Key Uncertainties in the Global Carbon-Cycle:

Perspectives across terrestrial and ocean ecosystems

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POSTER ABSTRACTS

* denotes ASP Colloquium Student

The global NPP dependence on ENSO: La-Niña and the extraordinary year of 2011

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The terrestrial ecosystems are one of the main global carbon sinks, being responsible for the removal of approximately 25% of fossil fuel emissions from the atmosphere. In turn, the ecosystems' activity is limited by climate constraints such as temperature, water availability and radiation (Nemani et al., 2003). The increasing strength and future behaviour of this sink is still an on-going debate (Zhao and Running, 2010; Ahlstrom et al., 2012) due to high interannual variability observed and uncertainties on the global sink response to climate variability (Ballantyne et al. 2012).

Remotely sensed Net Primary Production (NPP) datasets are a valuable tool to assess geographical and temporal variability on the carbon uptake by vegetation Since 2000, the Moderate Resolution Imaging Spectroradiometer (MODIS) has been used to retrieve a global NPP product which now comprises 12 years of data (2000-2011) with global coverage at 1km resolution (Zhao and Running, 2010).

In 2011 the highest global NPP anomaly, higher than 1.5Pg, was observed on the MODIS record. This extraordinary high global NPP anomaly, which was registered especially in the southern hemisphere, followed a decade of apparent decreasing trend (Zhao and Running, 2010). 2011 also registered one of the strongest La-Niña events on the instrumental record that brought generally cooler conditions, heavy rainfall on many regions of the southern hemisphere and was associated to high water retention on soils (Blunden and Arndt, 2012). Our goal is, therefore, to evaluate the reasons for such productivity enhancement (namely the role of the La-Niña event) and its relationship with climate variability.

Results indicate that high global anomaly was mainly driven by very high anomalies observed in the southern hemisphere, mostly in arid to semi-arid regions receiving much higher amounts of rain than average. At the same time, cooler than average temperatures were observed, which reduced soil water loss by evaporation. Furthermore, a strong correlation between NPP anomalies and El-Nino/Southern Oscillation is found in some of these regions and appears to drive a large fraction of global NPP anomalies.

Changes in dominant mixing length scales drive phytoplankton bloom initiation in the subpolar North Atlantic

Sarah Brody, Duke University*

The timing of the subpolar phytoplankton bloom has important consequences for marine ecosystems and carbon export to the deep ocean. The conventional explanation of subpolar phytoplankton bloom timing maintains that as the upper ocean stratifies in the spring, phytoplankton mix to shallower depths, experience higher light levels, and begin to bloom. However, recent studies have challenged this theory and proposed new explanations for the initiation of the bloom. One such explanation posits that decreases in upper mixed-layer turbulence, rather than seasonal stratification, reduces the depth to which phytoplankton are mixed, thereby increasing light exposure and promoting a bloom. The decrease in turbulence has been attributed to the onset of ocean surface net heating and lowered wind stress.

Recognizing that seasonal stratification, net ocean warming, and decreasing wind strength have all been invoked to explain how phytoplankton can increase their light exposure within a one-dimensional, light-limited system, we examine these mechanisms individually for the subpolar North Atlantic. We then reframe the discussion of light exposure in terms of the dominant mixing length scale, and allow that scale to be set at times by the local buoyancy forcing, and at times by the local winds. We find that decreases in this length scale better predict bloom initiation than do changes in seasonal stratification or individual forcings. Our model can also provide an alternative explanation for conditions observed during the bloom initiation in other studies that have invoked top-down mechanisms and three-dimensional processes to explain the timing of subpolar phytoplankton blooms.

Committed carbon emissions from oil palm plantation expansion onto Kalimantan peatlands

Kimberly Carlson, University of Minnesota

Oil palm plantation expansion is occurring predominantly in Indonesia, where draining and burning of extensive peatlands causes substantial carbon emissions. Here, we report plantation development at nested regional (Kalimantan, 538,346 km2) and local (Ketapang, 12,038 km2) scales from 1990-2010, and project expansion to 2020 within government-allocated leases. With Landsat satellite imagery and above- and below-ground carbon accounting, we develop carbon flux estimates from plantations. Across Kalimantan, by 2010, 13% of total oil palm area (31,640 km2) occurred on peatlands, contributing 27-39% of 1990–2010 net oil palm emissions. Although peatland oil palm area expanded ~1,500% from 2000-2010, 86% of allocated peatland leases remained undeveloped. If these leases are cleared, Kalimantan peatland oil palm could contribute ~10% to Indonesia's CO_2 equivalent emissions by 2020. In Ketapang, plantation land sources exhibited distinctive temporal dynamics, comprising 81% forests on mineral soils (1994–2001), shifting to 69% peatlands (2008–2011). By 2007–2008, oil palm directly caused 40% of peatland deforestation. Business as usual scenario results indicate that ~40% of Ketapang peatlands will be planted with oil palm by 2020, with carbon emissions from peatlands projected to contribute 87% of total regional land-based emissions. While existing regulations prohibiting using fire to prepare lands for plantation agriculture may mitigate peat burning emissions, peat draining will result in committed carbon emissions that will continue beyond 2020.

The Relationship Between Wind Stress and Surface Carbonate Chemistry in the Southern Ocean

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Understanding change and variability in the global carbon cycle requires accurate representation of ocean carbonate chemistry. The Southern Ocean, whose mid-latitude mode and intermediate waters sequester nearly 40% of global anthropogenic CO_2 emissions annually, is of particular interest. Here, we examine interannual variability in Southern Ocean carbonate chemistry using output from a hindcast (1957-2007) simulation of the Community Earth System Model. Below 44 degrees South, we find a significant negative correlation between windspeed and surface carbonate ion concentration. This suggests that wind driven variation in ocean circulation has a significant impact on Southern Ocean carbonate chemistry.

Impacts of compost and manure applications on soil C in managed grasslands

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Compost and manure amendments are often applied to grasslands to improve soil conditions, enhance net primary productivity, and sequester carbon (C). Due to the global prevalence of grasslands, and degraded grasslands in particular, this strategy could contribute to climate change mitigation. The mitigation potential of organic amendments likely depends on several factors, including amendment quality (i.e., C, C:N). To investigate the ecosystem response to different soil amendments, we established research plots on three separate grazed annual grasslands in California. In October 2011, before the rainy season, we applied a thin layer of organic amendments to the study plots. At each site, replicate plots were treated with fresh manure, commercial plant-waste compost, or left untreated. At one site, additional plots were treated with compost with a relatively lower N concentration. The plots were sampled for soil chemical and physical properties (bulk density, temperature, and moisture), plant community composition, and net primary productivity prior to and following treatment applications. Additionally, plots were sampled for greenhouse gas emissions (N_2O, CH_4, and CO_2) following rain events. Results indicated that different amendments had variable impacts on soil C pools. Also, although dry amendments were associated with negligible trace gas fluxes, these fluxes increased after rain events. Nitrous oxide emissions peaked in treatment plots following the first rain event during two consecutive years post-treatment. Lower N2O emissions were observed following rain events later in the rainy season. These field observations will be employed to validate and improve the DayCent biogeochemical model, and to estimate the long-term C sequestration potential of managed California grasslands.

Observed strengthening of the Pacific Equatorial Undercurrent in the SODA record: coupled mechanisms, ocean dynamics, and implications

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The Pacific equatorial undercurrent (EUC) plays a crucial role in global climate and geochemical cycles. It delivers cold, CO_2 - and nutrient-rich water to the eastern Pacific where it feeds the cold tongue. Here, EUC water contributes to the largest oceanic source of atmospheric CO_2 and to maintaining the zonal sea surface temperature (SST) gradient across the Pacific. This thermal gradient is one of the primary drivers of tropical Pacific atmospheric circulation, which affects global weather patterns and climate. Thus, changes in EUC intensity could have dramatic geochemical and climatic repercussions.

