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"Towards a Global Carbon Observing System: Progresses and Challenges“

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ABSTRACTS OF PRESENTATIONS

SESSION: Tropical C-budget and hotspots

Keynote speech by O. Phillips *(Universiy of Leeds)*

What's happening to the planet's remaining intact tropical forests?

Tropical forests are global centres for biodiversity and carbon. While they are obviously threatened by agricultural expansion, logging, and hunting, how the changing atmosphere and climate should affect forests is much less clear, and the exact behavior of tropical forests has a significant impact on the global greenhouse gas burden. There is therefore a societal imperative for the scientific community to better measure, monitor, and predict tropical carbon function this century. In this talk, I will: (1) review some key, but conflicting, predictions of intact tropical forest carbon dynamics in the Anthropocene, and then (2) explore what the hard-won evidence from the ground indicates is actually happening. Finally, (3) I will explore why long-term botanical and ecological fieldwork is likely to remain an essential complement to space-borne and air-borne approaches to monitoring tropical forest carbon.

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Global Forest Observations Initiative

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The Global Forest Observations Initiative (GFOI) is an initiative of the inter-governmental Group on Earth Observations (GEO) that aims to:

1. foster the sustained availability of observations for national forest monitoring systems;
2. support governments that are establishing national systems by providing a platform for coordinating observations, providing assistance and guidance on utilizing observations, developing accepted methods and protocols, and promoting ongoing research and development; and
3. work with national governments that report into international forest assessments (such as the global Forest Resources Assessment (FRA) of the Food and Agriculture Organization, FAO) and the national greenhouse gas inventories reported to the UN Framework Convention on Climate Change (UNFCCC) using methods of the Intergovernmental Panel on Climate Change (IPCC).

GFOI is being led by: Australia, Norway, the USA, FAO, and the Committee on Earth Observation Satellites (CEOS). Experts from the UNFCCC, the greenhouse gas inventory programme of the IPCC, the World Bank Forest Carbon Partnership Facility, Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) and institutions in GEO member countries are represented on the Steering Committee. The UK supports participation of the Chair of the Advisory Group for the Methods and Guidance Documentation.

CEOS has committed resources from the world's space agencies to provide a systematic contribution of observations to meet the needs of countries participating in GFOI. This coordination is being led by the European Space Agency (ESA), the Norwegian Space Centre (NSC) and the United States Geological Survey (USGS) with coordination support provided by Australia. Other

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national space agencies engaged to date include those of Argentina (CONAE), Brazil (INPE), Canada (CSA), China (CRESDA, NRSCC), France (CNES), Germany (DLR), Japan (JAXA) and the USA (NASA).

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First net annual carbon balances of the Amazon basin from in-situ vertical profile sampling

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Tropical land is a very poorly constrained component of the carbon cycle, although it is potentially very important because it hosts a very large fast releasable carbon pool in forests and soils potentially amenable to feedbacks with climate. The tropics are a poorly constrained component because until recently there have been very few lower troposphere greenhouse gas measurements that are regionally representative. Amongst the tropical land regions the Amazon is by far the largest and also hosting the largest carbon pools (~200 PgC). Here we report the results from a recently established pan Amazon lower troposphere biweekly to monthly atmospheric sampling program for the years 2010 and 2011. 153 vertical aircraft profiles were performed over 4 sites distributed to represent entire Amazon Basin during this period. 2010 was anomalously dry while 2011 was a wet year thus providing an interesting contrast, particularly given the intensification of the hydrological cycle over the last few decades with an increase in severe droughts and extreme flooding events. Our data permit us not only to estimate net carbon fluxes but using carbon monoxide also carbon release via fires and thus the net carbon balance of the unburned land vegetation. We will discuss the annual and seasonal carbon balances for these two years derived from the atmospheric data using a simple but powerful back-trajectory based atmospheric transport inversion approach, will relate them to controls of land vegetation functioning and independent diagnostics like fire counts and precipitation and will finally put the results into a global perspective.

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Impacts of land use change on soil organic carbon in the humid tropics

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Land-use change in the humid tropics is recognized as one of the major contributors to anthropogenic greenhouse gas emissions. In contrast to aboveground carbon stocks, comparatively little is known on the magnitude of soil organic carbon (SOC) stock changes following land-use conversion in the tropics. In this study, we quantified SOC stock changes associated land use conversion in deeply weathered soils in three countries spanning the tropics (Indonesia, Cameroon and Peru). Using a space-for-time substitution sampling approach we quantified SOC stock changes by comparing undisturbed forests with adjacent converted land uses. In total 157 plots were established across the three countries, where soil samples were taken to a depth of three meters from a central soil pit and pooled composite samples. In each region we investigated the most predominant land use trajectories, including conversions of natural forest to: (a) tree plantations (cacao, oil palm and rubber), (b) cattle pastures and (c) shifting cultivation systems. Results from the three case studies found that conversion of natural forests to intensively managed land uses such as oil palm, rubber, cacao and pastures caused significant losses in SOC in all three countries. In the top 30cm, SOC stocks in cacao plantations decreased by 30±4%, oil palm plantations decreased by 25±4%, rubber decreased by 11±5% and pasture decreased by 21±3%. In contrast, the extensively managed shifting cultivation systems showed no significant changes in SOC. Despite the fact that the majority of SOC stock from the three meter profile is found below one meter depth (50 to 60 percent of total SOC stock), the only significant changes in SOC were measured in the top meter of soil, while the subsoil carbon stock remained relatively unchanged by the land-use conversion. Overall, SOC concentrations were controlled by texture, soil density, pH and precipitation.

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Carbon Losses due to Tropical Forest Fragmentation: A Forgotten Process in the Global Carbon Cycle

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Tropical forests play an important role in the global carbon cycle. Thereby, deforestation is not only responsible for direct carbon emissions but also alters the forest structure and extends the forest edge area in which trees suffer increased mortality due to altered microclimatic conditions. Our aim is to quantify the global amount of anthropogenically created forest edge area and the resulting additional CO_2-emissions by combining remote sensing data with previous empirical and modelling results.
We found that 1,106 million ha and thereby 10% of the global tropical forested area lies within the forest edge area and that 84% of this area is anthropogenically created. From this area, a total amount of 8 Gt C is emitted due to tropical forest fragmentation, which accounts for an annual loss of 0.25 Gt C equalling 17% of the annual carbon losses due to deforestation. Fragmentation in the tropics hence augments carbon loss from deforestation substantially and should be taken into account both when analysing the role of vegetation in the global carbon balance and when adopting new management strategies in tropical forests.
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SESSION: In situ observations

Keynote speech by H. P. Schmid *(Institute of Meteorology and Climate Research - Atmospheric Environmental Research)*

In-Situ Observations: How Local Flux Sites Help to Understand Global Carbon

In-situ observations of carbon also include the high-precision CO_2 concentration network on high towers or mountain tops. This network is invaluable for the diagnostic analysis of total atmospheric carbon, temporal developments and attribution to anthropogenic or natural sources and sinks on regional to global scales. However, this talk focuses on in-situ carbon *flux* measurements. Currently,

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a few hundred eddy-flux stations, sprinkled unevenly over the world, are well-known under the heading of Fluxnet – a global network of regional eddy-flux site networks. These sites arguably remain much to sparse to deserve to be called *data network*; the term “network” refers to exchange of knowledge between scientists, common protocols for observation system design, data handling and analysis. EC-flux sites are expensive to operate and the flux information they provide is strictly local, because the flux footprints of such sites extend to about a kilometer around the site, at best. The local carbon exchange of remote places like Harvard Forest, Heinich, Tumbarumba or Morgan-Monroe is hardly relevant on a global scale. So, why do we expend huge efforts and considerable resources of equipment and labor to build and maintain such sites? The first hint is that a flux is a process-quantity that directly links atmospheric carbon to sources and sinks at the surface. Moreover, in-situ observations are the only viable possibility to span almost seamlessly from seconds and minutes, at which biophysical drivers influence ecosystem functioning, to seasons and decades, where interannual climate variability and ecosystem dynamics express themselves. Long-term in-situ flux sites with integrated and comprehensive observation programs are thus important spawning grounds for knowledge of carbon dynamics in terms of ecosystem behavior, climate variability, nutrient availability and water relations, and test beds for bio-geo-chemical process models. This talk will present both successes and challenges of in-situ carbon flux measurements from selected sites.

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Precision and accuracy of in situ tower based carbon cycle concentration networks required for detection of the effects of extreme climate events on regional carbon cycling

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In situ observations are essential for precise observation and evaluation of regional scale terrestrial, oceanic, and anthropogenic carbon fluxes. In particular, continental tall tower and mountaintop observation networks have shown promise for quantification and evaluation of regional carbon fluxes from terrestrial or anthropogenic sources at scales of 100s - 1000s of km and validation of satellite-based carbon column observations. However, calibration needs are essential as are accurate characterization of source air masses over short distances requires sufficient precision and intercalibration. Most of the focus on regional flux estimation has been on quantification of total flux magnitudes. However, an open question remains on to what extent can these tower networks adequately capture the effect of extreme climate events and other stressors on carbon flux changes or disentangle subgrid fluxes within complex landscapes. This presentation discusses recent work in two US regions focused on these questions. The first details work on simulating and observing the effect of drought and insect disturbance on mountaintop carbon fluxes in the US Rocky Mountains. The second highlights work with the NOAA ESRL tall tower network to characterize atmospheric CO_2 concentration footprints with LaGrangian back trajectory dispersion modeling and using these to identify the influence of large lakes on atmospheric CO_2 at a site in the north-central US. These examples emphasize the importance of calibration, accuracy of transport modeling, and advancing methods to identify the relationship between magnitude of flux change and required accuracy and precision required for in situ tower CO_2 measurements.

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Urban greenhouse gas observations

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At both continental and global scales, surface-based and continuous GHG observations are increasing in metropolitan regions. The availability of these long-term records is limited and often an understanding of the basic structure of this GHG dome across a metropolitan region is lacking. We present long-term records of CO_2 levels from fixed platforms across a dense metropolitan region in Utah, USA, and observations of the fine-scale spatial structure of GHG in cities using a mobile observatory. We link these observations to the First estimates of fossil fuel emissions, and of models to assess our capacity to relate observations and estimated urban carbon dioxide emissions. At the core of our observations is a 5-site, 12-year continuous record of CO_2 concentrations (at 5-minute intervals) in contrasting urban settings within the Salt Lake Valley, Utah, USA (~1,350 m). Complementing these data is an 8-year, high-elevation record from a non-urban site (Snowbird, Utah, USA, 3351 m). Fossil fuel emissions are currently estimated based on VULCAN, a NASA product, while the more complex HESTIA product is being completed. Both the box model and STILT-WRF model do an effective job of capturing the hourly and seasonal dynamics of CO_2 concentrations. More recently, we have added high-resolution spatial observations of CO_2, CH_4, CO, O_3, NOx, and PM2.5 collected using a mobile observatory. The highly structure spatial patterns observed at the city-block and urban-form levels are relevant to process-based studies and remote sensing, but are not yet incorporated into models of urban fluxes.

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Air-water CO_2 exchange along the Land-Ocean Aquatic Continuum: a regionalized reassessment at global scale

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Continental shelf seas represent 30 10^6 km^2 and account for 8% of the world's oceanic surface. With a continental shelf CO_2 sink recently estimated at 0.25±0.25 Pg C yr^{-1} (Laruelle et al., 2010, Cai, 2011), they contribute significantly to the reported global oceanic uptake of atmospheric CO_2 of 2.0±0.7 Pg C yr^{-1} (Takahashi et al., 2009). However, these estimates are based on extrapolations from limited datasets of local flux measurements.
Here, we propose to evaluate the CO_2 air-sea exchange using the global database of marine pCO_2 measurements SOCAT v2.0, together with global wind speed and atmospheric forcings as well as selected observational atmospheric pCO_2 data compiled in GlobalVIEW. Although the data coverage is highly heterogeneous in the SOCAT database, it contains hundreds of thousands of coastal measurements and allows constraining robust regional carbon budgets for several regions of the world. Our analysis uses a global segmentation of the shelf in 45 large units and 145 sub-units. Within each of these units, the data density determines the spatial resolution used to calculate the air-sea CO_2 fluxes, from a 0.5 degrees resolution in the best surveyed areas (e.g. East coast of the US, Baltic Sea) to a whole unit resolution in the least surveyed. Our results provide new quantitative estimates for well-known CO_2 sources (California Current) and CO_2 sinks (North Sea, Arctic shelves) on the shelves and allow constructing a regionalized budget for the global air-sea CO_2 exchange of the coastal ocean.

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Variability of the global ocean carbon sink (1998-2011)

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We investigate the seasonal to interannual variability of the ocean carbon sink over the period 1998 through 2011 on the basis of a new observation-based product of the surface partial pressure of CO_2 (pCO_2) with a monthly resolution and a spatial resolution of 1°. This product was obtained using a 2-step neural network approach starting from the gridded observations contained in the SOCAT v2 database. The data were first clustered into biogeochemical provinces, and then the non-linear relationship between proxy driver variables and observations was established using a feed-forward network approach. From these pCO_2 estimates we compute the air-sea gas flux using a bulk gas exchange formulation and high resolution wind speeds. The evaluation with independent observations shows that the method is able to reconstruct the sea surface pCO_2 reasonable well in different ocean basins. We estimate a mean global CO_2 uptake flux of 1.45±0.62 PgC/yr over the analysis period, excluding the Arctic Ocean, close to the most recent estimate based on the Takahashi et al. (2009) climatology. Adding recently derived estimates of 0.45±0.18 PgC/yr to account for the outgassing of riverine derived carbon and 0.12±0.06 PgC/yr for the Arctic Ocean sink, our estimate implies a global mean anthropogenic CO_2 uptake of 2.11±0.65 PgC/yr from 1998-2011. During the 1998 to 2011 period, this global sink varies from a minimum of 0.87±0.63 PgC/yr to a maximum of 2.19±0.68 PgC/yr, largely in concert with the El Nino Southern Oscillation (ENSO) climate mode, which explains 28% of the global variability. This ENSO-related variability stems primarily from the Pacific Ocean, where the fluxes have the highest standard deviation with a value ±0.12 PgC/yr.

