 777 and 747)	NIES/JAL
Action AI 12	Development of inexpensive, easy to use and accurate sensors to measure CO_2 continuously in situ	Instrument research community
Action AR 4	Conduct re-analysis of the NOAA_TOVS HiRs data following pioneer work by Chedin et al.	NOAA
Action AR 6	The capabilities of GOSAT and OCO to be explored through international cooperation between the principal research groups supported by the responsible space agencies. GOSAT science team is supported by MOE.	JAXA/MOE/NIES, NASA/NOAA, principal research groups
Action AR 7	Development of assimilation and transport models to be able to ingest the volume of all satellite CO_2 measurements	Space agencies, atmospheric modelling community, operational weather centres
Action AR 8	Coordinated international assessment of the value of OCO and GOSAT in improving the skill for estimates of CO_2 sources and sinks	Research Community, NASA/NOAA, NIES, ESA
Action AR 13	Advancement of chemical tracer transport models and inversion techniques to handle reactive gases.	Modelling community
Action AR 19	Ensure that future planned missions will acquire CO retrievals with the appropriate accuracy	Space Agencies
Action AR 20	Develop multi tracer inversion techniques using CO_2, CH_4 and CO to utilise properties of CH_4 and CO for differentiating types of C sources and sink to aid the remote sensing community with planning missions	Modelling community
Action OI 3	Install high precision continuous atmospheric sensors aboard ships carrying out pCO2 campaigns	IOCCP and the GCOS-GOOS-WCRP Ocean Observations Panel for Climate.
Action OI 8	Time-series of atmospheric deposition of iron/dust, nutrients, etc.; either islands or moorings	Ocean research community
Action OI 10	Expanded pilot studies for BGC sensors on Argo floats and glider survey tracks	Research community
Action OI 12	Develop systematic monitoring capability for quantifying the river and groundwater inputs of biogeochemical species to the coastal ocean	Terrestrial and ocean research communities
Action OR 1	Implement plans for a sustained and continuous deployment of satellite sensors and research and analysis; integrate in situ needs into VOS carbon network and OceanSITES timeseries network.	Satellite operators through the IGOS-P (CEOS) and in consultation with the International Ocean-Colour Coordination Group.
Action TI 2	Expansion of the current FluxNet network to cover major biomes and different stages of disturbance/recovery	Flux tower and ecosystem scientists, FluxNet and GTOS

Action TI 5	Increase ancillary data for physical and ecological characterisation of fluxes collected at FluxNet sites.	FluxNet and terrestrial carbon science community
Action TI 6	Develop new instruments to measure fluxes of CO_2 and energy budgets.	Research community and FluxNet, instrumentation scientists and technicians, private industry.
Action TI 8	Define methodology so that biomass inventories in forest and other wooded lands can be updated with appropriate spatial and temporal resolution	FAO and IGCO
Action TI 12	Develop a common global methodology for the sampling of soil carbon	FAO, SOTER and IGCO
Action TI 16	Following the protocol in action TI 15, collect and interpret anthropogenic carbon stores and transport data	FAO, IGCO
Action TR 2	Conduct cross-comparison exercise on existing land cover products to confirm similarities and highlight discrepancies. Establish translation methodology and tables	CEOS, GTOS, GOFC-GOLD
Action TR 4	Inter-compare and generate syntheses from the current products of global distribution and temporal variability of leaf area index	Space Agencies
Action TR 7	Support global availability of ALOS biomass data, after validation	JAXA K & C group for methods and validation, but then extra support needed
Action M 1	Build an integrated experimental design tool so that observationalists and planners can analyze the impact and potential value of future measurements	Data assimilation and process modelling communities
Action M 3	Initiate project to investigate model error when inverting satellite concentration data. this could start with the high-quality methane datasets	TransCom via the GCP
Action M 7	Build an atmospheric data assimilation system for the inversion of all atmospheric composition data	National and International weather services + NASA. National agencies may also offer this as a large project
Action M 8	Generate a 4d field of all relevant variables for comparison with observations. Couple this with a live access server. Preferably use more than one model, Fields should include fluxes to atmosphere	either PCMDI or OCMIP
Action M 12	Hold a full conference on the remote sensing and modelling of fire	IGCO, GCP and fire research community
Action M 13	Hold a full conference on the remote sensing and modelling of land management	GCP, IGCO and land use and land use change research community
Action M 14	Form a high-quality near-surface climatology for driving terrestrial models.	IGCO and terrestrial modelling community

Table 9 Long term action items

Action Item	**Summary**	**Responsible parties**
Action AR 9	Funding for continued operation of OCO beyond its nominal lifetime	NASA
Action AR 10	Follow-on mission for OCO/GOSAT	Space Agencies
Action AR 11	Continued programme in sensor development focusing on DIAL and/or LAS technique	Space Agencies
Action TI 9	Expand forest inventories to improve global coverage	FAO and IGCO
Action TI 13	Expand the spatial and temporal coverage of soil carbon inventories	FAO, SOTER and IGCO
Action TR 8	If biomass mission selected for development by ESA or NASA, involvement in assessing the limits of the technology, including theoretical studies and the design and support of airborne campaigns, with associated well-documented ground data.	IGCO community
Action F 4	Monthly emissions at political unit level to be disaggregated in space and time according to separate empirical functions appropriate	Fossil emissions research community
Action M 5	Measure tracers in the atmosphere valuable for transport model validation	GAW