Long-term trends in the SODA reanalysis indicate that the EUC has strengthened by as much as 16% since the mid-nineteenth century. Analysis of the zonal momentum budget in the equatorial Pacific explicitly diagnose the mechanisms responsible for this intensification and identify two dynamically distinct seasonal periods (boreal spring and summer) that account for the majority of the EUC's strengthening.

We propose that EUC intensification is key to reconciling the controversial and paradoxical co-occurrence of Walker circulation slow-down and zonal SST-gradient strengthening in the equatorial Pacific. Additionally, this provides support for the proposed ocean "thermostat" control on tropical Pacific circulation response to CO_2 forcing and reemphasizes that it is imperative for global climate models to rigorously incorporate ocean dynamics in order to produce accurate forecasts.

Implementation of Dynamic Leaf Area Index in a Land Surface Model to Improve Water, Energy and Carbon Fluxes

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Phenology defines the photosynthetic active period for plant and thus controls the seasonal activities of various ecosystem processes as well as the interactions and the feedbacks between the terrestrial ecosystems and the climate. In land surface models, phenology and leaf area index (LAI) regularly alters land surface boundary conditions by changing surface albedo, roughness, and surface water and energy fluxes. Therefore, it is a key variable for accurate estimation of seasonal variations of terrestrial ecosystem processes, such as photosynthesis and respiration, as well as land-atmosphere exchange of energy, water and carbon fluxes. In the modeling studies, LAI is prescribed through the use of satellite-based data, while the model accounts for prognostic phenology scheme leading to inconsistency between phonological stages and LAI seasonality. We implement a prognostic LAI method in a land surface model, the Integrated Science Assessment Model (ISAM) based on the leaf carbon content and environmental factors aimed at calculating continuous LAI consistence with plant phonological developments. We perform two model experiments, one with prognostic LAI and other with satellite-based LAI and compare our model results for land-atmosphere water, energy and carbon assimilation fluxes with site measurements. We investigate the advantages of using prognostic LAI for better estimation of the seasonal variation in water, energy and carbon assimilation fluxes. Our analysis reveals that better understanding of the environmental controls on phenology results in a better representation and implementation of phenology and LAI in a land surface model and hence improves the model results for land-atmosphere water, energy and carbon assimilation fluxes.

Can biospheric models reproduce spatiotemporal variability of CO_2 fluxes as observed through atmospheric measurements?

Yuanyuan Fang, Carnegie Institution for Science

Our capability to project future climate and the carbon-climate interaction largely depends on the accuracy of biospheric carbon cycle simulated by terrestrial biospheric models (TBMs).

Understanding the performance of the current TBMs to reproduce the net ecosystem CO_2 exchange (NEE) is an essential first step toward developing a robust TBM, and hence is a key question to the carbon cycle research community.

Geostatistical inverse modeling (GIM) estimates CO_2 fluxes with varying level of complexity of covariate matrix. When incorporated with model selection, GIM can determine covariate variables significantly explaining the spatiotemporal variability of CO_2 fluxes. In this paper, to directly evaluate the spatiotemporal variability of TBM simulated NEE, we develop the GIM-TBM method by applying simulated NEE fluxes as covariates. The TBM simulations discussed are CASA GFEDv2, ORCHIDEE, SiB3 and VEGAS from NACP. If a TBM is selected by GIM-TBM, it suggests this TBM reproduces the spatiotemporal variability consistent with that seen by the atmospheric measurement. We run an additional GIM case (GIM-ENV) using environmental variables as covariates to further interpret the model performance on a process level. Out of 4 TBMs, SiB3 and ORCHIDEE are most frequently selected to significantly explain the variability in fluxes. By assessing BIC associated with each TBM, the overall performance is ranked as: SiB3>ORCHIDEE>CASA-GFEDv2>VEGAS2. 2/3 out of all 84 biome/month are not selected with any TBM, suggesting two possibilities, 1) current atmospheric data is not sufficient to constrain environmental processes; 2) TBMs cannot reproduce the right environmental processes and hence do not reproduce the correct spatiotemporal variability. The GIM-ENV case, however, show more frequent selections than the GIM-TBM case, suggesting that in some biome/month, environmental processes are well constrained by atmospheric measurements, yet are not correctly simulated in TBMs. The inconsistent selection of simple environmental drivers and TBMs are specifically obvious during the transition months. For example, over Eastern Temperate forest, TBMs are not selected over March, April, October and November while environmental variables are selected throughout the year. Further investigation indicates that TBMs cannot represent well either the transition between the processes associated with water availability and radiations during these months, or the sign of the association of fluxes with water availability and temperature. Our study suggests that these 4 TBM simulations have problems in simulating the transition associated with phenology, the environmental processes associated with water and temperature. Focusing on model representation of environmental processes can be a promising new direction to assess, inter-compare and improve TBMs.

Carbon Balance of No-Till Soybean with Winter Wheat Cover Crop in the Southeastern United States.

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The southeast is an important agricultural region in the U.S. and key component of the continental carbon budget. Croplands in the region store a substantial amount of soil organic carbon (C). However, their C sink status may be altered under the projected changes in precipitation pattern for the region. The study was conducted at Winfred Thomas Agricultural Research Station, Hazel Green, Alabama (2007-2009). We investigated the seasonal and interannual variation in net ecosystem exchange of CO_2 (NEE) of winter wheat (Tricticum aestivum) and soybean (Glycine max) using the eddy covariance method. Annual C balance ranged from the highest source in 2007 (NEE = 100 g C m-2 y-1) to sink (-20 g C m-2 y-1) in 2009. Annual ecosystem respiration (Re) ranged between 750 and 1013 g C m-2 y-1, while gross ecosystem productivity (GEP) was 650-1034 g C m-2 y-1. Seasonal NEE for soybean ranged between 42 and -66 g C m-2. Stronger winter wheat NEE (-80.0, -80.4, -40.0 g C m-2 for 2007, 2008 and 2009) than soybean suggested the importance of winter C uptakes offsetting summer C losses. Re was controlled by air temperature, and it varied between 286 and 542 g C m-2 for soybean, and between 160 and 313 g C m-2 for winter wheat. Precipitation was key determinant of C balance implying larger C release during drought periods. During fallow months, the site was C source. If we include removal of grain off site, this system could become a C source under all conditions.

Large-scale increase in seasonal CO_2 exchange by northern terrestrial ecosystems since 1960

Heather Graven, Scripps Institution of Oceanography

As part of the measurement program of the International Geophysical Year (IGY), airborne observations of CO_2 concentration were conducted over the North Pacific and Arctic Oceans during 1958-61. Samples were collected at 700 and 500 mb (approx. 3 and 6 km altitude) and provide good spatial and seasonal coverage, particularly at 500 mb. With the HIAPER Pole-to-Pole Observations (HIPPO) campaign sampling similar regions of the northern troposphere during 2009-11, direct comparison of the two datasets provides a measure of the change in the seasonal cycle of CO_2 between the 1950s-60s and the 2000s. We will show that the seasonal amplitude at 500 mb has increased by 40-60% at latitudes north of 45°N, while amplitude changes south of 45°N are smaller than 25%. This pattern is similar to long-term ground-based CO_2 measurements at Barrow and Mauna Loa. The atmospheric observations demonstrate that large-scale changes in the seasonal flux of CO_2 from northern ecosystems have occurred over the last 50 years. We will investigate the changes in net ecosystem production (NEP) required to produce the observed growth in CO_2 amplitude, discuss mechanisms for the changes in NEP, and examine whether such changes are captured by the terrestrial models participating in the IPCC CMIP5.