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SESSION: Observation from space

Keynote speech by R. A. Houghton *(Woods Hole Research Center)*

What satellites tell us about the global carbon budget

From a terrestrial perspective, there are two approaches for measuring changes in the distribution of carbon on land. One approach measures and models short-term (seconds to years) exchanges of CO_2 between the atmosphere and land, for example, the uptake of CO_2 by photosynthesis. This approach sometimes uses satellite measurements of "greenness", a surrogate for GPP, to infer changes in terrestrial carbon. The approach is complementary with CO_2 eddy flux measurements and with short-term atmospheric CO_2 variability, soon to be enhanced with the Orbiting Carbon Observatory. The processes involved in these short-term exchanges are largely metabolic.
A second approach measures and models longer-term (years to decades) changes in carbon storage, including structural as well as metabolic changes, for example, changes in carbon density (MgC/ha)

in response to disturbance and recovery of forests. MODIS and Landsat data have been used estimate land use and land-cover change (LULCC), for example, deforestation. More recently these same satellites, in combination with lidar and/or radar data from GLAS and ALOS-PALSAR instruments, have been used to estimate carbon densities (MgC/ha) of aboveground woody vegetation, thereby improving the accuracy of estimated sources and sinks of carbon because of the constraints imposed by co-location of LULCC and density data. When satellite density data are good enough (and the record long enough) to estimate change in density directly, two further advances will be possible. First, LULCC data will no longer be necessary except to attribute density changes to a particular activity, and, second, changes in carbon density not associated with LULCC may also be determined (i.e., the residual terrestrial sink). Unfortunately, there are other changes in terrestrial carbon not readily derived from space-based observations.

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A new era for measuring global forest properties: the ESA Biomass mission

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In May 2013, after a competitive selection procedure taking 8 years, ESA selected BIOMASS as its 7th Earth Explorer to be launched in 2020. This will radically change our knowledge about the global distribution of forest biomass stocks and their changes. The five-year mission will produce global twice-yearly maps of woody biomass and forest height at a spatial scale of 200 m, and will also measure deforestation at a scale of 50 m. These will be of accuracy comparable to current ground-based measurements of biomass made at scales of 1 ha in the tropics. The key technology is a 70-cm wavelength radar; this wavelength has never been used for Earth observation from space before, since it only became permissible under international regulations in 2004. At this wavelength the radar waves interact with the largest, most stable elements of a forest (trunks and large branches) where most of the biomass resides. Recovering the biomass nonetheless requires careful processing to remove environmental effects, such as changes in soil moisture, and topographic effects. It also requires effective links with ground measurement networks, both to parameterise the inversion algorithms for different biomes and to validate the inversions. The unique data from BIOMASS will allow us to: (a) test C models and their predictions about forest properties, such as mortality; (b) provide crucial information on disturbance regimes in different forests; (c) greatly improve the estimates of carbon changes during Land Use Change; and (d) greatly reduce the uncertainties in both C emissions from forest degradation and C uptake from forest growth. Crucially, it will also offer unbiased systematic estimates of forest changes that can be used as a reference for initiatives such as the UN's REDD programme.

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Global monitoring of terrestrial sun-induced chlorophyll fluorescence from space measurements

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A small fraction of the solar radiation absorbed by green leaves is emitted as sun-induced chlorophyll-a fluorescence (SIF) in the 650-780 nm spectral window. Extensive research at the laboratory and field scales during the last years has demonstrated that SIF is a good indicator of photosynthesis and gross primary production from the leaf to the canopy levels. Space observations of SIF can therefore provide a completely new view of vegetation carbon update rates on a global basis.
The first global maps of SIF were produced in 2011 thanks to the advent of high spectral resolution measurements by the Fourier Transform Spectrometer (FTS) on board the GOSAT platform. GOSAT-FTS SIF maps are typically presented as monthly averages gridded in 2º cell-boxes. The next breakthrough in the field of SIF monitoring was achieved in 2013 with the derivation of global maps from the GOME-2 instrument on board the MetOp-A platform. The SIF retrievals from GOME-2 allow to map SIF on 0.5º grid boxes with a better temporal resolution than GOSAT. The SIF global data set derived from GOME-2 comprises the 2007-2011 time period.
In this contribution we will provide an overview of existing global fluorescence data sets and their potential to improve our knowledge of the carbon cycle and land-atmosphere interactions. We will show examples of ongoing research exploiting fluorescence data to study carbon exchange and photosynthetic periods of different ecosystems such as the tropical and boreal forests and agricultural areas. In addition, we will discuss the promising near-future scenario for further space-based fluorescence data sets from the upcoming NASA JPL OCO-2 mission, the ESA/Copernicus Sentinel-4, Sentinel-5 and Sentinel-5 precursor and either FLEX or CarbonSat as the next ESA Earth Explorer mission.

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GOSAT and GOSAT-2 : Achievements and Future Plan

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GOSAT (Greenhouse Gases Observing Satellite) is a Japanese satellite dedicated to atmospheric carbon dioxide (CO_2) and methane (CH_4) measurement from space. It was launched in January 2009 and has been operated for more than 4 years in space. It is a joint mission by Ministry of the Environment (MOE), Japan Aerospace Exploration Agency (JAXA), and National Institute for Environmental Studies (NIES) with the collaboration of domestic and foreign scientists from more than 20 countries.
Column averaged CO_2 and CH_4 concentrations are calculated from data of Fourier Transform Spectrometer (FTS) onboard GOSAT by Japanese, US, and European groups independently. Their results are compared and validated using ground truth data such as TCCON, a network of ground-based Fourier transfer spectrometers. Global CO_2 fluxes are also being calculated from GOSAT CO_2 data by several groups. GOSAT CO_2 and CH_4 concentrations and CO_2 flux are publicly available as GOSAT Standard Products from http://data.gosat.nies.go.jp.
Based on the success of GOSAT, MOE, JAXA, and NIES have decided to launch the successor satellite, GOSAT-2, with enhanced instruments for greenhouse gases and aerosols measurement. In addition to CO_2 and CH_4, carbon monoxide will be measured by Fourier Transform Spectrometer 2 (FTS-2). Intelligent pointing, one of new capabilities of FTS-2, will increase cloud-free FTS data

more than GOSAT. More detailed aerosol characterization without sunglint will be available by Cloud and Aerosol Imager 2(CAI-2) with forward/backward viewing capability and more UV bands.
These improvements will lead to the more precise estimation of the global and regional CO_2 flux and the better understanding of carbon cycle by GOSAT-2. GOSAT-2's contributions to climate change mitigation policies, such as Joint Crediting Mechanism and Reducing Emissions from Deforestation and Forest Degradation +, are also expected.

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The GHG-CCI Project of ESA's Climate Change Initiative: Overview

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The GHG-CCI project (www.esa-ghg-cci.org) is one of several projects of ESA's Climate Change Initiative (CCI) implemented to generate Essential Climate Variables (ECV) using satellite data. The goal of the GHG-CCI project is to generate and deliver global satellite-derived atmospheric carbon dioxid (CO_2) and methane (CH_4) data products in line with GCOS and other user requirements. The GHG-CCI core products are near-surface sensitive column-averaged mixing ratios of CO_2 and CH_4, denoted XCO_2 (in ppm) and XCH_4 (in ppb). Two core sensors are used to generate these data products: SCIAMACHY on ENVISAT and TANSO onboard GOSAT. Initially, user requirements have been formulated for the main application, which is the usage of these atmospheric data products for inverse modeling of CO_2 and CH_4 regional-scale surface fluxes. To achieve this, several European retrieval algorithms have been further developed in competition. At the end of a so-called Round Robin phase, the best algorithms have been selected to generate the first version of the ECV GHG called "Climate Research Data Package" (CRDP). The initial validation and user assessment of the CRDP will be finished in October 2013. In this presentation an overview about this project will be given focusing on the CRDP.

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OCO-2: The Next Step in Space-Based CO_2 Measurements

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The NASA Orbiting Carbon Observatory-2 (OCO-2) is currently scheduled for launch in July 2014. It will fly in the 705-km Afternoon Constellation (A-Train), and carry a 3-channel, imaging, grating spectrometer that records co-bore-sighted, high resolution spectra within the 765 nm O_2 A-band, and within the CO_2 bands centered near 1610 and 2060 nm. These spectra will be analyzed with remote sensing retrieval algorithms to yield surface-weighted estimates of the column-averaged CO_2 dry air mole fraction, X_{CO2}. The instrument will record 24 soundings per second along a narrow swath, almost one million soundings per day over the illuminated hemisphere. The high signal to noise ratio and small (< 3 km^2) sounding footprint should yield some useful full-column X_{CO2} soundings even in partially cloudy or topographically rough regions. These capabilities, combined with the spacecraft's ability to observe the bright ocean glint spot over the entire sunlit hemisphere, are expected to yield far better coverage than earlier missions. However

the OCO-2 measurements will pose some unique challenges for calibration and validation. This presentation will summarize the OCO-2 development status and plans for early operations.

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CEOS Strategy for Carbon Observations from Space

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The *GEO Carbon Strategy* clearly explains the limitations of our current understanding of the global carbon cycle and explains why improved scientific understanding will be essential to underpinning societal responses to global climate change. The report unequivocally states that a key reason for our lack of understanding of the global carbon cycle is the dearth of global observations, and calls for an increased, improved and coordinated observing system for observing the carbon cycle as a prerequisite to gaining that understanding. The Committee on Earth Observation Satellites (CEOS) is well positioned to meet this challenge and provide needed coordination for the space-based observations called for in the *GEO Carbon Strategy*.
A new report entitled *CEOS Strategy for Carbon Observations from Space* has been drafted by the CEOS Carbon Task Force, and feedback on its content and recommendations is now sought from the GEO carbon community. This report is CEOS's response to the *GEO Carbon Strategy* and the ambitions expressed therein for the realization of an Integrated Global Carbon Observing system (IGCO). In this report, CEOS identifies what can be achieved by better coordination as well as those
improvements that require additional resources and/or mandates beyond the present capacity of space agencies.
An overview of the *Strategy for Carbon Observations from Space* will be presented, including the major actions to be taken in 1) assuring continuity of time-series observations, 2) obtaining new space-based observations optimized for quantifying carbon pools and fluxes, 3) producing high-quality data and useful data products, 4) ensuring the availability and accessibility of data and data products, and 5) improving institutional and infrastructural support of carbon observations. The report will describe how CEOS member agencies will implement their carbon observation programs in ways that maximize the scope, coverage, accessibility and utility of carbon observations from space.

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SESSION: Global methane cycle

Keynote speech by E.G. Nisbet *(Dept. of Earth Sciences - Royal Holloway, University of London)*

The Changing Global Methane Cycle

Methane is arguably the most interesting of the greenhouse gases. Its sources and sinks can fluctuate significantly from year to year and region to region; its present global atmospheric burden is proportionately much further from pre-industrial mixing ratios than CO_2; yet its lifetime is roughly a decade, so there is hope that the methane burden can be effectively reduced in a relatively short period, within the span of many governments. Sources include wetlands of various sorts, from swamps to ricefields, the fossil fuel industry, ruminant eructation (breath), biomass burning, landfills and human and animal waste.

Pre-industrial CH_4 mixing ratios were very roughly 750 ppb. Now were over 1800 ppb. In the 1980s and early 1990s, methane mixing ratios rose annually by 10-15 ppb. Then, concurrently with the collapse of the Soviet Union, growth rates fell near zero and the global North/South balance tilted sharply. This lasted until about 2007, when growth picked up again, >5 ppb per year. Within this pattern are major regional variations. In 2003 and 2010, there was sharp growth in the northern mid-latitudes; in 2007 in the Arctic. From 2008 until about 2012 there was been sustained multi-year growth in the southern tropics.

Deciphering these changes in the context of the global budget of methane sources and sinks is a major challenge. Observation is fairly limited, especially as measurements must be rigorously intercompared in order to be useful, though trajectory analysis using particle dispersion models can give powerful insight into sources. Data are mainly provided by the invaluable US NOAA flask network in parallel with other national programs and the Global Atmosphere Watch.

Available data suggest that much of the recent southern hemisphere increase is from wetlands. Isotopic data, that can discriminate powerfully between source types and track changing source strengths, are very few. For example, isotopes suggest that Arctic wetlands dominate summer methane inputs and that hydrates are not currently a significant source, but that wetlands. The main atmospheric sink, OH, is poorly known, and controls on soil methanotrophy are also not well understood. Global and regional modelling, coupled with accurate boundary layer measurements can give strong insights into sources.

Methane is important, and has been important through the planet's history. In the past, there were episodes when the methane burden changed very rapidly. For example, this took only a few decades at the final end of the last glacial period. Longer ago, in the Paleocene-Eocene Thermal Maximum about 55 million years ago, a very sharp increase in methane may have driven intense sudden warming. Much much longer ago, the Archean atmosphere was probably kept warm by methane, under a fainter younger Sun.

Reduction of anthropogenic emissions, especially from gas extraction and reticulation, may be facilitated by a measurement revolution: we now have robust and precise optical instruments to locate and quantify leaks. Similarly, there is some evidence that pressure to cut tropical biomass burning is effective. This cuts emissions. Reducing atmospheric methane offers a potent short-term way to ameliorate the global warming we have initiated.

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Constraining methane emissions in North America by high-resolution inversion of satellite data: from SCIAMACHY to GOSAT and beyond

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Satellite observations of atmospheric methane provide dense coverage for constraining methane emissions with high spatial resolution. Combining these data with aircraft and ground-based data in an inverse analysis system offers a powerful resource to quantify, understand, and monitor methane emissions in North America to serve policy needs. We present an adjoint inversion of methane emissions in North America with ~50 km resolution for summer 2004 using SCIAMACHY satellite data, taking advantage of methane observations from the NASA INTEX-A aircraft campaign to validate the satellite data and test the inversion. Our results indicate that US national emission inventories underestimate the livestock source but not the natural gas source. A more focused inversion of aircraft observations over California during the CalNex campaign (May-June 2010) confirms this result, and shows robustness across adjoint inversion approaches (Lagrangian and Eulerian) and observing platforms (aircraft and satellite). Satellite methane observations are presently available from GOSAT, which are of high quality but sparser than SCIAMACHY. We present a new approach to quantify the information content of the GOSAT data for constraining methane emissions in North America, and apply it to an inverse analysis that provides not only an optimal estimate but also a full error characterization. Results are presented for the duration of the GOSAT record (2009-present) with particular focus on the rapidly changing source associated with oil/gas recovery activities in the western US. Finally, we show results from an observation system simulation experiment (OSSE) to demonstrate the value of future methane observations from TROPOMI (2015 launch) and potentially from the geostationary constellation (2018-2019 launch). We discuss how our work can provide an effective tool for monitoring methane emissions for societal benefit as part of the NASA Carbon Monitoring System (CMS) and GEOCARBON.

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Monitoring Carbon Budgets in the Arctic: The Value of Long-Term Monitoring and Assimilation Techniques

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Vast stores of organic carbon are frozen in Arctic soils; as much as 1,700 billion tonnes of carbon, several times the amount emitted by fossil fuel use to date. If mobilized to the atmosphere, this carbon would have significant impacts on global climate, especially if emitted as CH_4. Model studies project that by the middle of the 21st Century the Arctic will be a net source of carbon to the atmosphere.