The Inorganic Carbon Cycle in a Simple Box Model

Corinne Hartin, Joint Global Change Research Institute

The inorganic carbon cycle is represented in a simple 4-box ocean model. The model contains two surface boxes, a high and low latitude box, an intermediate box, and a deep box. Each ocean box contains a reservoir of total carbon, which is transported between the boxes via advection and water mass exchange; the system can optionally be spun up to a steady-state preindustrial equilibrium. Net air-sea fluxes within the surface boxes are calculated explicitly from the delta pCO_2 between the ocean and atmosphere. The pCO_2 of each surface ocean box is calculated as a function of dissolved inorganic carbon, alkalinity, and equilibrium constants dependent on temperature and salinity. Simple box-models like this can reproduce many of the observations and larger-scale GCM outputs of global trends in atmospheric CO_2 and temperature when coupled with a simple land and atmosphere model. By explicitly calculating the carbon parameters (dissolved inorganic carbon, alkalinity, pH, and pCO_2) in the surface boxes, we can begin to decipher changes to the carbon system under differing climate scenarios. This study will show some preliminary results of this 4-box ocean model and the simple global model of which it is a part of.

Drake Passage oceanic pCO_2: Evaluating CMIP5 Coupled Carbon/Climate Models using in-situ observations

ChuanLi Jiang, Earth and Space Research

Surface water pCO_2 variations in Drake Passage are examined using the decade-long underway shipboard measurements. North of the Polar Front (PF), the observed pCO_2 shows a seasonal cycle that peaks in the August, and dissolved inorganic carbon (DIC)-forced variations are significant. Just south of the PF, pCO_2 shows a small seasonal cycle that peaks in February, and SST and DIC play equal roles. At the PF, the wintertime pCO_2 is nearly in equilibrium with the atmosphere, leading to a small sea-to-air CO_2 flux.

These observations are used to evaluate eight available CMIP5 Earth System Models (ESMs). Six ESMs show spatial mean pCO_2 values that are comparable to observations. However, the model amplitude of the pCO_2 seasonal cycles exceeds the observed amplitude of the pCO_2 seasonal cycles due to models biases in SST and surface DIC. North of the PF, deep winter mixed layers play a larger role in model pCO_2 than they do in observations. Four ESMs show elevated wintertime pCO_2 near the PF, causing a significant sea-to-air CO_2 flux. Wintertime winds in these models are generally stronger than the satellite-derived winds. This not only magnifies the sea-to-air CO_2 flux but also upwells DIC-rich water to the surface and drives strong equatorward Ekman currents. The poleward eddy-driven currents are likely too weak to compensate for these strong equatorward Ekman currents, the residual equatorward currents are thus found stronger in the models than in satellite-derived currents. These strong model currents likely advect the upwelled DIC further equatorward due to strong stratification that precludes subduction below the mixed layer.

The Role of Lateral Processes on Mixed Layer Spring Stratification

Leah Johnson, University of Washington*

Spring stratification can be characterized as warm waters cap off the underlying cold deep winter mixed layer, therefore influencing air-sea interactions and ocean primary productivity. This can happen trivially as wind forcing dies down and the ocean is heated from above, as captured by 1-D mixed layer models. This view fails to capture processes that advect warmer surface waters over colder waters, which initiates stratification faster than would be expected from heat flux alone. Theory and models suggest that small submesocale baroclinic instabilities (mixed layer eddies, or MLEs) that arise at strong lateral density gradients are a prevalent leading order process acting to restratify the mixed layer by advection. MLEs are parameterized in ocean climate models as an overturning streamfunction proportional to the horizontal density gradient and mixed layer depth, yet few observations have been able to validate the global importance of these phenomena. This work takes a global perspective to evaluate the importance of these lateral processes on the timing and properties of the shoaling mixed layer during spring. Observations from the global ARGO database are compared with results predicted by 1-D mixed layer models to suggest where MLEs may be influential in the evolution of the seasonal mixed layer.

Improving predictions of Amazon forest dynamics with a new phosphorus cycle model

Michelle Johnson, University of Leeds

Tropical forests represent a large sink of carbon, however, the future of this sink in response to changing environmental conditions such as temperature and increased droughts is uncertain. Dynamic global vegetation models (DGVMs) are currently used to predict the response of forest carbon to these climate variables. The models predict that rising atmospheric CO_2 concentrations will mitigate the negative impacts on vegetation carbon of higher temperatures and increasingly drier dry seasons in the Amazon. However, the response of tropical forests to rising CO_2 concentrations is still uncertain. Nutrient availability, particularly phosphorus (P) may act to constrain this predicted fertilization effect. I will present work on the development of a dynamic soil phosphorus model evaluated with P observations across the Amazon basin. The model will initially be coupled to an individual, trait-based forest model (TFS) (Fyllas et. al. in prep), which is tailored to be used alongside permanent sample plots in the Amazon.

Carbon-based phytoplankton functional types via remote retrievals of the particle size distribution

Tihomir Kostadinov, University of Richmond

Understanding the spatio-temporal variability of phytoplankton functional types (PFTs) is essential for the characterization of oceanic ecosystems' structure and function and thus for assessment of the ocean's role in biogeochemical cycling and climate formation. Satellite remote sensing of ocean color is the best available tool for sustained continuous oceanic ecosystem observation. Various algorithms for the retrievals of PFTs have been developed in recent years, using different theoretical bases and PFT definitions. The algorithm of Kostadinov et al. (2009, 2010) defines the PFTs in terms of percent contribution to biovolume of three size-based PFT groups: picophytoplankton (here, cell diameter between 0.2 and 2 um), nanophytoplankton (2–20 um) and microphytoplankton (20–50 um). This method is based upon retrievals of the parameters of an assumed power-law particle size distribution (PSD), using existing spectral backscattering retrievals and a theoretically derived look-up table. Phytoplankton carbon biomass (rather than biovolume) is more closely related to phytoplankton productivity, biogeochemical cycling and climate. Here, we develop a procedure to recast the PFTs in terms of relative contribution to carbon biomass, rather than volume. We start with the same PSD retrievals as the volume-based approach (here, derived from monthly SeaWiFS r2010.0 imagery), but convert cell volumes in each size class to carbon biomass before PFT calculation. We use the allometric relationships of Menden-Deuer and Lessard (2000), as in the initial effort by Kostadinov (2009). At this stage the presented products are preliminary and retrieved variables may not be necessarily geophysically accurate. While this especially applies to the absolute values of carbon biomass, carbon-based PFTs are defined by ratios of biomass and are thus subject to less uncertainty. Next steps will focus on further methodology improvements, comparison to existing algorithms and validation of this novel satellite ocean color product.

Re-thinking spring blooms using optimized NPZD models

Angela Kuhn, Dalhousie University*

Understanding the mechanisms controlling the spring bloom of phytoplankton is key to assessing uncertainties in trophic interactions and biogeochemical feedbacks within the context of climate change. The initiation of the North Atlantic spring bloom is receiving a wave of renewed scientific interest, as several new hypotheses have challenged its traditional explanation. According to the traditional critical depth hypothesis, the bloom initiates when the mixed layer (ZMLD) becomes shallower than the critical depth (Zcr, where integrated net phytoplankton growth is zero). Using an evolutionary algorithm, we optimized the parameters of a one-dimensional NPZD (Nutrient – Phytoplankton – Zooplankton – Detritus) model, in order to replicate annual cycles of satellite-based chlorophyll concentrations in the subpolar North Atlantic, with emphasis on the abrupt increase during the winter-spring transition. The optimized models represented the observations accurately. Taking advantage of the low computational cost and flexibility of our model configuration, a set of simple experiments was developed in order to isolate the effects of mixed layer fluctuations and grazing on the timing of the bloom. Our model experiments even achieved an accurate bloom onset using a constant ZMLD, suggesting that the shoaling of the mixed layer was not a requirement for the spring bloom initiation, but determined nutrient depletion and bloom termination. Nevertheless, the critical depth criterion for positive net growth (ZMLD < Zcr) held true for all of our model experiments, as expected. In order to assess the effects of changes in nutrients, zooplankton, light and temperature on net phytoplankton growth, we performed a model sensitivity analysis using a second-order Taylor approximation of the phytoplankton equation. Our results indicate that changes in light and zooplankton have a major effect on winter phytoplankton concentrations, while changes in nutrients mainly affected fall concentrations.

The Carbon Balance of the Terrestrial Biosphere under Climate Change

Emma Littleton, University of East Anglia*

The terrestrial biosphere is the most variable and uncertain of the major components in the global carbon cycle. Inter-annual variability in the terrestrial carbon sink is large, and the processes underpinning this variability are not well understood. This is further confounded by carbon dioxide emissions from anthropogenic land use change, which are also poorly constrained and highly variable both in space and time. Although global carbon cycle models perform reasonably well at replicating observed trends in terrestrial vegetation carbon cycling, there is very poor agreement between models about whether the terrestrial biosphere will remain a sink or become a source during the 21st century. Moreover, the likelihood of large-scale outgassing of carbon from the terrestrial biosphere is unknown and this possibility is poorly constrained in model predictions of 21st century climate change.

Historical Changes to Ocean Fluxes of CO_2

Joseph Majkut, Princeton University

Understanding the long-term trends in the ocean CO_2 flux is challenging because of inadequate measurements and strong seasonal and interannual variability. I present a method for estimating ocean surface pCO_2 using statistical inversion and biogeochemical models. The trends that I calculate show an increasing oceanic uptake of CO_2 and indicate that large oceanic feedbacks are unlikely to have already occurred.

Improving long-term forecasts of ecosystem-climate dynamics through community-based model-data fusion

Jaclyn Matthes, Boston University

The co-evolution of rapidly growing and more automated ecological data collection along with advances in ecological data assimilation has created excellent opportunity for increased interactions between data and models. In this big-data framework, models are particularly useful as scaffolds for analyzing connections between ecological and climate processes occurring at multiple scales through time and space. While model accessibility and data informatics can be obstacles to successful model-data fusion for large-scale terrestrial biosphere models, we argue that these challenges are surmountable through collaborative community efforts. We present two case studies of on-going model-data fusion projects to highlight how barriers of accessibility and data informatics can be overcome: 1) the Predictive Ecosystem Analyzer (PEcAn) project lowers accessibility barriers by providing a generalized web-based framework for rigorous model-data fusion, and 2) the PaleoEcological Observatory Network (PalEON), unites paleoecologists, statisticians, and modelers to improve long-term forecasting of ecological dynamics by synthesizing diverse paleoecological data and ecosystem models with data informatics.

Invasion of a semi-arid shrubland by annual grasses increases autotrophic and heterotrophic soil respiration rates due to altered soil moisture and temperature patterns.

Marguerite Mauritz, San Diego State University*

Shrub <-> grassland conversions are a globally occurring phenomenon altering habitat structure, quality and nutrient cycling. Grasses and shrubs differ in their above and belowground biomass allocation, root architecture, phenology, litter quality and quantity. Conversion affects soil microbial communities, soil moisture and temperature and carbon (C) allocation patterns. However, the effect of conversion on C storage is regionally variable and there is no consistent direction of change. In Southern California invasion by annual grasses is a major threat to native shrub communities and it has been proposed that grass invasion increases NPP and ecosystem C storage (Wolkovich et al, 2009). In order to better understand how this shrub <-> grassland conversion changes ecosystem C storage it is important to understand the partitioning of soil respiration into autotrophic and heterotrophic components.

Respiration was measured in plots under shrubs and grasses from February when it was cold and wet to July when it was hot and dry, capturing seasonal transitions in temperature and water availability. Roots were excluded under shrubs and grasses with root exclusion cores to quantify heterotrophic respiration. Using total soil respiration (Rt) = autotrophic respiration (root) (Ra)+ heterotrophic respiration (microbial) (Rh) the components contributing to total soil respiration can be evaluated. Respiration, soil moisture and temperature were measured daily at four hour intervals using Licor 8100 automated chamber measurements.

Throughout the measurement period, Rt under grasses exceeded Rt under shrubs. Higher Rt levels under grasses were mainly due to higher Ra in grasses rather than changes in Rh. On average grass Ra was almost double shrub Ra. Higher grass respiration levels are partially explained by differences in soil moisture and temperature between shrubs and grasses.

Respiration rates responded similarly to seasonal transitions regardless of treatment although Rt had a much stronger seasonal response. Across all months changes in respiration rates are explained by changes in soil moisture. However, within wet periods respiration rates increase with temperature. From February to April the soil was wet and respiration levels gradually increased as day time soil temperatures increased. From April onwards absence of precipitation events and rising soil temperatures caused the soils to rapidly dry out. As a result Rt rates declined and gradually converged with Rh levels. As soils dried, grass Rt declined more gradually than shrub Rt. This was contrary to our expectation that shrub roots would respire longer into the dry season because they have deeper roots and can access water. The high late-season levels of respiration observed in the grass community are possibly due to the presence of invasive forbs which have deep tap roots and continue to grow after the grasses have senesced.

Conversion from native shrubs to annual invasive grasses increased both Rt and Rh which indicates changes in plant C allocation and decomposition rates of soil C. The continued encroachment of grasses on shrubland has important implications for the future of C storage in this system.

Ocean Circulation During the Last Glacial Maximum Simulated by PMIP3 Climate Models

Juan Muglia, Oregon State University*

Computer simulated meridional streamfunction data were obtained from several PMIP3 models, from the Last Glacial Maximum (LGM, ~20,000 years ago) and the pre-industrial Holocene. Meridional streamfunction has units of volume transport, and is a measure of the strength of the zonally-integrated meridional water flow in an ocean. We evaluated the difference between both time periods, by taking yearly averages in a time span of 50 years for each model in both periods, and subtracting, for each model, the averaged values for the LGM and the pre-industrial Holocene streamfunction. We defined two regions, the Atlantic Ocean, between 30° S and 60° N, and the World Ocean, containing all of Earth's water masses. We identified the areas where the difference in water transport is most conspicuous, finding a 50% strengthen of the Atlantic Overturning Circulation in the LGM, as averaged from all the PIMP3 models used. Current work is aimed at understanding the reason for the circulation changes by studying correlations with changes in other relevant variables, such as the potential density contrast between and within ocean basins. In the future we will investigate the effects of the circulation changes on the carbon cycle.

Iron-light colimitation increases sensitivity of oceanic CO_2 drawdown to dust deposition

Levin Nickelsen, Helmholtz Centre for Ocean Research Kiel*

The iron hypothesis suggests that in large areas of the ocean phytoplankton growth and thus CO_2-uptake is limited by the micronutrient iron. Indeed, iron fertilization experiments show that phytoplankton needs iron in particular for nitrate uptake, light harvesting, synthesis of chlorophyll and in the electron transport chain of photosynthesis. One important source of iron to the open ocean is dust deposition. Previous global biogeochemical model studies about the sensitivity of oceanic CO_2-uptake to dust deposition do not consider direct effects of iron availability on light limitation. Here we show that this sensitivity is increased significantly when iron-light colimitation, i.e. the impact of iron on light harvesting capabilities and chlorophyll synthesis, is explicitly considered in a global biogeochemical ocean model. Iron-light colimitation increases the shift of export production to higher latitudes at high dust deposition and amplifies iron limitation at low dust deposition. Our results suggest that iron fertilization by increased dust deposition may explain a larger portion of the observed past CO_2 variability than thought previously. Our results emphasize the role of iron as a key limiting nutrient for phytoplankton in the ocean, with a high potential for changes in oceanic iron supply affecting the global carbon cycle and climate.