NOAA ESRL and other agencies have collected observations of greenhouse gases for several decades. Analysis of this data does not currently support increased Arctic emissions. However, it is difficult to detect changes in Arctic emissions because of transport from lower latitudes and high inter-annual variability. Arctic surface emissions are also especially difficult to detect from space, and current satellite platforms do not constrain greenhouse gas budgets in the lower Arctic troposphere. Modeling/assimilation systems, such as NOAA's CarbonTracker-CH_4 help to untangle the Arctic budget and trends of greenhouse gases. CarbonTracker-CH_4 has shown success in

simulating the inter-annual variability of Arctic fluxes, and is able to distinguish Siberian fluxes from Boreal North American fluxes. In addition, regional models can help us to understand whether process models are able to capture the spatiotemporal variability, thereby increasing confidence in predictions of future carbon cycle climate feedbacks.
We address the plausibility of monitoring the Arctic greenhouse gas emission trends. How large would Arctic emission trends have to be before they could be identified in network observations? What spatial information could be recovered? How would the spatial density of observations affect our ability to perceive and attribute trends in Arctic emissions? Long-term surface observations of greenhouse gases are crucial to monitoring the fate the vast and currently frozen Arctic soil carbon reservoir.

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Variation of global methane (CH_4) emission and concentration during the past century

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Methane (CH_4) is produced both naturally and anthropogenically on the Earth's surface, and second only to carbon dioxide (CO_2) as an agent of present/future global warming caused by human activities. Methane is chemically active, contributing to formation of tropospheric ozone and stratospheric water vapor, which further increases its importance to the Earth's radiative balance.
Atmospheric CH_4 concentration has increased from 900 ppb during the 1900s to ~1800 ppb during the 2000s. During the same period, the anthropogenic CH_4 emission has increased from 92 Tg/yr to about 321 Tg/yr (EDGAR-HYDE). However, much less is known about the evolution of CH_4 concentrations over the past centuries. Here we use combined emissions from bottom-up inventories (i.e., EDGAR-HYDE), terrestrial biogeochemical model (i.e., VISIT) simulated sources from wetland and rice paddies, and the CCSR/NIES/FRCGC Atmospheric General Circulation Model (AGCM)-based Chemistry Transport Model (ACTM) to simulate CH_4 concentrations for the period 1900 to 2010. The model simulations are compared with the constructed CH_4 concentrations time series from polar ice core data from Arctic and Antarctic, and direct measurements since 1980s at multiple sites around the globe.
Our results suggest that the EDGAR-HYDE underestimated the rate of CH_4 emission increase during 1940-1980, and the global total emissions are overestimated for the 1980s. Results on the variation of CH_4 emission and concentration during the past century are being analyzed using isotopic record of CH_4 to understand the strength and variability of different source types.

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A synthesis of the global sources and sinks of methane over the past 3 decades, and implications for future monitoring

"Towards a Global Carbon Observing System: Progresses and Challenges"
1-2 October 2013 – Geneva
WMO building

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The atmospheric growth rate of methane has shown significant fluctuations over the past three decades that are only partially understood. In the framework of GCP-CH_4 and GeoCarbon efforts have been made to combine the available information from emission inventories, process models, atmospheric measurements and inverse modeling to reconstruct how the sources and sinks of methane have changed in this period. Scenarios have been formulated which explain the observed growth. The reduction in
growth rate during the 1990s has most likely been caused by a stabilization of the fossil fuel emissions, combined with stable to increasing emissions from agriculture. The recent transition from stable to increasing methane concentrations has larger uncertainties, despite the improved availability of measurements in this period. The available estimates from inverse modeling point to important roles of natural wetlands and growing Asian economies. The inability to distinguish between those influences points to a limited longitudinal resolution of the inversions in the Tropics. Satellites measurements from the SCIAMACHY and GOSAT instruments have significantly improved the data coverage over tropical continents. However, it is only in recent years that the retrieval quality is reaching the required accuracy. This presentation provides on overview of the available estimates and discusses developments and opportunities for improved monitoring of methane in the future.

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SESSION: Model data fusion at global and regional scale

Keynote speech by J.B. Miller *(NOAA – National Oceanic & Atmospheric Administration, Earth Systems Research Laboratory)*

Progress in global and regional inverse modeling using mixing and isotopic ratio constraints
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For several decades, atmospheric CO_2 concentration measurements have been incorporated into inverse models to determine surface sources and sinks of CO_2. As the global network of measurement sites has expanded from the remote marine boundary layer to the interior of continents, fluxes are now being estimated not only at continental scales, but also regional scales (~105 - 106 km^2). Here, we will present examples of state of the art global- and regional- scale CO_2 inversions: CarbonTracker and a regional North American inversion. We will discuss the degree to which we can trust these results, and what steps might be taken to improve their quality.
Even if we could perfectly trust inversely estimated CO_2 fluxes, their information content is mainly limited to a time-space accounting of net CO_2 fluxes. Top-down (i.e. inverse) approaches to determine fluxes generally trade mechanistic information of flux behavior for inclusiveness of all flux process. Here, we will describe the addition of 13C:12C ratios to the CO_2 inverse problem in

an attempt to derive more mechanistic information on biospheric fluxes. The motivation for using atmospheric 13C data over the past 20 years has been as a tracer that would help partition global surface carbon fluxes into terrestrial and oceanic components. While this is still useful, exploiting the sensitivity of atmospheric 13C to stomatal conductance and C3:C4 photosynthesis variations, via photosynthetic isotope discrimination (Δ), may be a more important application. Because we have enough CO_2 data (and information on ocean fluxes) to constrain land/ocean uptake reasonably well, 13C can then constrain these important terrestrial biosphere parameters. We will present two preliminary examples (again from CarbonTracker and a regional North American inversion) in which carbon isotopic fractionation during photosynthesis (Δ) is optimized to best fit atmospheric data. Conductance and C3:C4 are independently important, but may also help explain patterns in net CO_2 fluxes.

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Coupled carbon and water balances of the Australian continent

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Information about the carbon cycle constrains the water cycle, and vice versa. This work uses multiple observation sets (eddy fluxes, litterfall, carbon stocks, streamflow) to constrain a land surface model and thence determine the coupled carbon and water balances of the Australian continent, a predominantly semi-arid region.
Over 1990-2011, results for carbon and water fluxes are as follows (to ±1 standard error): (1) over half (0.64±0.05) of the water loss through evapotranspiration (ET) occurs through soil evaporation; (2) mean Australian Net Primary Production (NPP) is 2200±400 TgC/y, making the NPP/precipitation ratio about the same for Australia as the global land average; (3) Net Ecosystem Production (NEP) has a very high interannual variability, larger than Australia's total territorial anthropogenic greenhouse gas emissions in 2011; (4) Net Biosphere Production (NBP, positive to land) offset territorial fossil fuel emissions by 32±36%, but territorial emissions are dwarfed by fossil fuel exports.
Further, to assess past and future responses of the carbon and water cycles to climate change and variability, we examine sensitivities of fluxes and stores to long-term changes in precipitation (P), temperature (T) and CO_2 concentration. We find: (5) ET has a large positive sensitivity to P, a positive sensitivity to T, and a negative sensitivity to CO_2, so likely changes in T and CO_2 over the next half century will have opposing effects on ET; (6) Runoff has a large sensitivity to P (positive) and significant sensitivities to T (negative) and CO_2 (positive); (7) Sensitivities of soil moisture to P, T and CO_2 have similar signs and spatial patterns to those for runoff, but are much smaller; (8) NEP is increased by rising CO_2 but simultaneously reduced by warming, by nearly as much in likely scenarios.

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Ocean-atmosphere CO_2 flux variability estimated from SOCAT pCO_2 observations

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A temporally and spatially resolved estimate of the global sea-air CO_2 flux is presented, obtained by fitting a data-driven diagnostic model of ocean mixed-layer biogeochemistry to surface-ocean CO_2 partial pressure data from the SOCAT data base.
The estimated seasonality is well-constrained from the data in most regions, and compares well to the widely used monthly climatology by Takahashi et al. (2009). Comparison to independent data tentatively supports the slightly higher seasonal variations in our estimates in some areas. The estimated interannual variations are largest in the Tropical Pacific, and tied to ENSO.
Extending the diagnostic model to link carbon variability to variability in nutrients and oxygen, it offers a way to implement multiple data constraints on sea-air CO_2 fluxes. As a prerequisite towards this goal, we demonstrate that the seasonality estimated from the pCO_2 data is consistent with an independent seasonal climatology of the surface-ocean PO4 concentrations. Likewise, tropical interannual signals estimated from SOCAT data are compatible with signals from atmospheric oxygen data.
Using the sea-air CO_2 flux estimates from oceanic data as prior in atmospheric inversions based on CO_2 mixing ratio observations also improves land flux estimates, remedying the inversion's difficulty in partitioning CO_2 fluxes from neighbouring land or ocean regions.
Sea-air CO_2 flux variability is also estimated from pCO_2 data by other groups using a range of complementary methods (interpolation, regression, neural networks, data assimilation). An international intercomparison project is underway.

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FLUXCOM – Towards an ensemble of improved global data-driven products of carbon fluxes

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Global spatial-temporal fields of FLUXNET derived carbon and energy fluxes are increasingly used for analysing variations of the global carbon and energy cycles, and to evaluate global land surface models. Here, we report on FLUXCOM - an ongoing activity that aims at providing an array of improved data-driven flux products. Two types of approaches participate in FLUXCOM: pure machine learning based regression methods, and semi-empirical models, both trained at FLUXNET sites. We use objective variable selection from a large number of potential predictor variables containing extensive remote sensing records such as reflectance, leaf area index, and land surface temperature, to identify optimal predictor sets for the machine learning methods. FLUXCOM will deliver two complementary sets of products with enhanced spatial and temporal resolution in comparison to existing products: a) a 5min spatially and 8 day temporally resolved product driven solely by remote sensing based variables, and b) a daily and vegetation type specific product at 0.5°.

Consistent cross-validation across all participating approaches facilitates objective inter-comparison of the methods and estimating the individual uncertainties.

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Progress and challenges towards comprehensive carbon cycle observations and analyses in the United States

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The U.S. Carbon Cycle Science Plan (2011) sets forth an ambitious agenda for studying the integrated carbon cycle including marine, terrestrial and anthropogenic systems. The plan calls for research to advance both fundamental science and operational applications. Progress is being made in a number of areas. I will highlight progress and challenges from across the span of U.S. research activities and agencies (carboncyclescience.gov) fostered largely by two major U.S. research programs, the North American Carbon Program (nacarbon.org), and Ocean Chemistry and Biogeochemistry Program (us-ocb.org). Recent advances include strong progress towards a sound, sustained terrestrial observing system (AmeriFlux, National Ecological Observatory Network - NEON), development of new marine observational systems and synthesized data sets, vigorous synthesis studies (including flux towers,continental, and coastal oceans), agreement of regional-scale, top-down vs. bottom-up flux estimates (Midcontinental Intensive), and dramatic improvement in quantification of terrestrial disturbance (Landsat, MODIS records). Ongoing and imminent activities include increased emphasis on tropical and high latitude ecosystems (CARVE, ABOVE, NGEE), urban systems (INFLUX and LA experiments - part of the International Megacities Project), expanded remote sensing capabilities (OCO-2, SMAP), and increased airborne GHG sampling (NOAA GMD, HIPPO). Challenges include integrating a vigorous research program on anthropogenic processes, including appropriate observational systems, the transition from experimental observations to long-term monitoring, creating support for remote sensing of terrestrial biomass, maintaining support for atmospheric observations, and understanding the challenges and opportunities posed by a rapidly changing energy system. I will present an overview of efforts to integrate these observational and experimental systems into coherent understanding of the carbon cycle that can be used both for basic scientific understanding and for applications to climate and carbon management.

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Global model-data-fusion estimates of ecosystem carbon fluxes.

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There are large uncertainties associated with terrestrial carbon flux estimates on a global scale due to uncertainties in critical processes and the current distribution of C stocks. In order to gain an improved understanding of ecosystem C states and fluxes, we implement a Monte Carlo based model-data-fusion approach: we assimilate MODIS LAI, plant-trait data, and the Harmonized World Soil Database (HWSD) into the Data Assimilation Linked Ecosystem Carbon (DALEC) Model. We implement our approach on an 8-day timestep at 1 x 1 degree resolution for the period 2001-2010. In addition to observational constraints, we implemented a novel Bayesian parameter inter-dependence network in order to impose ecological and dynamic constraints on DALEC parameter values, including initial conditions. There are no assumptions about plant functional types; instead parameters are selected for each grid cell that are most consistent with data. We determined the spatial and temporal dynamics of major terrestrial C fluxes and model parameter values on a global scale (GPP = 103 +/- 19 Pg C yr-1& NEE = -1 +/- 10 Pg C yr-1). In order to validate our approach, we also implemented our model-data-fusion setup at flux-tower scale, and compared DALEC NEE fluxes against in-situ NEE measurements (AMERIFLUX network) across multiple biomes and plant-functional types (NEE bias = +/- 1gC m-2 day-1). In anticipation of the BIOMASS mission, we examine the additional uncertainty reduction resulting from above-ground biomass data assimilation. We anticipate that our global model-data-fusion approach will be an important step towards bridging the gap between globally spanning remotely-sensed biometric data and the full ecosystem C cycle.

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Land and ocean C-fluxes estimated from several CCDAS within the GEOCARBON project

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The European FP7 project GEOCARBON aims to synthesize existing information on the recent terrestrial and ocean carbon budget, with one component specifically employing data assimilation techniques to optimally combine observations and process-based models. Within this component, a wide variety of models and methods (carried by 7 different groups) are used to best extract the information brought by limited observational constraints. The overall aim is to quantitatively assess the outcome of each data assimilation effort, to identify robust features across methods, and to synthesize multi-model results into a final estimate of land and ocean carbon exchanges and their uncertainty. After a brief review of the systems (going from flux inversion to model parameters optimization) and the optimization methods (either variational or ensemble techniques), we will present the current flux estimates from 4 global, 2 ocean-only and 1 land-only data assimilation systems. These systems are based on a variety of observations (atmospheric CO_2 concentrations, satellite vegetation indexes, eddy-covariance flux measurements, surface ocean pCO_2, chlorophyll,..). The analysis will distinguish long term mean carbon fluxes, from year to year flux variations and will focus on independent evaluation of the GEOCARBON results to better assess the associated uncertainties. In particular we will use the estimates from land and ocean biogeochemical models.

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SESSION: Carbon and policy

Policy needs for carbon monitoring systems

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The robustness and relevance of observational systems that seek to inform and support carbon policy-makers and other stakeholders will depend critically on well-posed requirements for those systems. Recent progress has been made in qualitatively exploring needs for policy-relevant carbon observations (e.g., *Cias* et *al 2013, West et al 2013, Duren & Miller 2012*). However, key questions remain unanswered including: "how good is good enough" in terms of accuracy, precision, completeness, temporal and spatial resolution of data products; what policy questions can inspire new science; what policy questions can science illuminate; and how the carbon cycle science community can anticipate user needs in the short and longer terms.
Requirements and observational concepts for monitoring systems that can establish policy-relevant assessments of the links between specific human entities and sectors and atmospheric concentrations of carbon (and vice-versa) will be different from systems that have traditionally been used to study the natural carbon cycle. The process of deriving policy relevant requirements itself warrants a new, iterative approach involving: 1) *policy analysis* to identify high-priority policy scenarios that might be addressed by robust carbon information; 2) *emission/stock analysis* to determine the characteristics of the carbon emissions and stocks that are the target of policies, leading to requirements on carbon data sets; 3) *biogeophysical analysis* to determine the characteristics of how carbon fluxes and stocks actually manifest as observable quantities, leading to requirements on the monitoring system; and 4) *capability and gap analysis* to evaluate existing and planned observational systems, models and data sets relevant to the resulting requirements on the monitoring system. We will describe this process, including a case study applied to monitoring urban carbon emissions and also describe plans for a new project to identify user requirements and evaluate carbon data for policy relevance.

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Building an Integrated, Global Greenhouse Gas Information System

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Changes in atmospheric composition have been driving climate change today and over the past century with a dominant role of long-lived greenhouse gases. Although there currently is no all-encompassing, global agreement to reduce greenhouse gas emissions, the actions at different levels to reduce carbon footprint were not able to limit the growth of atmospheric CO_2. To adjust accordingly, society needs robust measures to know how well they are doing in reducing greenhouse gas emissions and these measures must be on scales to support decisions where they are made.
Currently, emission reductions are monitored through inventories, but it has become clear that these require independent verification. To be useful for verification on policy-relevant scales, independent analyses are best derived with atmospheric inversions. Because carbon has large

reservoirs in the terrestrial and oceanic environment that exchange carbon with the atmosphere, the verification process must be able to separate human from natural influences. Doing this requires a Greenhouse Gas Information System that is global in scale, but also addresses sub-continental, policy-relevant regions.
We have begun to address this need through WMO by strengthening regional collaborations and building from the existing Global Atmosphere Watch (GAW) and World Weather Research Programmes (WWRP) to improve observation density and complexity, transport resolution, and information delivery. Efforts already underway include such programs as the North American Carbon Program (NACP) in the US, Canada, and Mexico, the Integrated Carbon Observation System (ICOS) in Europe, expansions of observation suites in developing countries such as China and Brazil, cross-cutting initiatives involving commercial aircraft, and even private organizations that can enhance observing system infrastructure and information delivery. By integrating these and other observations through analyses such as high-resolution CarbonTracker, one can deliver sub-continental scale information that is globally coherent.

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The Value of a Global Carbon Observing System

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We briefly summarize and categorize the 59 programs and policies for managing carbon and now in place in 42 countries and regions around the world. A global carbon observing system has a significant role because all of these programs require measurement and monitoring at a range of spatial and temporal scales. The programs include mandatory and voluntary caps, targets, taxes, fees, and tradable offsets for emissions and emissions reductions. The scope of the programs is broad, encompassing major economic sectors in forestry, manufacturing, electricity, and transportation. We give special emphasis to the role of observations in setting goals and monitoring progress, and to the need for measurement, reporting, and verification (MRV). We also summarize the policies, technologies, financing, and practices in place, and underscore the need for improved characterization of uncertainty to gain public trust. Special emphasis is also given to the role of Earth observations, international coordination, and GEOCarbon.

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The International Ocean Carbon Coordination Project (IOCCP)

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Ocean carbon research, observations, and modelling are conducted at national, regional, and global levels to quantify the global ocean uptake of atmospheric CO_2 and to understand controls of this process, the variability of uptake and vulnerability of carbon fluxes into the ocean. These activities require support by a sustained, international effort that provides a central communication forum and coordination services to facilitate the compatibility and comparability of results from individual efforts and development of the ocean carbon data products that can be integrated with the terrestrial, atmospheric and human dimensions components of the global carbon cycle. The International

Ocean Carbon Coordination Project (IOCCP) was created in 2005 by the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the Scientific Committee on Oceanic Research (SCOR) to provide an international, program-independent forum for global coordination of ocean carbon observations and integration with global carbon cycle science programs.

In this presentation I will update you on a highly diverse set of activities coordinated by the IOCCP to facilitate the development of globally acceptable strategies, methodologies, practices and standards, homogenizing efforts of the research community and scientific advisory groups as well as integrating ocean carbon programs and activities into globally integrated Earth system observing networks. Our main focus is on hydrographic survey cruises, surface ocean carbon observations, time-series observations, developing and implementing a Global Ocean Acidification Observing Network (GOA-ON), and implementing a biogeochemical element of the Framework for Ocean Observing and supporting development of biogeochemical sensors.

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USG SilvaCarbon Program in support of GEO GFOI Forest Carbon Monitoring Capacity Building

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SilvaCarbon is a flagship program of the United States government that aims to provide technical support to developing countries seeking fast, initial financing from participation in the United Nations' Reducing Emissions from Deforestation and Degradation (REDD) program. SilvaCarbon works in the Andean Amazonian region (Colombia, Ecuador and Peru), South East Asia region (Indonesia, Philippines, Thailand, Vietnam, Cambodia, Lao PDR and Nepal), and Africa region (Cameroon, Gabon, Democratic Republic of Congo, and Central Africa Republic). The goal of the program is to provide assistance in the implementation of Monitoring, Reporting and Verification Systems (MRV) for REDD+ by developing and delivering good practice guides, manuals, trainings, and tools; facilitating learning exchanges, regional forums, and networks to enhance sharing among countries; providing technical advice and assistance to governments, including Global Forest Observation Initiatives (GFOI) countries; and partnering with other donors and with International Organizations to multiply impact and reach.
SilvaCarbon is federal, multi-agency program of the United States. For example, the U.S Forest Service provides technical assistance in the development of forest inventories including field work, statistical support, and inventory design in cooperation with FAO in the countries. The U.S Geological Survey which facilitate, in cooperation with the Committee on Earth Observing Satellites (CEOS) and other partners in the GEO GFOI, the collection and dissemination of earth observation data related to forest and terrestrial carbon monitoring and management, as well as providing the capacity to manage and use remote sensing data. The U.S Environmental Protection Agency provides technical assistant on ways to improve greenhouse gas (GHG) monitoring and reporting for agriculture, forestry and land use sectors. This presentation provides an opportunity to show some the outcomes from the capacity building in these regions, and how a coordinated program can multiply the impact of international cooperation.

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GlobAllomeTree, an international platform for tree allometric equations

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GlobAllomeTree is an international platform for tree allometric equations. It is the first worldwide web platform designed to facilitate the access of the tree allometric equation and to facilitate the assessment of the tree biometric characteristics for commercial volume, bio-energy or carbon cycling. The webplatform presents a database containing tree allometric equations, a software called Fantallomatrik, to facilitate the comparison and selection of the equations, and documentation to facilitate the development of new tree allometric models, improve the evaluation of tree and forest resources and improve knowledge on tree allometric equations. In the Fantallometrik software, equations can be selected by country, ecological zones, input parameters, tree species, statistic parameters and outputs. The continuously updated database currently contains over 5000 tree allometric equations classified according to 73 fields. The software Fantallometrik can be also used to compare equations, insert new data and estimate the selected output variables using field inventory. The GlobAllomeTree products are freely available at the URL: http://globallometree.org for a range of users including foresters, project developers, scientist, student and government staff.

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POSTER PRESENTATIONS (alphabetical order)

Global Numerical Analysis and Prediction of CO_2 and CH_4 at ECMWF within the MACC-II project

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As part of the European Copernicus programme, MACC-II (Monitoring of Atmospheric Composition and Climate - Interim Implementation) is exploring and implementing innovative ways to contribute to the operational monitoring of the carbon cycle. Combining existing NWP infrastructure with specific carbon cycle models and observations , three different products with different spatial resolutions and delivery times are provided.
A high resolution (16km) global daily near-real-time forecast of atmospheric CO_2 concentrations using a combination of modelled and prescribed fluxes and the operational ECMWF analysis is

now routinely provided. The forecast is monitored using the near-real-time ICOS network observations, but no observations are currently assimilated. However, as soon as there are enough observations in the global observing system available in near-real time, this will be explored as well.
Observations from SCIAMACHY/GOSAT/IASI are being assimilated at 40km resolution with a 6 month delay to allow for the current latency of these observations. The expertise gained from this delayed system will be used for the near-real-time system to ensure optimal extraction of the information from these satellite observations.
The third data stream consists of simulations for the period 2003-2011 of CO_2/CH_4 at 80km resolution based on optimized fluxes constrained by in-situ observations and satellite retrievals. These simulations provide our current best estimate of atmospheric concentrations of CO_2/CH_4 and form the baseline for the other two systems.
All these products are available freely to users. Possible applications include providing boundary conditions for regional modelling and flux inversions; improving the modelling of radiative transfer, radiation and evapo-transpiration in NWP analysis and forecasts; evaluation of transport processes in NWP models; providing prior information for CO_2/CH_4 satellite retrievals; supporting the interpretation and quality control of observations and planning of field experiments. An evaluation of the analysis and forecast products will be shown using a variety of independent observations.

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Global datasets on land carbon stocks and changes related to land use, fire, harvest, forest age and biomass

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Several global datasets highly relevant to the carbon cycle and its dynamics were developed by elaborating, harmonizing and synthesizing existing datasets within the EU GEOCARBON project. In-situ networks, field inventories and remote sensing approaches were integrated to produce global information on land carbon stocks and key changes related to land use, fire, harvest, forest age and aboveground biomass. The approach consisted on evaluating and integrating existing global or large-area data, improving and filling gaps using regional/local studies where needed.
The first task synthesized global land cover/use dynamics from existing datasets in the era 1990-2010 with primarily focus on forests. Global, regional and national land change datasets were combined using a regionally-tuned procedure. Specific effort was also put on the comparative validation of land cover products using a series of reference datasets.
The second task analysed existing burned area and emission estimates to highlight regional strength and weaknesses of various approaches. Burned area products were compared with fire emissions estimates and deforestation area assessments, and specific attention was given to the role of small fires.
The third task produced global maps of harvest and forest age. Forest harvest was derived from statistical downscaling of several wood removal datasets while forest age distribution was derived from downscaling forest inventory data describing species-age-area statistics at country or sub-country levels. For the tropics, age-biomass curves were inverted to estimate forest age.

The fourth task derived global aboveground forest biomass using a regionally-based approach. For the boreal region, model-based estimates of growing stock volume and biomass were derived from multiple Envisat ASAR images. For the tropical region, regional datasets based on MODIS and Lidar data were integrated using a stratified weighted-average approach based on reference field data and high-quality local maps.

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Improving tropical forest biomass mapping using a fusion approach

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Several biomass datasets have been recently produced at different scales in the tropical region using a variety of approaches and input data. Large scale maps provide wall-to-wall biomass density values at moderate resolution for the tropical belt but their estimates may present large disagreement at local levels. In such cases, given the lack of reference data and difficulties to assess the maps accuracy, it is often unclear which product is more appropriate. In the context of the EU GEOCARBON project, the present research developed a fusion approach to optimally integrate the existing regional biomass products and higher quality local datasets into an improved pan-tropical forest biomass map at 1 km resolution.
The regional datasets were integrated using a bias-removal and weighted-average approach, performed independently per vegetation strata to account for different error patterns in the regional maps. The map weights were quantified using a calibration dataset, which consisted of a variety of high-quality biomass data including research field observations, forest inventory plots, regional estimates and high-resolution biomass maps. The reference data were screened and harmonized, developing specific procedures to upscale the field observations to the map resolution and to integrate datasets with different characteristics.
The statistical procedure applied for the fusion model assures that the error variance of the fused map is lower than that of the individual input maps or when a simple averaging is used, and more accurate biomass estimations are achieved if proper calibration data are available. A specific evaluation analysis based on reference data confirmed the improved accuracy of the fused map. This dataset was then integrated with the boreal component into the GEOCARBON global aboveground forest biomass product.

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Carbon emissions from forest fires: monitoring, modelling, and inventory development

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Forest fires play a crucial role within the natural ecosystems, with impacts on biosphere components and with reverberations on different scales, from local to global. For example, forest fires pose a significant risk of reversal of carbon stored in the biomass through vegetation combustion, soil degradation, organic matter consumption, and decrease of biodiversity. Wildfire is also a significant source of carbon, greenhouse gases, solid particulate matter, and pollutant emissions, all interfering significantly with atmospheric budgets and air quality at local, regional, and even global scale. Under global warming, climate driven increases of wildfire danger and severity might exacerbate the current situation.
Over the last decades, the demand for fire emission (FE) quantification increased with the amplified need of accounting for GHG emissions by governments and companies, providing key inputs to analysis and modelling of air quality and climate change issues. Several experiments and modelling studies were conducted to improve knowledge of the atmospheric impact of vegetation fires. A crucial point to support FE inventories and modelling has been recognized in up-to-date, accurate, and consistent FE estimates, normally affected by a number of errors and uncertainties depending on multiple and interdependent factors (fuel characteristics, burning efficiency, fire type, weather, and geographical location). Improvements were made possible through new advances in remote sensing, experimental measurements of emission factors, and the use of fuel consumption models.
From this context, this work aims firstly to present the contemporary state of the art on forest fire emission monitoring, modelling, and inventory development, then focalizing on the development of an integrated methodology to assess the estimation of greenhouse gas emissions through the coupling of fire behaviour, risk exposure model, and semi-physical fire emission models.

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A first in-situ data based annually and seasonally resolved Methane Budget for the Amazon basin

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Tropical land regions have until recently been poorly observed with large-scale integrating in-situ observations. Thus sometimes adventurous claims of very high methane emissions based on poorly verified methods have been publicized. Here we present the first proper atmospheric sampling of the lower troposphere over the Amazon basin to provide solid seasonal and annual CH_4 budgets with course spatial resolution. Our aircraft based vertical profile sites are located along the main airstream operating effectively like a conveyor belt for surface sources and sinks. The main air-stream enters the basin from the Atlantic in the latitude band from above the easternmost tip of South America, travels across the basin towards the Andes where it is deflected south and travels back to the Atlantic further south. We will present spatially and seasonally resolved methane flux estimated from our profile using a simple atmospheric back-trajectory approach. From the flux estimates we will calculate basin wide budgets with some differentiation of underlying processes based on carbon monoxide from fires. For the same purpose, and specifically the quantification of wetland emissions, we will also use simulation results of the atmospheric chemistry and transport

model TOMCAT. We will then put our estimates in a global context of our current knowledge of status and trend of the methane cycle.