Steps Towards a Multi-year Continental Inversion: Comparing Simulated CO_2 Mixing Ratios in ABL to the North American Tower Network

Caroline Normile, Penn State University*

Continental scale inversions of carbon sources and sinks require the use of atmospheric transport models that are often the main contributors of inverse flux uncertainties. Multi-model comparisons and assessments of the simulated atmospheric transport have been performed at larger scales but our understanding of model error impact remains limited at higher resolutions. Our forward simulations, a preliminary step towards quantifying the impact of transport models on inverse fluxes, use initial conditions, lateral boundary conditions, and biogenic surface fluxes from the Carbon Tracker system, fossil fuel emissions from both Vulcan and CDIAC, and transport from WRF-Chem. We show measurements and simulations of the seasonal and weather-driven temporal and spatial patterns of the mole fraction of CO_2 in the atmospheric boundary layer (ABL) and the vertical column over the continent. The simulations capture many but not all characteristics of the observed spatial distributions and temporal patterns of atmospheric CO_2, indicating that errors in the surface flux fields and differences between WRF and Carbon Tracker (TM5) atmospheric transport may be possible explanations. Next steps include multi-year continental inversions that include reasonable variations in atmospheric transport and investigation of the possible benefits of column CO_2 observations from the Orbiting Carbon Observatory-2. This work is motivated by the need for improved land-atmospheric carbon exchange modeling over the North American continent.

Modeled Seasonality of the Biogeochemistry of Pre-*Dreissena* Mussel Lake Michigan

Darren Pilcher, University of Wisconsin*

The MIT General Circulation Model was configured to the bathymetry of Lake Michigan at 1-minute resolution to model the physical and biological characteristics of the lake. This eddy-resolving computational model is forced by atmospheric data from the North American Regional

Reanalysis Program. The purpose of this model is to provide an effective tool towards assessing the spatial impacts invasive *Dreissena* mussels have had on lake productivity and biogeochemistry. The first step, detailed here, was the creation of a pre-*Dreissena* model state based on lake observations collected prior to the arrival of invasive mussels. Comparisons with observational data show that the model sufficiently captures the timing and magnitude of late winter/early spring primary production. This timeframe is critical towards incorporating invasive mussels, since the recently established quagga (*Dreissena rostriformis bugensis*) mussel is able to colonize offshore regions inaccessible to the once dominant zebra (*Dreissena polymorpha*) mussel. Stratification effectively blocks quagga mussel interaction with the euphotic layer during the summer and fall, however, the mussels are able to directly interact with the entire water column during late winter/early spring isothermal mixing. This study provides the pre-*Dreissena* model that is verified with physical and biological observational data, providing confidence that it is reasonable representation of pre-*Dreissena* Lake Michigan biogeochemistry.

Links between soil water availability and soil respiration in semi-arid ecosystems along the Colorado Front Range

Katherine Powell, University of Colorado*

Drylands cover approximately 40% of the world's terrestrial ecosystems, and this includes mostly arid and semi-arid regions. As water-limited environments, they are sensitive to changes in soil water content which may result in large carbon efflux from soils in response to precipitation events. Previous research has demonstrated that soil temperature and soil water content (e.g. volumetric or gravimetric) are the primary controls on soil respiration (Rs), however, few studies relate soil water potential to Rs, although it may be a better metric for representing how water is available to soil microbes and vegetation. Therefore, resolving how episodic changes in soil water potential cause arid/semi-arid ecosystems to shift from a carbon sink to a source is important for improving future estimates of terrestrial ecosystem fluxes in these areas. Our study focuses on above and belowground fluxes of CO_2 and water at two grassland sites and one montane forest site in Colorado. Continuous (hourly) soil CO_2 concentration profile measurements, at 5 cm, 10 cm and 20 cm (15 cm in the grasslands) are coupled with continuous (30 minute), collocated soil water content and soil temperature (Ts) measurements. Soil water availability is determined by using tensiometers at each site to relate volumetric water content to matric potential values. All of the sites have ongoing eddy covariance-based surface measurements of water, carbon and energy fluxes, including net ecosystem exchange (NEE). To estimate Rs at the surface, discrete fluxes of CO_2 are measured with a portable photosynthesis system (chamber) and soil surface CO_2 concentration measurements. To characterize changes in aboveground biomass, vegetation samples are routinely collected from each of the sites and leaf area index (LAI) and dry biomass are determined. Time-series plots of Rs are compared with aboveground fluxes of CO_2 as well as soil water, Ts, precipitation, air temperature (Ta), photosynthetically active radiation (PAR), humidity, evapotranspiration (ET), and LAI. Preliminary results show soil CO_2 concentration increases were well correlated with soil water content increases at the same soil depth following precipitation events. More measurements and calculations will be required to determine monthly and seasonal responses and to make further comparisons with aboveground fluxes and biomass changes.

Identifying Sources of Uncertainty to Improve the Simulation of Long Term Carbon Sequestration in Northern Wisconsin

Brett Raczka, Penn State University*

A significant portion of uncertainty related to climate change is attributed to the terrestrial system feedback upon the climate. The Ecosystem Demography Model (ED2), a terrestrial biosphere model (TBM), is uniquely suited to help diagnose, quantify and predict the net exchange of carbon between the atmosphere and land, thereby specifying the sign and magnitude of the climate feedback. ED2 uses size and age structured vegetation equations to capture the competition that a single tree experiences for light and nutrients. This gap-level competition is important for simulating successional growth and long term carbon dynamics that other 'big-leaf' models may miss. Here, we strive to identify sources of uncertainty that impact the carbon sequestration of a forest at centennial time scales including the impact of initial conditions, meteorology and the model's parametric uncertainty. To that goal we perform a 100 year simulation at Willow Creek, Wisconsin (1901-2010). In order to Initialize the model simulation we sample from witness tree observations from the year 1900 that define forest composition and structure. We create synthetic meteorology in which to drive the model by combining inter-annual variation in weather variables as defined by CRU-NCEP re-analysis data, and include sub-annual variation as measured by tower-based observation at Willow Creek. Initial findings indicate that the simulated carbon sequestration is sensitive to the type and temporal resolution of the meteorology (50% difference in cumulative NEE), as well as the initial forest composition and structure (25% difference in cumulative NEE). We find that the suite of parameters most consistent with present day observations at Willow Creek use identical density dependent mortality amongst all plant function types. We intend to perform a parametric sensitivity analysis based on carbon sequestration for 10, 50 and 100 year simulation periods. These findings will help guide future observational system studies.

Distinguishing Nutrient and Light Drivers of Productivity Trends In the North Atlantic Intergyre Region

Alexis Santos, University of Wisconsin*

The North Atlantic Ocean absorbs 23% of the atmospheric carbon dioxide taken up by the ocean, making it the most intense carbon sink region. The solubility pump is major driver for this sink, with the added influence of the biological pump that is characterized by a dramatic spring phytoplankton bloom. In the boundary zone between the subtropical and subpolar gyre, a large region spanning 40-60 N, 20-40 W experienced a significant decline in satellite-observed chlorophyll a concentrations over the period 1998 to 2007. Phytoplankton growth is limited by the abundance of light and nutrients in the ocean, and this intergyre region is one of transition between subtropical nutrient-limitation and subpolar light-limitation. We are using a biogeochemical general circulation model to quantify the degree to which nutrients and/or light have driven the decreasing chlorophyll a concentrations in the intergyre region.

Circumpolar assessment of permafrost C quality and its vulnerability over time using long-term incubation studies

Christina Schädel, University of Florida

High latitude ecosystems store approximately 1700Pg of soil carbon (C), which is twice as much C as is currently contained in the atmosphere. Permafrost thaw and subsequent microbial decomposition of permafrost organic matter could add large amounts of C to the atmosphere, thereby influencing the global C cycle. The rates at which C is being released from the permafrost zone at different soil depths and across different physiographic regions are poorly understood but crucial in understanding future changes in permafrost C storage with climate change. We assessed the inherent decomposability of permafrost C once thawed by assembling a database of long-term (>1year) aerobic soil incubations from 121 individual cores from 23 high latitude ecosystems located across the northern circumpolar permafrost zone. Using a 3-pool decomposition model, we estimated pool sizes for C fractions with different turnover times and their inherent decomposition rates using a reference temperature of 5°C. Fast cycling C accounted for less than 5% of all C in organic and mineral soils whereas the pool size of slow cycling C increased with increasing C:N ratio. The stable C pool was particularly large in deep mineral soils and accounted for up to 90% of the total C in these soils. Turnover times of fast cycling C typically ranged below one year, between 5-15 years for slow turning over C, and more than 500 years for stable C. With our findings we scaled up potential C loss from these high latitude soils over time and calculated that between 20-90% of the organic C in the studied soils could be lost within 50 years with the highest vulnerability to loss in soils with high C:N ratios. These results demonstrate the vulnerability of C stored in permafrost to increasing temperatures, and show that the wide range of potential loss significantly correlates with C:N ratio, which needs to be incorporated in to models projecting permafrost C loss.

Millennial variability of ocean circulation and biogeochemical cycles during the last ice age

Andreas Schmittner, Oregon State University

Millennial time-scale variability of ocean circulation during the last ice age was associated with some abrupt and large climate changes particularly in the North Atlantic. Ice-core data show that atmospheric CO_2 and other greenhouse gas concentrations co-varied on these time scales. Model simulations reveal the effect of large changes in the Atlantic Meridional Overturning Circulation on global cycling of nutrients, oxygen, and carbon in the ocean and the effects on atmospheric greenhouse gas concentrations. Gradual millennial changes in CO_2 can be understood by variations in the efficiency of the biological pump due to circulation changes. New high resolution ice-core data show abrupt CO_2 variations that are currently not understood.

Reducing Uncertainty in the Global Carbon Cycle from Land Use Application of Earth System Model Initialization

Lori Sentman, NOAA/GFDL

NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) has developed two new Earth System Models (ESMs) to better understand the interactions and feedbacks between biogeochemical cycles and the climate system. ESM2M and ESM2G, recent contributors to the Coupled Model Intercomparison Project Phase 5 (CMIP5) database, are based on GFDL's coupled Climate Model version 2.1 (CM2.1) and successfully simulate the global climate and carbon cycle. The land component, LM3, has been designed to simulate the effects of land use on terrestrial carbon pools, including secondary vegetation regrowth following land use disturbances which has been shown to be an important terrestrial carbon sink. Because of the long time scales associated with the carbon adjustment of imposing land use when simulating secondary vegetation regrowth, special consideration is required when initializing the GFDL ESMs for historical CMIP5 simulations. We explore the uncertainty in the terrestrial carbon stores and fluxes associated with land use application using the uncoupled, land-only model by instantaneously applying estimates of historical land use in five experiments beginning in calendar years 1500, 1600, 1700, 1750, and 1800. The application of land use results in the land carbon pools experiencing an abrupt change – a carbon shock – and the secondary vegetation needs time to regrow into consistency with the harvesting history. Our analysis shows that it takes approximately 100 years for the vegetation to recover from this carbon shock, whereas soils take longer to recover, at least 150 years. The vegetation carbon response is driven primarily by land-use history, while the soil carbon response is affected by both land-use history and the geographic pattern of soil respiration rates. Around the start of the historical CMIP5 simulations in 1850, we computed the simulated net land carbon sources to be 0.418 GtC yr-1, 0.412 GtC yr-1, 0.427 GtC yr-1, 0.390 GtC yr-1 and 0.166 GtC yr-1, when land use was applied in 1500, 1600, 1700, 1750 and 1800, respectively. These fluxes were compared to the most recent estimate of 0.501 GtC yr-1 in 1850, and show the importance of land use on the historical carbon fluxes. Based on these results, we recommend the application of historical land-use scenarios in 1700 to provide sufficient time for the land carbon in ESMs with secondary vegetation to equilibrate to adequately simulate carbon stores at the start of the CMIP5 historical integrations. Additional results exploring the effect of land use on the global carbon cycle in the recent GFDL ESM CMIP5 simulations will also be presented.

Assessment of iron cycling in the CESM-BEC model using high resolution CLIVAR data

Elliot Sherman, UC Irvine*

We use high resolution CLIVAR dissolved iron measurements and the Tagliabue et al. 2012 dissolved iron dataset to quantitatively assess simulation of the iron cycle in the global scale Biogeochemical Elemental Cycling (BEC) model. The goals of this study were to evaluate iron cycling in the BEC model and to better understand what parameters are driving model errors. Comparisons and statistical analysis of field observations to model simulations were conducted at the same geographical location and depth in the water column. We found that the BEC model does well in simulating dissolved iron distributions with correlation coefficients >0.5 in many regions. The model is able to capture general characteristic features and basin specific features of dissolved iron in the ocean. Parameters governing iron scavenging, implicit iron ligands and the iron sedimentary source seem to be responsible for model errors. The next step in improving iron cycling simulation in the BEC model is to use available dissolved iron measurements to further constrain and improve the mentioned parameters.

How do microarthropods impact soil carbon sequestration during litter decomposition in a tallgrass prairie?

Jennifer Soong, Colorado State*

Soil microarthropods are commonly understood to accelerate the process of litter decomposition in temperate ecosystems. However, it is unknown how microarthropods affect the litter decomposition process in ways that may change the relative amount of carbon (C) mineralized and lost as CO_2 vs. that stored in the soil as soil organic matter (SOM). The acceleration of litter decomposition by microarthropods could increase the loss of litter C as CO_2 from the ecosystem, or it could increase the amount of litter C transformed into long-term stabilized SOM products of decomposition. In order to examine how microarthropods impact the soil microbial community involved in litter decomposition, soil CO_2 efflux, and SOM formation we incubated 13C and 15N labeled leaf litter (Andropogon gerardii) in a native tallgrass prairie in Kansas, USA, and applied a naphthalene treatment to suppress microarthropods. Over the first two years of decomposition, we traced the decomposing litter C, both with microarthropods and with naphthalene suppressant, into CO_2 fluxes, bulk soil, the microbial community using phospholipid fatty acid biomarkers (PLFA), and soil microarthropods. We found that the presence of microarthropods reduced microbial biomass, in particular the abundance of fungi and gram-negative bacteria, but increased microbial litter-C utilization. Litter C loss as CO_2 varied throughout the two year period and soil C incorporation does not appear to be different between the microarthropod suppression and the control. These results provide new insight into the role of microarthropods in controlling the incorporation of litter C into microbial biomass, which is important for longer term carbon sequestration in soils. This understanding of how soil biodiversity impacts soil carbon sequestration can provide insight into our ability to accurately model terrestrial ecosystem C cycling under changing global conditions.