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Towards disentangling natural and anthropogenic GHG fluxes from space

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Understanding and quantifying climate feedback and forcing mechanisms involving the two most important anthropogenic greenhouse gases, CO_2 and CH_4, requires to disentangle natural and anthropogenic greenhouse gas (GHG) fluxes globally, with regional to local spatial resolution. The objective of the CarbonSat mission is therefore to improve our knowledge on natural and anthropogenic sources and sinks of CO_2 and CH_4. The unique feature of the CarbonSat mission concept is its "GHG imaging capability", which is achieved via a combination of high spatial resolution (breakthrough: 4 km^2) and good spatial coverage (breakthrough: 240 km wide swath, continuous ground sampling). This capability enables global imaging of localized strong emission source areas such as cities, power plants, methane seeps, landfills and volcanos, and better disentangling of natural and anthropogenic GHG sources and sinks. The latter will be further supported by CarbonSat's ability to characterise natural CO_2 variability by measured vegetation chlorophyll fluorescence, a parameter strongly correlating with GPP. CarbonSat data therefore also contribute to the quantification of natural fluxes of CO_2 and CH_4 (biospheric CO_2, wetland CH_4 etc.). Source/sink information will be derived from the retrieved atmospheric column-averaged mole fractions of CO_2 and CH_4 via inverse modeling. CarbonSat aims to deliver global data sets of dry column mixing ratios of CO_2 and CH_4 with high precision and accuracy. Benefiting from its imaging capabilities, CarbonSat will provide at least one order of magnitude larger number of cloud free measurements and at least one order of magnitude better spatial coverage than GOSAT and OCO. CarbonSat was selected by ESA as a candidate for the Earth Explorer Opportunity mission (EE8). Recent results from the scientific studies and supporting campaigns documenting the expected data quality and potential application areas will be presented.

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The NASA Carbon Monitoring Flux Pilot Project as an Integrated Carbon Cycle Observational and Analysis System

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A key objective of the Geo Carbon Strategy is the development of an Integrated Global Carbon Observation and Analysis System (IGCOAS) capable of synthesizing observations across the entire carbon cycle to provide observationally constrained global and regional carbon budgets. The NASA Carbon Monitoring Study (CMS) Flux Pilot Project is a prototype IGCOAS that integrates NASA observational, modeling, and assimilation capabilities in order to attribute changes in globally distributed CO_2 concentrations to spatially resolved surface fluxes across the entire carbon cycle. To that end, CMS has initiated a coordinated effort between land surface, ocean, fossil fuel, and atmospheric scientists to provide global estimates of CO_2 constrained by satellite observations and informed by contemporaneous estimates of "bottomup" fluxes from land surface, ocean, and fossil fuel models. We will first show "top-down" flux estimates from the CMS Flux for 2010.We will then discuss how the CMS Flux can take advantage of the CEOS Strategy for Carbon Observations from Space and provide a NASA contribution to the Geo Carbon Strategy as part of a broader international effort.

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The potential of current and future CO_2 atmospheric measurement networks for the estimation of CO_2 natural fluxes

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A global and a European scale atmospheric inversion systems are used to assess the potential of existing and realistic future configurations of atmospheric networks for the estimate of CO_2 natural fluxes. This potential is quantified in term of uncertainties in the inverted fluxes, which, in the statistical inversion framework, is independent of the actual values of the measurements. Therefore, it can be estimated for "synthetic" (future) observing systems. The reliability of the estimates of uncertainties from the inversion systems is assessed based on results when using real data and comparisons to independent eddy covariance or atmospheric measurements. The potential of satellite missions is compared to that of ground based networks. In mid to high latitudes, the uncertainty reduction (compared to the uncertainty in the prior knowledge of the natural fluxes) from dense ground based networks is relatively constant in time through the year while that from satellite data strongly depends on the season (on the length of the day and on the cloud coverage). With both types of observations, a 40 to 70% uncertainty reduction can be expected for Europe at the monthly scale. However, results based on satellite measurements can bear large biases. The study details how the uncertainty reduction evolves as a function the spatial scales considered from the 0.5° to the continental resolutions. The sensitivity to the spatial resolution and error of the satellite measurements, to improvements of the atmospheric transport models or of the prior knowledge on the fluxes, and the potential of combining satellite and ground based networks are also investigated.

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Carbon Dynamics in the Sustainable Productivity and Environmental Rehabilitation on the Post Open Mining of Coal in Tropical Region

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Exploration C-coal mining in tropical region increased (1.336 million ha) and give impact on world environmental damage due to the emission of CO_2 and extensive of buried heavy metal. This research aims to improve land productivity and reestablish the ecosystem through the integration of appropriate rehabilitation technology by using cheap, eco-friendly, and sustainable development. The research in PT Berau Coal, East Borneo, Indonesia was carried out through management of organics materials, utilization of selected adaptive bioremediation and pioneer plant, reestablish forest land by fast growing species, integrated organic cycles, soil amendment, plant growth stimulation, legume cover crop, and bio-fertilizer. Opencast coal mining cause environmental problem including soil erosion, pollution of dust, noise and water, and negative impact on biodiversity. Site growth environment changing drasticaly due to open coal mining which result the unfavourable site condition for plant growing and the other live. Removing top soil and integrated land rehabilitation should managed carefully based on environmental management plan. Development of GAMA POT pooting system, GAMA INTEGRATED BIO-CYCLES FARMING SYSTEM, GAMA BIOFERTILIZER and GAMA BIOREMEDIATION, CARBON RE-SEQUESTRATION, SOIL AMELIORATION could be a good reference for establishment of land ecosystem rehabilitation of coal mining in tropical region which is very important for sustainable life and environment in the world.

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Validation of TCCON observations of CO_2/CH_4/CO at Sodankylä using AirCore

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As an essential network to validate satellite observations, TCCON observations of CO_2/CH_4/CO need to be tightly linked to ground-based observations, i.e. on the WMO reference scale. AirCore, a long tube descending from a high altitude with one end open and the other closed, has been demonstrated to be a reliable, cost-effective sampling system for high-altitude profile measurements of CO_2 and CH_4, and an ideal tool to validate TCCON observations. We will present AirCore profiles of CO_2/CH_4/CO over Sodankylä during the AirCore campaign in the first week of September 2013 near the TCCON site at Sodankylä (67.368N, 26.633E, 179 m.a.s.l). Different from previous studies, this effort is to validate total column measurements at relatively high latitude. These activities are becoming important as active satellite sensors, which are currently under development and planned for launch in the near future (e.g. Merlin and ASCENDS), will allow year around measurements at high latitudes. We would perform routine AirCore observations at this site so that we could not only correct any systematic seasonal biases of TCCON retrievals, but also improve model simulations of CO_2 and CH_4, e.g. from CarbonTracker at high latitude.

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The evolving space-based CO2 constellation: The CEOS Carbon Task Force Strategy

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One way to improve the spatial and temporal sampling of the ground-based greenhouse gas network is to collect precise, spatially-resolved, global measurements of the column-averaged CO_2 dry air mole fraction, XCO_2, from space. XCO2 can be retrieved from observations of reflected sunlight in near infrared CO_2 and O_2 bands. The ESA EnviSat SCIAMACHY instrument pioneered this approach and returned estimates of XCO_2 and XCH_4 over land from 2002 to 2012. The Japanese Greenhouse Gases Observing Satellite, GOSAT, has been returning XCO_2 and XCH_4 estimates over the sunlit hemisphere since April 2009. These data are now yielding new insights into the carbon cycle. The NASA Orbiting Carbon Observatory – 2 (OCO-2) is currently scheduled to launch in July 2014. OCO-2 will measure only CO_2, but is expected to provide improvements in coverage, resolution, and precision. The Chinese TanSat will follow about one year later, and the proposed NASA OCO-3 instrument will be deployed on the International Space Station in 2017. Other CO_2 satellites, including the CNES MicroCarb, European Space Agency CarbonSat, and Japanese GOSAT-2 missions are in the planning stages. These "passive" sensors will then be joined by active CH_4 and CO_2 sensors, including the French-German MERLIN CH_4 satellite, and the proposed NASA Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) mission. While each of these missions has unique measurement capabilities, much greater benefits could be realized if they can be coordinated as part of a global network of surface and space-based CO_2 sensors, whose data can be cross calibrated, cross-validated, and assimilated into source-sink inversion models. This would be the first step in the implementation of a CO_2 monitoring system with the spatial and temporal coverage and resolution of the current weather monitoring system.

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Carbon budget for a newly flooded subtropical hydroelectric reservoir: Nam Theun 2, Lao PDR

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Identification and quantification of sources and sinks of greenhouse gases (GHGs) have become an important environmental, political and public issue. Notably, tropical hydroelectric reservoir projects have been identified as a significant carbon source at the global scale. Assessing this source and the underlying carbon dynamics in such man-made impoundments is now an important challenge. In this context, we studied carbon dynamics in a subtropical Nam Theun 2 Reservoir (Lao PDR, impounded in 2008).
A total 29 sampling stations located in the pristine inflowing tributaries, reservoir and downstream have been monitored fortnightly from April 2009-to date for dissolved CO_2, CH_4, inorganic carbon, dissolved organic carbon and particulate organic carbon concentrations. In addition, direct in-situ CO_2 and CH_4 flux measurements were performed with different technique i.e. eddy covariance, floating chamber, thin boundary layer, static chamber and submerged funnel during five intensive

field campaigns. All major emission pathways (emissions from the reservoir water surface (diffusive fluxes and ebullition), downstream (degassing and diffusive fluxes), and on the soils of the drawdown area) were quantified.
The pelagic aerobic methane oxidation was determined in laboratory conditions, as well as kinetics of potential GHG production from one-year incubated soils. Primary production rates were determined using chlorophyll concentrations.
Total carbon emissions from the reservoir were 378±89 and 437±72 $GgC.year^{-1}$ respectively for the years 2010 and 2011. For the years 2010 and 2011, CO_2 contributed for around 95% of the total carbon emissions, CH_4 only contributing for the remaining 5%. The magnitude of carbon import and export reveals that around 85-90% of the total carbon released was fueled by flooded carbon stock at the reservoir bottom. Our results suggest that within first two years after flooding, a significant amount of carbon has been released, which corresponds to around 15% of the stock of carbon originally flooded.

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The Megacities Carbon Project

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Carbon emissions from cities represent the single largest human contribution to climate change. Robust verification of emission changes due to growth or stabilization policies requires that we establish measurement baselines today and begin monitoring representative megacities immediately. Mayors of megacities, local regulatory agencies, and other stakeholders are implementing mitigation policies now and are asking for scientifically robust information to evaluate the efficacy of those actions. An observing system designed to monitor the atmospheric "domes" of carbon dioxide, carbon monoxide, methane and other gases of megacities and link those observables with space-time resolved emissions data sets will involve a tiered set of surface, airborne, and satellite sensors as well as an integrated and transparent framework for modeling, analysis, and data sharing. We present a vision, strategy, and requirements for a framework to assess directly the carbon emission trends of the world's megacities that leverages and extends established measurement infrastructure in (initially) three megacities and applies techniques being developed in methodological studies of smaller cities. We provide a detailed description of the LA component of the project including using it as a testbed for evaluating urban-scale carbon observations from geostationary and low earth orbiting satellites, aircraft, and surface-based in situ and remote sensing instruments.

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MERLIN CNES-DLR

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A new Earth-Observation mission MERLIN dedicated to methane has been initiated late 2009 in Franco-German cooperation for a launch in 2017 and 3 years operation. The two national agencies i.e. CNES and DLR are in charge of the full project. In 2013, MERLIN is in phase B. CNES is responsible for the full satellite and ground control center, whereas DLR will provide the IPDA Lidar operating in the 1.64 µm spectral region. The two agencies share the data processing activities. The main science objective is to bring a significant improvement on regional CH_4 fluxes that call for 1 % accuracy on XCH_4 i.e. column averaged dry-mixing ratio, at a 50 km horizontal resolution. MERLIN is a mini-satellite using the new CNES Myriade Evolutions spacecraft. MERLIN will be operated at an altitude of 506 km, on a sun-synchronous orbit either at 6:00 or 18:00 LTNA depending on launch opportunities. The IPDA technique enables measurements in all seasons at all latitudes and during nighttime. The IPDA technique relies surface reflectance and DIAL measurements using a pulsed laser emitting at two wavelengths. For the measurement objectives are the methane sources located at surface, the methane weighting function calls for a careful selection of the methane absorption line and accurate determination of the spectroscopic parameters. It also calls for accurate range measurement (better than 3 m) to the surface using the time-of-flight technique. Accurate surface pressure (better than 1 hPa) and temperature profile (1 K) will be provided by NWP centers. Presently, two objectives drive the MERLIN activities, namely i) an affordable and reliable mission ready on time, ii) an efficient way to provide the scientific community with methane products of great value in terms of accuracy and resolution.

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Recent decadal trends of land carbon sources and sinks at the regional scale from a joint ocean-atmosphere inversion

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Over more than 5 decades, the carbon sinks in the ocean and on land have been able to keep up remarkably well with the dramatic increase in the emissions from the burning of fossil fuel (Ballantyne et al., 2012). Both land and ocean have contributed to this strong increase in the total carbon sinks, but their relative contribution to this trend, and particularly the spatial distribution of the trends on land are not well known. Here, we determine the evolution of the land and ocean carbon sinks over the period 1980s until 2008 using a regional joint ocean-atmosphere inversion. We focus on the decadal mean trends by comparing solutions for the three periods 1980-89, 1990-99 and 2000-08. In addition to atmospheric CO_2, constraints from ocean interior DIC and surface ocean pCO_2 are included, yet no explicit land prior. We find the land to contribute only 20% (-0.11 PgC/yr/decade) to the change in the overall removal of carbon from the atmosphere over the 1980 to 2008 period, whereas the oceans contribute 80% (-0.44 PgC/yr/decade) to this trend. Land uptake intensified in the 1990s by 0.4 (± 0.3) PgC/yr compared to the 1980s, but then weakened slightly by 0.2 (± 0.4) PgC/yr in the 2000s. The northern extratropical land sink increases throughout the examined period, with boreal regions contributing 86% to this trend, induced by enhanced net uptake during the growing season in boreal America and declining dormant season net release in boreal Asia. Tropical land is estimated to act as an increasing source of carbon, caused by an intensified carbon loss in tropical America during the Amazon-mean wet season. By contrast, aggregated tropical Africa and Asia acts as carbon sink with little discernible trend.