Regional footprints and transport regimes for CO_2 measurement sites in New Zealand from backward Lagrangian dispersion modelling

Kay Steinkamp, NIWA

Since 1990, New Zealand's CO_2 equivalent greenhouse gas emissions increased by about 20%, yet it is estimated that its net greenhouse gas budget remained at 1990 levels due to a compensating increase in carbon uptake by forests. This terrestrial uptake plays a key role in the contemporary and future carbon cycle of the country, but remains poorly quantified. Global studies suggest that natural carbon sinks are sensitive to changes in climate and could already have become less efficient, with strong impacts on net carbon release. We use the UK Met Office's Lagrangian dispersion model NAME III to link CO_2 observations at stations directly to atmospheric transport and potential source regions at the surface. By running the model in backward mode, we identify the degree to which potential regional sources of CO_2 contribute to observed mixing ratios, i.e. the footprint of the station. Footprints are computed over the period 2011-2012 for the three stations Baring Head, Lauder and Rainbow Mountain. NAME III uses hourly meteorological input from the regional forecast model NZLAM-12 over a domain covering New Zealand and the Tasman Sea at a horizontal resolution of 12 km. In addition, we use the large body of back trajectories to identify the predominant transport pathways for each station and to cluster the CO_2 observations into a discrete set of transport regimes. We present preliminary results of the footprint and cluster analyses and outline how the results will be used to estimate terrestrial sources and sinks of CO_2 at a regional scale.

Production and Accumulation of Organic Carbon in the Southern California Current Region

Brandon Stephens, UC San Diego*

The California Current is subject to decadal scale variability in terms of both physical (i.e. stratification, temperature regimes) and biological (e.g., abundance of anchovies versus sardines) parameters. Identification of such long-term trends has been facilitated by the rich dataset maintained by the California Cooperative Fisheries Investigations (CalCOFI) program, which was incepted in 1949. Recent CalCOFI observations have demonstrated an increase in biological productivity (Kahru M, et al., Deep-Sea Res II, 2012), a shoaling of the nitricline and euphotic zone (Aksnes and Ohman, 2009) and an increase in offshore wind stress curl-derived upwelling (Rykaczewski and Checkley, 2008). To study the effects of climate variability on carbon stocks in the Southern California Current the research presented here combines total carbon observations and measured hydrographic variables.

Preliminary assessments of organic carbon data indicate that particulate organic carbon (POC) in the Southern California Bight is 5-20% of the total organic carbon (TOC) pool, peaking within 100km of shore in spring due to upwelling-induced biological productivity. Recently produced TOC appears to be quickly remineralized within the surface layers (i.e. depth <150m or potential density<26.0 kg m-3) down to the background TOC concentrations of 40-50 uM C. With the support of pCFC-12 water mass age estimates, the more recently produced organic carbon appears to be remineralized at a rate of 1-15 umol C yr-1 depending on the season and region in CalCOFI, while breakdown of the highly reactive carbon pool could contribute up to as much as 50% of oxygen utilization (as carbon equivalents). Given the importance of eastern oceanic boundary systems for the global carbon cycle we aim to delineate the role of climate variability, if any, in controlling the size of the dissolved and suspended organic carbon reservoir. Partitioning of net community production into these reservoirs has important implications as they may be available for horizontal transport away from sites of production and also serve as fuel for a range of ecosystem components.

Strong Observational Constraints on Seasonal Northern Extratropical CO_2 Exchange

Britton Stephens, NCAR

Seasonal CO_2 exchange with northern extratropical terrestrial ecosystems is the largest of all influences on atmospheric CO_2 distribution. Yet, this quantity is remarkable for how poorly it is known. Quantitative estimates of the amount of CO_2 that leaves and enters the Northern Hemisphere extratropical troposphere each year vary by a factor of 4 for state-of-the art prognostic models, and by 50% for global atmospheric inverse models. I will present new estimates of this quantity, based on airborne and ground-based CO_2 observations, that provide valuable constraints on global terrestrial ecosystem models and carbon budgeting exercises. Prognostic models of terrestrial CO_2 exchange have typically been validated by propagation through atmospheric transport models and comparison of the resulting signals to observations from surface stations, making such validations particularly sensitive to the large uncertainties in seasonal vertical mixing in the transport models. Furthermore, global atmospheric CO_2 inverse models with incorrect estimates for this seasonal exchange, or incorrect dilution of northern terrestrial signals in different seasons, will by necessity make biased estimates of the much smaller residual annual-mean fluxes, such as tropical or northern terrestrial net ecosystem exchange.

We use high-resolution airborne CO_2 observations from the HIAPER Pole-to-Pole Observations (HIPPO) campaigns, spanning the Pacific Basin from 67 S to 87 N and the surface to 14 km and collected at 9 different times of year, to provide direct measurements of seasonal hemispheric-scale CO_2 exchange. I use output from the ACTM atmospheric transport model and output from the TransCom 3 collection of models to show that a slice down 180 W provides a very good approximation of zonal mean concentrations, and to establish that the link between extratropical atmospheric molar abundances and extratropical surface fluxes is largely model-independent. I use observations from surface stations and ongoing aircraft vertical profiles to aid interpolation of the 9 HIPPO missions to the full annual cycle and to place these 2009-2011 campaigns in context of longer-term interannual variations. Finally, I will show comparisons of our observations to terrestrial ecosystem fluxes from CMIP5 models and a range of atmospheric inverse results.

Surface CO_2 flux in weekly temporal resolution over the globe inferred from the CONTRAIL dataset

Shoichi Taguchi, National Institute of Advanced Industrial Science and Technology, Japan

The atmospheric concentrations of CO_2 measured on board the passenger aircraft Comprehensive Observational Network for Trace gases by Air Liner (CONTRAIL) combined with a global atmospheric transport model (Simulator of Trace Atmospheric constituent on a Global scale; STAG) were used to estimate the emissions and absorptions of atmospheric CO_2 at the surface of the globe. A Bayesian synthesis inverse method was used to measure weekly emissions at 64 areas during the years 2005–2009 (261 weeks) using 206912 tropospheric (PV < 2, 5 km <) samples outside a 2° × 2° area around the Narita Airport. The results indicated a significant increase in emissions during the winter in North America and tropical Africa. The largest weekly emission (2.9 PgC/yr) was measured in the northeastern United States from June 28 to July 4, 2008. The largest weekly absorption (2.9 PgC/yr) was measured in Southeast Asia on March 17–23, 2007. The corresponding measurements for the largest emission are those over Europe (July 5–14, 2008). Those for the largest absorption were those over Japan and the west coast of the United States (March 24–31, 2007). The root-mean-square error between the model and the observations was 1.7 ppm when using the sources and sinks of Carbon Tracker/NOAA, while it was reduced to 1.3 ppm using the revised flux. The seasonal cycle in the model and the data mismatch remained at a size of 6 ppm (peak to peak) north of 60°N in the simulations with revised flux, which indicates an unknown transport error in the model.

Carbon Climate Interactions in India

Yogesh Tiwari, Indian Institute of Tropical Meterology

The association between atmospheric CO_2 and rainfall and vegetation over India is a critical question. Indian subcontinent is a portion of monsoon Asia where a significant seasonal shift of wind patterns occurs throughout the entire area and is covered by a range of ecosystems including tropical forests and tundra in Himalayan Mountains. These ecosystems contribute significantly in global terrestrial net primary productivity. On the other hand, India is supporting a population of around 1.2 billon and experiencing a steep rise in energy demand. Therefore Indian subcontinent is of critical importance to the understanding of how climate drivers and elevated atmospheric CO_2 interacts to influence the functioning of ecosystem and biosphere. Given the dependence of large populations on monsoon rainfall, the response of Indian summer monsoon dynamics to elevated atmospheric greenhouse gas concentrations is an issue of both scientific and societal importance. More information on how the biosphere associates with atmospheric CO_2 is needed to understand the Earth's carbon cycle. Consequently studies should be undertaken to delineate the relations between atmospheric CO_2 concentrations and changes in climate drivers such as rainfall and vegetation. In this study we investigate with available data sets to examine how variations in atmospheric CO_2 observations are associated with rainfall and vegetation over India.

Changes in Carbon Pools 50 Years after Reversion of a Landscape Dominated by Agriculture to Managed Forests in the Southeastern Atlantic Coastal Plain

Carl Trettin, US Forest Service

The landscape of the upper coastal plain of South Carolina in the late 1940's was typified by rural agricultural communities and farms comprising cleared fields and mixed-use woodlots. Approximately 80,000 ha of that landscape was appropriated by the US Government in the early 1950's to form the Savannah River Site which is now managed by the US Dept. of Energy. The US Forest Service was engaged to reforest the agricultural parcels, 40% of the tract, and to develop sustainable management practices for the woodlots and restored areas. We've used those inventories in conjunction with soil resource data to assemble a carbon balance sheet encompassing the above and belowground carbon pools over the 50 year period. We've also employed inventories on forest removals, forest burning and runoff to estimate fluxes from the landscape over the same period. There was a net sequestration of 5,486 Gg of C in forest vegetation over the 50 yr. period (1.5 Mg ha-1 yr-1), with carbon density increasing from 6.3 to 83.3 Mg ha-1. The reforestation of the agricultural land and the increased density of the former woodlots was the cause of the gain. The forest floor increased by 311 Gg carbon. Fluxes in the form of harvested wood and oxidation from burning were 24% and 10% respectively of the net gain in vegetative biomass. These findings document real changes in carbon storage on a landscape that was changed from mixed agricultural use to managed forests, and they suggest responses that should be similar if reforestation for biofuels production is expanded.

Bottom-up Scaling of Net Ecosystem Exchange over North America and Evaluation with an Atmospheric Inversion Setup

David Turner, Oregon State University

Diagnostic carbon cycle models produce estimates of net ecosystem production (NEP, the balance of net primary production and heterotrophic respiration) by integrating information from 1) satellite-based observations of land surface vegetation characteristics, 2) distributed meteorological data, and 3) eddy covariance flux tower observations of net ecosystem exchange (used in model parameterization). However, a full bottom-up accounting of net ecosystem exchange (NEE, the vertical carbon flux) that is suitable for integration with atmosphere-based inversion modeling also includes emissions from decomposition/respiration of harvested forest and agricultural products, CO_2 evasion from streams and rivers, and biomass burning. In this study, we produce a daily time step NEE for North America for the year 2004 that includes NEP as well as the additional emissions. This NEE product was run in the forward mode through the CarbonTracker inversion setup to evaluate its consistency with CO_2 concentration observations. The year 2004 was climatologically favorable for NEP over North America and the continental total was estimated at 1730 ± 370 TgC yr-1 (a carbon sink). Harvested product emissions (316 ±

80 TgC yr-1), river/stream evasion (158 ± 50 TgC yr-1), and fire emissions (142 ± 45TgC yr-1) counteract a large proportion (35 %) of the NEP sink. Geographic areas with strong carbon sinks included Midwest U.S. croplands, and forested regions of the Northeast, Southeast, and Pacific Northwest. The forward mode run with CarbonTracker produced good agreement between observed and simulated wintertime CO_2 concentrations aggregated over 8 measurement sites around North America, but overestimates of summertime concentrations that suggested an underestimation of summertime C uptake. Because terrestrial NEP is the dominant offset to fossil fuel emission over North America, a good understanding of its spatial and temporal variation ─ as well as the fate of the carbon it sequesters ─ is needed for a comprehensive view of the carbon cycle.

Refining expectations of soil organic carbon storage under future climate change with observational studies

Julie Wolf, University of Maryland

The effects of multiple global change factors on soil carbon stocks are difficult to capture in short-term experiments. Urbanization and other microsite qualities can impose long-term, gradual increases in temperature, carbon dioxide and ozone levels that fluctuate over time and interact freely with other ecosystem attributes. These increases can simulate realistic, near-future climate change conditions.

At 62 golf courses in the temperate, mesic, mid-Atlantic region of the U.S., I conducted an observational study of soil carbon in minimally managed soils at varying distances from urbanized areas, where cool-season turfgrasses had been grown without soil disturbance for ≥ 25 years. Replicate soil cores were taken to a depth of 30 cm, hourly soil temperatures were recorded for seven months, tropospheric ozone levels were passively monitored during the late-summer peak season, and site and management variables were recorded. Soil chemistry, texture, and total and active carbon content were measured from the composite soil core samples. Correlations of total and active soil carbon with potential explanatory factors were explored using multiple regression analysis.

Total soil carbon was positively correlated with increasing February-only mean daily minimum soil temperature, which ranged from 0.3 - 2.7 °C. Mechanisms may include freeze/thaw disruption and subsequent mineralization of soil organic carbon, and/or reduced plant inputs to soil resulting from increased cold stress. No relationships were detected between total or active soil C and overall mean Dec.-May temperature, which ranged from 6.0 – 9.0 °C, or maximum May-only temperature, which ranged from 18.0 – 23.3 °C. Total and active soil carbon were positively correlated with increasing ozone levels and negatively correlated with fertilization; potential mechanisms include recalcitrance of ozone-oxidized plant tissues, ozone inhibition of soil microbial respiration, and fertilizer-induced carbon consumption by soil microbial biomass. Total soil carbon was also positively correlated with soil lead content and CEC. Together, the suite of detected correlations suggests that within a climatic region, factors impacting soil carbon availability explain a large part of the variation in soil carbon storage. These results also highlight that small increases in temperature ranges can have important effects, and that commonly-held expectations based on controlled experiments and models are not always observed in complex natural systems.

CH_4 Emissions from Tropical Fires

John Worden, JPL and Caltech

Dry conditions from a moderate El Nino during the fall of 2006 resulted in enhanced burning with fire emissions of approximately 4-6 times larger than the year before. Here we use tropospheric methane and CO data from the Aura Tropospheric Emission Spectrometer (TES) and CO profile measurements from the TERRA Measurements of Pollution in the Troposphere (MOPITT) satellite instruments to quantify methane emissions from these fires. We estimate methane emissions of 4.5 Tg +/- 4.0% with an accuracy of XXX % for October-November 2006. The accuracy is driven by errors in convection in the GEOS-Chem model and is evaluated by comparing MOPITT CO profiles to GEOS-Chem CO profiles. Despite this pulse of methane from the Indonesian fires, the total global distribution of atmospheric methane remained approximately constant, relative to 2005, indicating that tropical biomass burning emissions can compensate for expected decreases in wetlands emissions elsewhere resulting from ENSO related drying.

Changing seasonality of convective events in the Labrador Sea

Fan Zhang, Georgia Institute of Technology*

The long-term goal of this ongoing project is to understand the interannual variability of oxygen and nutrients in the Labrador Sea, one of major sites for deep water formation in the North Atlantic. We hypothesize that fluctuations of oxygen and nutrients share some characteristics of hydrographic (T,S) variability due to changes in physical circulation, mixing and water mass structures. We first investigate the interannual variability of the deep convection in the central Labrador Sea from 1980 to 2009. It is found that the deep convection in the central Labrador Sea since the late 1990s experienced weakening magnitude, shifting seasonality by approximately three weeks, and shortening duration. Such changes are dominated by the local atmospheric forcing and are associated to a weakening of heat fluxes from December to April and winds from November to March. Those changes are enhanced by the warming of the Irminger Current that is ongoing since the late 1990s. Irminger water is advected to the central Labrador Sea through eddy-propagation. Moreover, the convection correlates significantly with the local atmospheric forcing in winter and the following spring, when convective events mainly occur. No significant correlations are found between the convection and atmospheric forcing in other seasons, indicating that the convection has little memory of the atmospheric conditions.