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The AMIGO Instrument

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An overview of the operation of the AMIGO instruement will be presented. The Abundance of Methane by Interferometric Glint Observation (AMIGO) instrument employs three Fabry-Perot interferometers to measure atmospheric absorption spectra for several greenhouse gases in solar glints over oceans and from small bodies of water over landmasses. The need to understand the behavior of greenhouse gases as they contribute to climate change is critical for scientific understanding as well as in a regulatory capacity as international protocols are developed to help moderate the release of these gases into the atmosphere. Space borne measuring systems are needed because of the global nature of the problem; but, identification of release sites from space is difficult because each surface phenomenon contributes a small fraction to the total column abundance of greenhouse gases that is measured from space. This has led to a SNR requirement of 100:1 or larger for the measurement of the column abundance to adequately identify and quantify surface sources and sinks.
Over the last ten years, the AMIGO team at Goddard Space Flight Center (GSFC) has developed (with support from the Earth Science Technology Office (ESTO) as well as internal GSFC funds) a series of differential radiometers based upon the Fabry-Perot (FP) interferometer. This instrumentation is capable of high precision measurement of the total atmospheric column for a variety of atmospheric species. This includes the three most active greenhouse gases: water vapor, carbon dioxide, and methane. Detailed knowledge of the global sources and sinks of the latter two gases will be a powerful tool in understanding the growth of greenhouse gases in the Earth's atmosphere. The AMIGO instrument will provide critical contributions to our understanding of the global carbon cycle and the processes that occur on local and regional levels.

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Estimating methane emissions from tropical wetlands using new tools for combining process understanding with atmospheric measurements

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Tropical wetlands are an important and highly uncertain term in the global budget of methane. Unlike wetlands in higher latitudes, which are dominated by water logged peatlands, tropical wetlands consist primarily of inundated river floodplains responding seasonally to variations in river discharge. Thus far, the complexity of these emissions, in combination with the limited availability of measurements, has hampered model development. As a result, the process models used for estimating methane emissions from global wetlands commonly lack a dedicated parameterization for the tropics. Within the GeoCarbon project, scientists join forces to improve this situation by developing a parameterization for use in the global dynamical vegetation model LPX, and by gathering the available hydrological and atmospheric measurements for evaluating the performance of the new model. The LPX simulated methane fluxes are translated into atmospheric concentrations using atmospheric transport model TM5, for evaluation using aircraft measured vertical profiles, collected around the year at several sites in the Amazon Basin, and total column methane measurements from the GOSAT satellite. In our presentation we will discuss the current status of this activity, and implications in the context of future monitoring of tropical methane emissions.

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Summary of the discussion on "CL-02 task in Japan" at JpGU session

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We held an un-official meeting of the activity of GEO CL-02 task in Japan during the annual meeting of Japan Geophysical Union (JpGU), on May 22, 2013 at Makuhari Messe, Japan. At the meeting 10 oral lectures and 5 posters were presented. The motivation to hold this meeting was to enhance the
coordination of carbon research related to GEO CL-02 task in Japan. There are some communities related to the study of carbon cycle; for example, satellite remote sensing using GOSAT, in situ measurement using airplane (CONTRAIL), flux measurement using flux towers (JAPAN FLUX), observation in ocean and various modeling studies. Although some institutions in Japan; JAXA, NIES, JMA, AIST, NIAES and University of Tokyo, participated in this task as leads and contributors, the available information related to the task activity was very limited so far. Then the meeting was planned to enhance the communication, exchange of information, and collaborative activity in Japan. Not only from the group of the registered task leads and contributors but also the potential contributors in a broad range of disciplines were solicited.
A variety of ideas were discussed for coordination, research planning, and potential outcome of the research. Among them, the modeling, which may include not only natural science but include social benefit and risk analysis, may play an important role, although the way from the carbon researches to it is not always straight forward.

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SPRUCE (Spruce and Peatland Responses Under Climatic and Environmental Change) experiment data infrastructure

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The Carbon Dioxide Information Analysis Center (CDIAC) at Oak Ridge National Laboratory (ORNL), USA has provided scientific data management support for the US Department of Energy and international climate change science since 1982. Among the many data activities CDIAC performs are design and implementation of the data systems. One current example is the data system and network for SPRUCE experiment.
The SPRUCE experiment (http://mnspruce.ornl.gov) is the primary component of the Terrestrial Ecosystem Science Scientific Focus Area of ORNL's Climate Change Program, focused on terrestrial ecosystems and the mechanisms that underlie their responses to climatic change. The experimental work is to be conducted in a bog forest in northern Minnesota, 40 km north of Grand Rapids, in the USDA Forest Service Marcell Experimental Forest (MEF). The site is located at the southern margin of the boreal peatland forest. Experimental work in the 8.1-ha S1 bog will be a climate change manipulation focusing on the combined responses to multiple levels of warming at ambient or elevated CO_2 (eCO_2) levels. The experiment provides a platform for testing mechanisms controlling the vulnerability of organisms, biogeochemical processes and ecosystems to climatic change (e.g., thresholds for organism decline or mortality, limitations to regeneration, biogeochemical limitations to productivity, the cycling and release of CO_2 and CH_4 to the atmosphere). The manipulation will evaluate the response of the existing biological communities to a range of warming levels from ambient to +9°C, provided via large, modified open-top chambers. The ambient and +9°C warming treatments will also be conducted at eCO_2 (in the range of 800 to 900 ppm). Both direct and indirect effects of these experimental perturbations will be analyzed to develop and refine models needed for full Earth system analyses. SPRUCE provides wide range continuous and discrete measurements. To successfully manage SPRUCE data flow and support climate change research, CDIAC has designed flexible data collection system using proven network technologies and taking advantage of existing software components.
The SPRUCE data system comprised primarily of a set of network components, relational database, a web server to monitor data collection status, FTP server and replication/backup arrangement. Later the data interface on the existing website will be expanded to allow users to query the SPRUCE collection in a variety of ways and then subset, visualize and download the data. From the perspective of data stewardship, on the other hand, this system is designed for CDIAC to easily control database content, automate data movement, track data provenance, manage metadata content, and handle additions and corrections.
In this presentation, we share our approaches to meet the challenges of designing and constructing data system for managing sources of high volume in situ observations in a remote location. It will demonstrate the dataflow starting from the sensors and ending at the archiving/distribution points, discuss types of hardware and software used, and examine considerations that were used to choose them.

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AIRS retrieved CO_2 and its association with climatic parameters over India during 2004-2011

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Atmospheric Infrared Sounder (AIRS) retrieved mid-tropospheric Carbon Dioxide (CO_2) have been used to study variability and association with the climatic parameters over India during 2004 to 2011. Study also aims in understanding of CO_2 transport from surface to mid-troposphere over India. Annual cycle of mid-tropospheric CO_2 show gradual increase in concentration from January till the month of May. It decreases continuously during summer monsoon (JJAS) during which strong westerlies persists over the region; slight increase is seen during winter monsoon (OND). Being a greenhouse gas, annual cycle of CO_2 show good resemblance with annual cycle of surface air temperature with positive correlation coefficient of +0.88. Annual cycle of vertical velocity indicate inverse pattern compared to annual cycle of CO_2. High values of mid-tropospheric CO_2 correspond to upward motion of vertical wind, while low values of mid-tropospheric CO_2 correspond to downward motion of vertical wind. In addition to vertical motion, horizontal winds also are seen to contribute towards the transport of CO_2 from surface to mid-troposphere.

Vegetation as it absorbs CO_2 at surface level show inverse annual cycle to that of annual cycle of CO_2 with negative correlation coefficient, - 0.64. Seasonal variation of rainfall-CO_2 shows similarities with seasonal variation of NDVI-CO_2.

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The Integrated Carbon Observation System in Germany

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Due to the strong anthropogenic disturbance of the global carbon cycle, carbon dioxide and other greenhouse gases increase in the atmosphere and contribute to climatic change. Currently, the ocean and the land biosphere still sequester parts of this anthropogenically emitted carbon dioxide. However, the sustainability of these sinks is not guaranteed. Measures to reduce emissions of greenhouse gases are depending on our ability to monitor atmospheric concentrations of greenhouse gases and changes in the environment with high precision. Understanding the complex interactions between the climate system and biosphere, hydrosphere as well as atmosphere must, therefore, be based on long-term precise and internationally comparable measurements. An infrastructure that provides these observations is the best investment for reducing uncertainties and for avoiding future surprises.
In order to develop a long-term perspective for a European monitoring system for greenhouse gases the Integrated Carbon Observation System (ICOS) has been approved by the European Council of Research Ministries as an important research infrastructure and will be established officially as a European Research Infrastructure Consortium (ERIC) in 2013. ICOS will be organized as a decentralized research infrastructure with the observational networks run by national programs. ICOS-D is currently a consortium of 13 research institutions, contributes to all monitoring networks and will provide a Central Calibration and Analytical Laboratory (CAL) and a Central Radiocarbon Laboratory (CRL) in Jena and Heidelberg, respectively, as central facilities.
In the Atmospheric Program continuous measurements of atmospheric trace gas concentrations and of their isotopic components will be conducted by tall-tower measurements. In combination with transport models, these measurements will enable the researches to calculate the European carbon fluxes with a resolution of 10 km. The ICOS-D Atmospheric Observational Network for Germany will comprise of 9 atmospheric sites.
In the Ocean Program, volunteer observing ships (VOS) plying regular routes in the Atlantic Ocean and the Baltic Sea will be instrumented to make autonomous observations of physical and biochemical parameters (temperature, salinity) and seasurface fugacity of CO_2 (fCO_2). In addition, two ocean observatories at the Cape Verde Islands and Svalbard ('Hausgarten') will be part of the long-term research infrastructure.
The Terrestrial Ecosystem Program will provide continuous measurements of trace gas fluxes between ecosystems and the atmosphere. The measurements will be conducted in forests, grasslands, croplands and wetlands and will partly build on sites that have been run for a decade or more in the framework of EU-project like CarboEurope. The Terrestrial Ecosystem Program will be designed in 5 – 6 clusters. A cluster is a group of sites at close range but under different land use. This will ensure high representativeness for climate, soils properties and regional land use criteria.
The CAL will provide standard gases for the entire network in order to minimize offsets and calibration uncertainties between the measurements at different stations. It will also provide a centralized analysis for all special trace gas flask samples taken within the ICOS network. The CRL

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will analyse flask samples for radiocarbon and support independent estimates of the regional fossil fuel emissions.

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Spatial and seasonal variability of CO_2 outgassing from rivers at the global scale

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The land-ocean transfer of carbon (C) via rivers is an important part of the global C cycle. Recently, growing attention has been paid to the CO_2 evasion from rivers to the atmosphere and global estimates in the range 0.3-1 PgC yr^{-1} have been proposed. The robustness of these global CO_2 evasion estimates critically depend on the amount and spatial coverage of observational data. For large areas of the world, including potential hot-spots of biological carbon-turnover and CO_2 emissions, data density is low and the available data only cover specific fluvial systems and only some periods of the seasonal cycle. In order to fill these data gaps and obtain representative global estimates of CO_2 evasion, advanced interpolation/extrapolation techniques are required.
It has been shown that spatial patterns in river water pCO_2 can, to some degree, be predicted at continental scale. This approach is used in a regional scale study to produce spatially and seasonally resolved estimates of CO_2 evasion from the fluvial network along the North East coast of North America, revealing significant seasonal patterns in river CO_2 evasion. We extend our approach to the global scale. Using the extensive hydrochemical data base GloRiCh, we calculate pCO_2 values for > 6,900 river water locations. Based on these data, we explore the relationships between river water pCO_2 and environmental variables that can be used as predictors of pCO_2 in regions not covered by field measurements. Existing empirical approaches are then used to calculate spatially explicit estimates of the river surface area and the gas exchange velocities at the air-water interface. The combination of all these estimates allows us to quantify the CO_2 evasion at 0.5 degree resolution for the global river network.

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Impact of transport model errors on the global and regional methane emissions estimated by inverse modeling

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A modelling experiment has been conceived to assess the impact of transport model errors on methane emissions estimated in an atmospheric inversion system. Synthetic methane observations, obtained from 10 different model outputs from the international TransCom-CH_4 model inter-comparison exercise, are combined with a prior scenario of methane emissions and sinks, and integrated into the PYVAR-LMDZ-SACS inversion system to produce 10 different methane emission estimates at the global scale for the year 2005. The same methane sinks, emissions and initial conditions have been applied to produce the 10 synthetic observation datasets. The same inversion set-up (statistical errors, prior emissions, inverse procedure) is then applied to derive flux estimates by inverse modelling. Consequently, only differences in the modelling of atmospheric transport may cause differences in the estimated fluxes.

In our framework, we show that transport model errors lead to a discrepancy of 27 Tg/yr at the global scale, representing 5% of total methane emissions. At continental and annual scales, transport model errors are proportionally larger than at the global scale, with errors ranging from 36 Tg/yr in North America to 7 Tg/yr in Boreal Eurasia (from 23% to 48%, respectively). At the model grid-scale, the spread of inverse estimates can reach 150% of the prior flux. Therefore, transport model errors contribute significantly to overall uncertainties in emission estimates by inverse modelling, especially when small spatial scales are examined. Sensitivity tests have been carried out to estimate the impact of the measurement network and the advantage of higher horizontal resolution in transport models. The large differences found between methane flux estimates inferred in these different configurations highly question the consistency of transport model errors in current inverse systems.
Future inversions should include more accurately prescribed observation covariances matrices in order to limit the impact of transport model errors on estimated methane fluxes.

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Using satellite data to constrain plant phenology of the terrestrial biosphere model ORCHIDEE

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Plant phenology plays a direct role in controlling the net amount of carbon that is assimilated during the growing season. A recent study (Richardson et al., 2012) showed that there is bias in the growing season length (GSL) predicted by most Terrestrial Biosphere Models. However, prior to parameter optimization it is unclear whether the misfit between modeled and observed LAI/fAPAR is the result of inaccurate parameter values or model error.
Here satellite-derived NDVI data are used to constrain the phenology parameters in ORCHIDEE. A 4D–variational data assimilation system is used to optimize all natural deciduous PFTs. In addition, the ability of the satellite data to improve the seasonal C fluxes is evaluated with FLUXNET and atmospheric CO_2 data, and the improvement in the inter-annual variability of the GSL is discussed.
For the boreal and temperate forest PFTs, the optimizations generally result in a decrease in GSL, with First reduction in annual GPP. However, the posterior value for certain parameters is at the edge of the prior range, suggesting that some processes in the model may be missing or inaccurate. The optimization of parameters controlling the phenology of tropical raingreen trees does not result in an improvement in the misfit between the observations and the model, suggesting that the current moisture threshold-based phenology models require improvement. For grassland PFTs, the posterior parameter values show that in some regions the timing of leaf phenology is responding more to temperature or moisture but not to both. This possibly indicates that the phenology parameters should not be optimized per PFT, but rather at the regional, biome, or even species level.
The misfit between observations and posterior fluxes provides valuable insights into how the modeling of phenology in TBMs can be improved. Preliminary investigations in this direction will be discussed.

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Soil Carbon Dioxide Efflux and The Impact of Logging in a 30 Years *Dipterocarpus Baudu* and *Verrucosus* Recovering Lowland Tropical Forest, Peninsular Malaysia

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Recovering logged-over forest ecosystem increases CO_2 efflux into the atmospheric carbon pool in response of environmental factors to change in soil temperature and moisture. These CO_2 outbursts can have a marked influence on the ecosystem carbon balance and thereby affect the atmospheric carbon pool. The study was conducted in a 30 years logged-over forest of Sungai Menyala forest, Port Dickson, Negeri Sembilan, Malaysia. The measurements of soil CO_2 effluxes were conducted using a continuous open flow chambers technique connected to a multi gas-handling unit and infrared CO_2/H_2O gas analyser. The aim of this study is to determine the percentage of CO_2 contributed into the atmosphere from a recovering 30 year logged-over lowland forest. One-way analysis of variance (ANOVA) was used to test the significance correlation between soil CO2 efflux and environmental variables. Post-hoc comparisons were made using Tukey test ($p< 0.05$), and multiple linear regressions were used to determine the impact of environmental factors on soil CO_2 efflux. Soil CO_2 efflux range from 345.6-600.4 mg/m-2/h-1 with the highest efflux in the afternoon attributed to increase in soil temperature and moisture. Higher soil temperature and moisture recorded signify the influential factor. Furthermore, the predictor environmental variables; Soil Organic Carbon (SOC), Total Organic Carbon (TOC), Soil Moisture Content (SMC), Bulk Density, Below Ground Carbon Stock, Total Aboveground Carbon Biomass (TAGB), soil pH, Nitrogen to Carbon ratio account for the spatial and temporal variation in soil CO_2 efflux. These factors and logging activities attributed to increase in CO_2 efflux into the atmosphere.

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Using a SVAT Model to Simulate Carbon Fluxes at Different Scales

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Considering different modelling approaches used to investigate mass and energy exchanges between ecosystems and atmosphere, the SVAT (Soil Vegetation Algorithm Transfer) models are useful tools to study ecosystems behavior. In recent years, the SVAT model ACASA (Advanced Canopy-Atmosphere-Soil Algorithm) was developed to simulate energy and mass exchanges over ecosystems. ACASA is based on higher order closure equations for turbulent fluxes calculation per 20 canopy layers (10 layers within and 10 above the canopy) and 15 soil layers with adjustable thickness. CO_2 fluxes are estimated using a combination of Ball-Berry and Farquhar equations. Recent improvements of ACASA include the parameterizations of leaf-facet scale interactions for accounting both biogenic and anthropogenic flux sources and sinks.
ACASA model is suitable to work at different scales: as a stand-alone model to simulate fluxes at local scale and coupled with mesoscale model to work at regional scale. For *in situ* applications,

meteorological measurements and structural ecosystem data are used to force the model. Previous comparisons of simulated fluxes with Eddy Covariance flux measurements demonstrated the skill of ACASA to estimate turbulent fluxes and capture distinctive flux pattern. Energy and carbon fluxes at regional scale can be obtained using ACASA coupled, for instance, with the meteorological mesoscale WRF (Weather Research and Forecast) model. In addition, carbon fluxes over future climate conditions can be simulated using climate projection data.
Over the past years, ACASA was successfully employed to simulate carbon fluxes over agricultural and forest ecosystems, and urban environment. Preliminary results showed success in using ACASA model to simulate carbon fluxes over such different ecosystems and scales. A description of the main model results obtained over the three ecosystems is here reported.

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Observing the Carbon Cycle from Geostationary Orbit

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Geostationary observations will transform the way we study, analyze and quantify the flows of carbon in the Earth system, including addressing the feedbacks that control the relationships between carbon storage in the atmosphere and land reservoirs and evaluating how rapidly changing anthropogenic emissions are changing the carbon cycle at local, regional and continental scales.
Recent technological advances have enabled the design of geostationary sensors that combine four critical observational requirements:

- Simultaneous, collocated measurement of carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO) and solar-induced chlorophyll fluorescence (SIF)
- High spatial resolution (< 5 km)
- Contiguous spatial imaging
- High temporal resolution (~hourly)

These advances enable geostationary observations to probe carbon cycle processes operating at the intermediate spatial and temporal scales that are not possible to study directly using more traditional surface, airborne, and space-based measurement techniques. The 'complete' spatial and temporal context afforded by geostationary observations mitigates several of the dominant uncertainties in current carbon cycle flux estimation methods, e.g., sparse spatiotemporal sampling and poorly constrained boundary conditions, and opens the door to a new generation of mass balance based flux estimation approaches.
Sub-orbital field experiments that demonstrate and validate geostationary carbon observing methods are essential and practical precursors to actual deployment in space. We describe efforts directed towards delivering this transformational approach to carbon cycle science.

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Field results from three campaigns to validate the performance of the Miniaturized Laser Heterodyne Radiometer (mini-LHR) for measuring carbon dioxide and methane in the atmospheric column

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In a collaboration between NASA GSFC and GWU, an instrument is being developed that can continuously monitor key carbon cycle gases in the atmospheric column. The instrument is based on a laser heterodyne radiometer (LHR) using near infrared (NIR) telecom lasers. Despite relatively weak absorption line strengths in this spectral region, spectrally-resolved atmospheric column absorptions for these two molecules fall in the range of 60-80% and thus sensitive and precise measurements of column concentrations are possible.
In the last year, the instrument was deployed for field measurements at Park Falls, Wisconsin; Castle Airport near Atwater, California; and at the NOAA Mauna Loa Observatory in Hawaii. For each subsequent campaign, improvement in the figures of merit for the instrument has been observed. In the latest work the absorbance noise is approaching 0.002 optical density (OD) noise on a 1.8 OD CO_2 signal.
An overview of the measurement campaigns and the data retrieval algorithm for the calculation of column concentrations will be presented. For light transmission through the atmosphere, it is necessary to account for variation of pressure, temperature, composition, and refractive index through the atmosphere that are all functions of latitude, longitude, time of day, altitude, etc. For temperature, pressure, and humidity profiles with altitude we use the Modern-Era Retrospective Analysis for Research and Applications (MERRA) data. Spectral simulation is accomplished by integrating short-path segments along the trajectory using the SpecSyn spectral simulation suite developed at GW. Column concentrations are extracted by minimizing residuals between observed and modeled spectrum using the Nelder-Mead simplex algorithm.
We will also present an assessment of uncertainty in the reported concentrations from assumptions made in the meteorological data, LHR instrument and tracker noise, and radio frequency bandwidth and describe additional future goals in instrument development and deployment targets.

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Long-term measurements of carbon budget in a cool-temperate deciduous forest ecosystem at Takayama in central Japan and their data analyses

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Impacts of climate change on terrestrial biospheric activities have been predicted in recent studies. In East Asia strongly influenced by Asian Monsoon, changes not only in temperature but also in amounts of precipitation and length of the rainy season associated with the climate change could have much influence on the carbon budget in the terrestrial biosphere. However, responses of the terrestrial biosphere to climate change are not yet fully understood. For the better understanding of the responses, further analyses using long-term measurement data of the carbon budget in terrestrial ecosystem are necessary.
We have made long-term systematic measurements of CO_2 flux between the atmosphere and forest ecosystem, atmospheric CO_2 concentration, and meteorological parameters in a cool-temperate deciduous forest at Takayama (36°08'N, 137°25'E, 1420 m a.s.l.), Japan since 1993. The related parameters such as CO_2 and H_2O isotopes and the O_2/N_2 ratio have also been observed at the site.

Takayama is the longest monitoring site in the AsiaFlux network. The CO_2 concentration data at Takayama have also been submitted to the WDCGG of WMO.
In this presentation, our research activities and some of the results obtained from the long-term measurements will be introduced. We will present the results of analyses of interannual variation of the carbon budget and atmospheric CO_2 observed at Takayama and environmental factors governing the variation as well as those for separation of each carbon flow in the forest ecosystem using the isotope and O_2/N_2 data. We will also give an overview of intercomparison experiments of GHG standard scales and development of SI traceable GHG standards which are being conducted in collaboration of observational laboratories and a metrology laboratory in Japan to standardize the observed data.

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FLUXNET: challenges and activities for a global coordinated network of ecosystem fluxes measurements

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In the last 15 years the network of sites monitoring green house gases exchanges between ecosystems and atmosphere developed rapidly in terms of number of sites, methods used and structural organization. The European (CarboEurope) and US (Ameriflux) networks contributed substantially to the development of the FLUXNET initiative that is progressively getting involved other continental networks from Asia, Australia and South America. The LaThuile_2007 initiative (www.fluxdata.org) marked an important step in the direction of a global standardized dataset accessilbe to the whole scientific community. Thanks to the important results obtained, with more than 40 papers published, the LaThuile FLUXNET initiative helped to highlight the importance of the ecosystem fluxes networks and the crucial role of these data in synthesis activities in particular when modelers and remote sensing experts are also involved.
In the last years large efforts have been made in US (NEON, Ameriflux) and in Europe (ICOS) to create long-term, standardized ecosystem monitoring networks to provide high quality data under a completely open data use policy. These initiatives will allow a simpler and better use of the data but they are still in a construction phase geographically concentrated in the two continents. This biased distribution contribute to justify the efforts to keep the FLUXNET dataset updated with the inclusion of new sites in particular from the under-sampled areas and the development of new data processing methods.
There are two main challenges in this activity: the political and sociological differences between continental communities in the data sharing principles and the difficulties to develop common processing methodologies valid across different ecosystems and climate regions.
In this presentation the current status of the FLUXNET data collection will be presented. Strategies, activities and problems in the organization of a global in-situ fluxes observation system will be also analyzed and discussed with the aim to identify the best solutions for an integrated global action.

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20 years land carbon fluxes and stocks reanalysis from a Carbon Cycle Multi-Data Assimilation System using in-situ FluxNet, satellite NDVI, and atmospheric CO_2 observations to optimize a process-based

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The prediction of ecosystem water and carbon fluxes with global models remains subject to large uncertainties, partly because of poorly calibrated parameters. Assimilation of in-situ data, remote sensing data and atmospheric CO_2 concentrations into these models is a promising approach to optimize key parameters. So far most of the studies have focused on using one single data stream, either FluxNet data at specific sites to constrain the hourly to seasonal time-scale processes, satellite vegetation activity to constrain the phenology of these models, or atmospheric CO_2 concentrations to provide overall large scale constraints. However, the combination of these data streams should provide a much larger constraint on the different processes controlling the carbon budget of terrestrial ecosystems from daily to inter-annual time scales.
In the context of CARBONES and GEOCARBON projects, we constructed a global Carbon Cycle Multi-Data Assimilation System to assimilate MODIS-NDVI observations, in situ NEE and LE fluxes (60 FluxNet sites), and atmospheric CO_2 flask measurements. We used a variational data assimilation framework that allows the optimization of the major parameters of the land surface model, ORCHIDEE. The optimization was perform over the past 20 years to provide a coherent global carbon flux and stocks re-analysis and an optimized land ecosystem model.
The estimated land carbon fluxes and stocks from the parameter optimization, using all data streams together will be compared against independent datasets and approaches to highlight the benefit of using a Multi-Data assimilation system. The potential of these data streams to reveal model deficiencies will be discussed through the analysis of the model-data fits and the parameter values. Finally, the impact of the parameter optimization on the simulated land carbon fluxes for the next century will be evaluated with climate forcing from the recent AR5-IPCC exercise.

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Optimizing the large-scale transport of a carbon cycle data assimilation model using sulfur hexafluoride

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We use a set of 30,000 observations of SF6 mole fractions taken in the remote background atmosphere to improve the transport characteristics of the global atmospheric transport model TM5. This model forms the heart of the CarbonTracker data assimilation system for carbon dioxide, and previous work has shown the linear dependence of estimated surface carbon fluxes on model transport. Inclusion of a new horizontal diffusion parameterization and optimizing its performance with surface SF6 mole fraction observations makes TM5 more diffusive especially in summer, and improves its representation of the north-south gradient of SF6 markedly. A comparison with independent observations from the free troposphere confirm the better performance. The effect of this improved transport on estimated carbon surface fluxes is small, but systematic: carbon sinks in the northern hemisphere mid-latitudes are weaker, and carbon sinks in the tropical regions are larger. The resulting small net tropical flux agrees well with other recent work that suggest a near-neutral tropical carbon balance.

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Data management and global data products from ocean carbon observations: a community approach

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The number of ocean carbon observations measured on various platforms (e.g. research vessels, time-series stations, voluntary observing ships and buoys) has been continuously increasing over the past decades. By now hundreds of investigators around the globe are measuring more than 1,5 million CO_2 observations on an annual basis and the number is still rising.
One of the main aims of the International Ocean Carbon Coordination Project (IOCCPS) sponsored by the International Oceanographic Commission (IOC) of the UNESCO and the Scientific Committee on Oceanic Research (SCOR) is the coordination those national efforts and to ensure that those data are accessible via data centres (e.g. CDIAC - Carbon Dioxide Information Analysis Center) and can easily be used.
By now more than one hundred scientists and data managers have been working on the creation on data products for observations of the ocean interior (GLODAP – Global Ocean Data Analysis Project, CARINA – Carbon Dioxide in the Atlantic Ocean and PACIFICA – Pacific Ocean Interior Carbon) and for carbon dioxide observations from the surface oceans (SOCAT – Surface Ocean CO_2 Atlas). Surface CO_2 observations are being used to quantify the spatial and seasonal to decadal temporal pattern of carbon uptake and release while discrete measurements are fundamental for assessing the oceanic carbon inventories and uptake rates.
One of the main community efforts was the establishment of consistent second level quality controlling procedures that ensure the best possible quality.
Within those products all data is among others metadata documented, available in a uniform format and citable using persistent identifiers.
Those data products are public, continuously being updated with recent and missing data and give modelers the possibility to easily access and integrate high quality marine carbon observations.

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Biomass (carbon) and diversity relationship in the Yasuni 50-hectare plot, Amazonian Ecuador

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In Amazonian tropical forests, the relation between the potential to sink carbon and the species diversity of a community is unresolved. To aid in their conservation, it is important to prove that these hyperdiverse forests also represent high carbon reservoirs. We relate patterns in above-ground biomass (AGB) and species diversity in one of the most biodiverse forests of the world: Yasuní, Amazonian Ecuador. In a permanent 50-ha forest plot, we evaluated the AGB vs. diversity relation in a sample of near 300,000 trees with diameter >=1 cm. To estimate biomass, we used generic "wet-forest" and "moist-forest" allometric equations because (1) there is still not a biomass allometric equation empirically developed for Yasuni, and (2) the forest is considered aseasonal (ca. 3000 mm rain/year), but not as wet as other rainforests. We found that the AGB estimate for the whole 50-ha plot according to the wet equation was approximately 30% lower than that based on

the moist equation (9,767 vs. 13,352 tons, respectively), and that the AGB vs. diversity relation at the quadrat scale, analyzed using subsamples of 20x20 m, 50x50 m and 100x100 m quadrats, was positive and statistically significant, except at the 100x100 m scale. These results were robust even after the analyses were corrected for spatial autocorrelation among quadrats. We conclude that, in the highly biodiverse lowland rainforests of northwestern Amazonia, (1) the application of biomass equations developed for other tropical forests are probably outputting relatively inaccurate AGB estimates, (2) to solve this problem, there is the pressing need to refine the empirical collection of carbon data from northwestern Amazonian forests, and (3) AGB and species diversity tend to be positively correlated, thus enhancing the conservation value of these forests both as carbon reservoirs and genetic reservoirs.

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Monitoring of greenhouse gases using various earth observation platforms: Impacts of disturbance in tropical ecosystems in Asia

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The Center for Global Environmental Research (CGER), National Institute for Environmental Studies (NIES) has established a fundamental infrastructure for strategic monitoring of the global environment with an emphasis on climate change since the early 1990s. The monitoring covers greenhouse gas (GHG) concentrations and their surface fluxes in the atmosphere, ocean, and terrestrial biosphere particularly in Asia and the Pacific regions. The data have been acquired from different kinds of earth observation platforms such as ground-based stations, ships, and airplanes. The long-term datasets help to estimate the temporal and spatial variations of regional and global carbon budgets, to clarify the essential mechanisms of the carbon cycle, to predict future climate changes, and to estimate projection uncertainties.
The effects of natural and artificial disturbances are significant factors affecting carbon cycles in tropical regions. Combining in-situ measurements, satellite observations, and an air trajectory simulation, CO emissions from biomass burning in Southeast Asia were identified, and substantial contributions from peat soil burning in Indonesia were observed. A growing number of recently developed GHG flux monitoring sites has a great potential to fill observational gaps in tropical ecosystems in Asia. The magnitude and seasonality of the carbon budget were evaluated by the datasets of net ecosystem CO_2 exchange in forests, grasslands, and croplands throughout Asia. The effects of forest fires and changes in hydrological processes from a constructed canal that enhanced drainage and decomposition of soil organic matter were significant factors that should be explicitly incorporated into updating the carbon budget estimation in Asia and the Pacific.

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Constraining the land-surface scheme of the MPI Earth System Model with observations of net ecosystem exchange and CO_2 mixing ratios

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Uncertainties of land surface models are to a large extent a consequence of uncertainties in their parametrisation and parameter values. Understanding and reducing these uncertainties is important to reduce the spread in global carbon cycle, and therefore climate change, projections. For this purpose we developed a Carbon Cycle Data Assimilation System (CCDAS) for the land surface scheme (JSBACH) of the MPI Earth system model as a tool to systematically confront the model with observations. Observations representative for different temporal and spatial scales and processes, such as plant trait observations, point-scale flux measurements, and globally integrating CO_2 abundance monitoring can be incorporated into the CCDAS to estimate net land-atmosphere carbon fluxes, which are consistent with the observations and the model structure.
Here we present results of the MPI-CCDAS incorporating observations of net ecosystem exchange of CO_2 (NEE) and atmospheric CO_2 mixing ratios. Eddy-covariance based measurements of NEE constrain the modelled carbon cycle on the scale of the flux measurement footprint at hourly time scale. CO_2 mixing ratios are observed at a network of atmospheric monitoring stations and provide a large-scale integrated view of the terrestrial carbon cycle at seasonal and inter-annual time scales.
Given the data streams complementarity, we evaluate their individual role in constraining the net land-atmosphere carbon exchange and discuss the benefits of their simultaneous assimilation. Additionally, we explore the importance of parameter prior uncertainties, as well as model and measurement uncertainties in the assimilation procedure to assess the robustness of NEE estimates. Our results emphasize the importance of integrating multiple data streams, as it allows for a more comprehensive assessments of model structures.

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GOSAT-2 mission requirements and concepts

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JAXA's Greenhouse gases Observing Satellite (GOSAT) is since 2009 in polar orbit to monitor the global distributions of GHGs such as CO_2 and CH_4 from space. The GOSAT consists of a Fourier Transform Spectrometer (TANSO-FTS) and a Cloud and Aerosol Imager (TANSO-CAI). The X_{CO2} and X_{CH4} (column-averaged dry air mole fraction) are derived from the retrieved CO_2 and CH_4 column amounts with surface pressure. The GOSAT achieves to observe X_{CO2} with 2 ppm accuracy after optimization of cloud screening and aerosol estimation. Space-based GHGs observation is investigated to carry on by the follow-on mission GOSAT-2.
The GOSAT-2 study has just started in pre-project phase. Lessons learned from GOSAT mission include an instrument upgrade and an optimization of observation strategy. For better understanding of carbon flux, the GOSAT-2 mission requires an increase of the effective data after screening, a higher SNR of each observation spectrum, and an addition of new targets related to carbon source and sink. We will start the design of GOSAT-2 sensors and satellite this year. It will be taken an approach to a smart-gridded pointing operation to avoid cloud by on-board estimation over land and an extension of sun glint observation area in high latitudes over ocean, an enhancement of the O_2A band spectra for aerosol optimized estimation and new-found vegetation chlorophyll fluorescence, and an addition of newly developed CO band. This presentation shows the GOSAT-2 mission requirements and the current study on mission concepts.

"Towards a Global Carbon Observing System: Progresses and Challenges"
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Improving estimates of gross primary productivity by integrating in situ reflectance measurements

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Light Use Efficiency (LUE) models are commonly applied to retrieve Gross Primary Productivity (GPP) estimates using spectral indices (e.g. NDVI and PRI), which are available at low spatial resolution satellite sensors (e.g. MODIS), as proxies of biophysical properties of the vegetation. In highly heterogeneous ecosystems composed of different plant functional types (PFT, trees, shrubs and grasses), such as Mediterranean oak woodlands, satellite data may not be representative of the intra and interannual dynamic of the ecosystem components. *In situ* spectral measurements can provide useful information on each PFT and their phenology.
The objectives of this study were to: i) analyze the temporal variability of NDVI and PRI for the three PFT and their relationship with biophysical properties; ii) optimize a LUE model integrating these indices derived from field data; iii) compare the performance of PFT-disaggregated GPP estimates with global GPP estimates.
Ground measurements of vegetation reflectance were performed in an oak woodland eddy covariance site located in Portugal, between April 2011 and June 2013, on a monthly basis, around noon, on clear days. Reflectance signatures of the herbaceous layer, shrubs and trees were acquired with a FieldSpec3 spectroradiometer, and FAPAR was measured by a ceptometer.
Time series of *in situ* NDVI and PRI were very different among the PFTs as well their relationship with biophysical properties. Significant linear relationships were obtained between NDVI and FAPAR for cork oak and one shrub species. PRI time series also showed differences among PFTs, with oaks showing low variability and shrubs and grasses showing a decrease in summer. These indices were integrated into a LUE model and individual parameters were optimized for each PFT. The evaluation of this PFT-disaggregated optimization against eddy covariance measurements revealed an increase in the model efficiency when compared with global GPP estimates using MODIS indices.

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Carbon and Energy Monitoring in Typical Mediterranean Ecosystems

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Mediterranean Basin represents a peculiar area of the globe, due to climate and vegetation characteristics.
The climate is characterized by a wide variation in rainfall and temperature, often exposing the ecosystems to pronounced summer drought periods, and the landscape is composed by a patchiness of ecosystems with different physiological behavior. Within these, the Mediterranean maquis is well adapted to grow in such environmental conditions and represents a typical vegetation of the Basin.

The contribution of these ecosystems to the global carbon budget is then complex and wide inter-annual differences in turbulent fluxes are expected. Moreover, it is important to evaluate the role of agricultural ecosystems to the global carbon balance. It is recognized that agriculture sector is an important source of greenhouse gases, which many scientists agree is contributing to observed climate change. In addition, agriculture can play an important role in climate change mitigation, acting as a carbon sink and storing it in the soil and plant matter. In the Mediterranean area, grapevine is one of the most important crops, so it is needed to know its role in C emissions and sequestration, and to study the variability of the Net Ecosystem Exchange (NEE) depending on environmental factors.
Long-term carbon and energy flux measurement data analysis from Eddy Covariance towers installed over a Mediterranean maquis ecosystem and a vineyard is reported. In addition, considering the role of urban areas in sequestering or releasing carbon in the atmosphere, this study will present a new urban monitoring site located in Sardinia, Italy. This network of experimental sites provides a wide range of information on the role of Mediterranean ecosystems to the global C budget.

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Carbon observing systems in India

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This study analyzes the atmospheric carbon dioxide (CO_2) and other greenhouse gases (GHGs) concentrations at a remote location Sinhagad (SNG) in western India through the use of accurate air-sample analysis technique established at the Indian Institute of Tropical Meteorology, Pune, India. The ground based measurements from the GHG monitoring program at this site are in good agreement with other global GHG monitoring programs and thus provides a basis to understand the spatio-temporal characteristics of GHGs over the Indian region. Further, a modeling investigation complements the observational investigation, where CO_2 transport model and lagrangian particle dispersion models are employed to study the variability in the regional tracer transport. In this study we present results from our GHG monitoring program in India and compare the results against model simulations and satellite retrievals. Surface observations from SNG site in India are compared with global reference monitoring sites such as Mauna Loa (MLO) in USA and Cape Rama (CRI) in India. Our preliminary results indicate that CO_2 seasonal amplitude is much larger at the Indian sites. We further investigate the effectiveness of surface monitoring stations in capturing regional CO_2 emissions over India and found that CRI showed more representivity to boundary layer fluxes.

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CarbonTracker South America: comparison of model results to Amazonian CO_2 observations and initial carbon flux estimates

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One of the regions with the largest uncertainties in the net carbon fluxes within the global carbon cycle are the tropics, specifically South America and the Amazon region. This region is important in the carbon cycle as the Amazon Basin contains a large carbon pool stored within the forests and soils which can be released fast (e.g. Gloor et al. 2012).
We have setup a regional scale CarbonTracker data assimilation system (CTDAS) (Peters et al. 2010) focusing on South America. We use TM5 with a zoom grid of 1x1 degrees resolution over South America. We include unique observations over South America, particularly those from NOAA ESRL's air sampling network and the novel, widespread observations from aircraft sampling since 2010 by IPEN, Brazil, as part of the UK NERC AMAZONICA project in close collaboration with NOAA ESRL. Different sets of prior land fluxes (from the CASA and SiBCASA models) and imposed biomass burning emissions (including daily burned areas) will be used to obtain the best fit to the observations.
At the conference we will show first results of our model's performance in comparison to atmospheric CO_2 observations, specifically from vertical CO_2 profiles from aircraft sampling over the Amazon. Furthermore, we will present a first estimate of strength and variability of the carbon sources and sinks of South America.

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Coupling of ecosystem-atmosphere fluxes and hydrometeorology under normal and extreme climate conditions: A novel extreme event detection framework.

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Here we propose a novel methodology to detect extreme climate events in time series governed by strong seasonal patterns and apply nonlinear statistics to investigate how ecosystem dynamics change under extreme conditions.
Many of the state of the art methods define "extreme" data points by identifying the low or high parts of the full distribution of values. For biogeochemical flux data dominated by strong seasonal patterns such an approach limits the detected extremes to the periods with very low/high fluxes (e.g. winter or summer). Here we here present a methodology overcoming this limitation. We identify extreme periods by calculating nearest neighbor metrics between different years for short moving windows. We apply this method on climate reanalysis data at several eddy covariance tower locations. We use remote sensing vegetation indices to identify periods of phenologically active vegetation and restrict the analysis to these periods.
To investigate the ecophysiological consequences of extreme climate on these ecosystems we subsequently apply nonlinear statistics to quantify nontrivial couplings of carbon fluxes with climate forcings. We investigate the temporal development and the difference between extreme and normal conditions for these couplings to gain insights into the changing internal ecosystem mechanisms.

Our methodology allows us to address the following questions: How do ecosystem carbon flux dynamics differ under normal and extreme conditions? How do coupling patterns and intensities under normal and extreme conditions differ between climatic regions and ecosystem type (i.e. plant functional types)? Once these patterns are quantified, we can adopt an inverse perspective and use abnormal nonlinear correlations to identify "extreme" periods where ecosystem behavior is governed by something else than the "normal" response of the ecosystem to its climate. Overall our approach focuses on dynamics during extreme events rather than flux anomalies.

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CASA modeling of CO_2 budgets across Russia with 1 km resolution

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Most biogeochemical models work on 1, 0.5, or 0.25 degree resolution (roughly 100 x 100, 50 x 50, or 25 x 25 km). With CASA, 1-km resolution modeling is possible.
NEE, which represents carbon fluxes, can be calculated by this simplified CASA model by simulating NPP and Respiration, NEE being the difference between them.
High resolution environmental and meteorological data are integrated and fed into this CASA model, including:
A. MODIS products:
- GPP : from MODIS products MOD17A2, 1-km resolution.
- fPAR : from MODIS products MOD15A2 and MCD15A2, 1-km resolution.
- PET : Potential Evapotranspiration, from MODIS products MOD16, 1-km resolution.

And,
B. ESRL NCEP-DOE Reanalysis 2 products:
- Meteorological data, including precipitation and air temperature, 1.8-degree resolution.

Coordinates conversion between MODIS tile system and conventional Lat/Lon system is also performed. Calibration is done by comparing NEE at Fluxnet sites and NEE from this model at the sites, assuming Fluxnet sites provide correct NEE values. The sigma value of the deviation distribution between the NEE from CASA and from Fluxnet sites provides an estimate of uncertainty at site level. Uncertainty estimation of NEE in a large area (upscaling) is achieved by applying the rule of error propagation to the site-level uncertainty.
The modeling technique is performed for the entire Russia, yielding an estimate of CO_2 budgets of the nation.
CO_2 budgets of Russia calculated using Chevallier 4DVAR inversion, CarbonTracker NOAA version and EU version are also compared.

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Constrained terrestrial ecosystem carbon fluxes of North America with eddy flux and satellite data from 2001 to 2005

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There are long standing interests in the role of the land ecosystems in the carbon cycling at large scales. Inverse modeling suggests the land ecosystems in North America are an ecosystem carbon sink for the last several decades. But the size of the sink is uncertain. Here we present an analysis based on eddy covariance studies across North America for the period of 2001-2005 using a Bayesian ensemble approach and an adjoint approach and a process-based biogeochemistry model. The uncertainty is further constrained with MODIS gross primary production data. Our regional estimates are the function of net carbon sink for this period of 0.13 ± 0.25 and 0.20 ± 0.21 Pg C yr^{-1} with a Bayesian approach and conventional parameterization approach, respectively; while the adjoint approach estimates a small source of -0.02 ± 0.13 Pg C yr^{-1}. This study suggests that the choices of flux data and parameterization methods to be made are important to quantifying regional carbon budgets and their uncertainties.

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