To understand human impacts on earth system function, we must develop internally consistent models for the biogeochemical cycle of major elements. We will show approaches to this challenge using, as an example, our recent attempt to synthesize the global boron cycle, using the few data currently available. The global B cycle is primarily driven by a large flux (1.38 TgB/yr) through the atmosphere derived from seasalt aerosols. Other significant sources of atmospheric boron include emissions during the combustion of biomass (0.26-0.43 TgB/yr) and coal, which adds 0.19 TgB/yr as an anthropogenic contribution. These known inputs to the atmosphere cannot account for the boron removed from the atmosphere in rainfall (3.8 TgB/yr), estimated dry deposition (0.8 to 2.2 TgB/yr) and the gaseous absorption of B by the oceans (1.2 TgB/yr). In addition to atmospheric deposition, rock weathering is a source of boron (0.19 TgB/yr) for terrestrial ecosystems, and humans mine about 0.31 TgB/yr from the Earth's crust. More than 4.8 TgB/yr circulates in the biogeochemical cycle of land plants, and about 0.51 to 0.61 TgB/yr is carried from land to sea by rivers. The biogeochemical cycle of boron in the sea includes 4.4 TgB/yr circulating in the marine biosphere, and an annual loss of 0.47 TgB/yr to the oceanic crust via a variety of sedimentary processes that collectively remove only a small fraction of the total annual inputs to the oceans. Thus, with our current understanding of the global biogeochemistry of B, the atmospheric budget shows outputs>inputs, while the marine compartments show inputs>outputs. Despite these uncertainties, it is clear that the human perturbation of the global B cycle has more than doubled the mobilization of B from the crust and contributes significantly to the B transport in rivers.

B52A-03 1400h

Large-scale Ecological Processes: the View from the Air

Steven C. Wofsy[1] (617-495-4566; scw@io.harvard.edu)

Christoph Gerbig[1] (617-495-9624; chg@io.harvard.edu)

John C. Lin[1] (617-495-5361; jcl@io.harvard.edu)

Wendy W. Chou[1]

[1]Harvard University, Division of Engineering and Applied Science and Department of Earth and Planetary Science, 29 Oxford St., Cambridge, MA 02138, United States

The processes of photosynthesis, respiration, and transpiration may be observed on the scale of a region or continent by measuring the changes in atmospheric CO2 and H2O from an aircraft platform. This paper reviews atmospheric measurements from a number of aircraft campaigns that allow diagnostic determination of large-scale fluxes of CO2 from tropical and midlatitude ecosystems. The signal of large-scale ecosystem processes is shown to provide clear, quantitative information on the largest scales of aggregation. We give several examples to show that the emergent properties of ecosystems are quantitatively and qualitatively different than small-scale properties. Mechanistic models of ecosystems on large scales must account for landscape-scale processes such as transport and deposition of organic matter, nutrients, and pollutants, as well as land use and fire history.

B52A-04 1415h INVITED

Carbon Cycle Model Linkage Project (CCMLP): Evaluating Biogeochemical Process Models with Atmospheric Measurements and Field Experiments

Martin Heimann[1] (49-3641-686720; martin.heimann@bgc-jena.mpg.de); I. Colin Prentice[1] (49-3641-643770; colin.prentice@bgc-jena.mpg.de); Jon Foley[2] (608-265-9119; jfoley@facstaff.wisc.edu); Thomas Hickler[3] (46-46-222-9298; thomas.hickler@planteco.lu.se); David W. Kicklighter[4] (508-289-7490; dkick@mbl.edu); A. David McGuire[5] (907-474-6242; ffadm@uaf.edu); Jerry M. Melillo[4] (508-289-7494; jmelillo@mbl.edu); Navin Ramankutty[2] (608-265-0604; nramanku@facstaff.wisc.edu); Stephen Sitch[6] (49-331-288-2536; sitch@pik-potsdam.de)

[1]Max Planck Institute for Biogeochemistry, Carl-Zeiss-Promenade 10, Jena 07745, Germany

[2]Center for Sustainability and the Global Environment, University of Wisconsin, 1225 West Dayton Street, Madison, WI 53706, United States

[3]Centre for Geobiosphere Studies, Lund University, Ekologihuset, Lund 223 62, Sweden

[4]The Ecosystems Center, Marine Biological Laboratory, 7 MBL Street, Woods Hole, MA 02543

[5]US Geological Survey, Alaska Cooperative Fish and Wildlife Research Unit, University of Alaska, 216 Irving I Building, Fairbanks, AK 99775, United States

[6]Potsdam Institute for Climate Impact Research, Telegrafenberg C4, PO Box 601203, Potsdam 14412, Germany

Models of biophysical and biogeochemical proceses are being used -either offline or in coupled climate-carbon cycle (C4) models-to assess climate- and CO2-induced feedbacks on atmospheric CO2. Observations of atmospheric CO2 concentration, and supplementary tracers including O2 concentrations and isotopes, offer unique opportunities to evaluate the large-scale behaviour of models. Global patterns, temporal trends, and interannual variability of the atmospheric CO2 concentration and its seasonal cycle provide crucial benchmarks for simulations of regionally-integrated net ecosystem exchange; flux measurements by eddy correlation allow a far more demanding model test at the ecosystem scale than conventional indicators, such as measurements of annual net primary production; and large-scale manipulations, such as the Duke Forest Free Air Carbon Enrichment (FACE) experiment, give a standard to evaluate modelled phenomena such as ecosystem-level CO2 fertilization. Model runs including historical changes of CO2, climate and land use allow comparison with regional-scale monthly CO2 balances as inferred from atmospheric measurements. Such comparisons are providing grounds for some confidence in current models, while pointing to processes that may still be inadequately treated. Current plans focus on (1) continued benchmarking of land process models against flux measurements across ecosystems and experimental findings on the ecosystem-level effects of enhanced CO2, reactive N inputs and temperature; (2) improved representation of land use, forest management and crop metabolism in models; and (3) a strategy for the evaluation of C4 models in a historical observational context.

B52A-05 1430h INVITED

Sustainability of Terrestrial Carbon Sinks

Christopher B Field ((650) 325 1521; chris@globalecology.stanford.edu)

Carnegie Institution of Washington, 260 Panama Street, Stanford, CA 94305, United States

The problem of predicting the future trajectory of terrestrial carbon sinks has five components. These are (1) the attribution of current sinks among causal mechanisms, (2) the intrinsic trajectory of the sink resulting from each mechanism, (3) the future trajectory of environmental conditions, (4) the sensitivity of sinks to future environmental conditions, and (5) the prospect for future sinks due to novel mechanisms. This analysis of sinks must be placed in the broader context of carbon balance, including not only sinks, but also sources.

The attribution problem is central to the question of the future of carbon sinks because each of the potential mechanisms has different intrinsic dynamics, responds differently to environmental changes, and is influenced by a different set of human actions. Until recently, most analyses assumed that the past and future trajectory of terrestrial carbon sinks could be understood as a function of climate and atmospheric composition alone, without a major contribution of direct effects of human actions. Increasingly, it is clear that this perspective is too limited. In many settings, current sinks are probably dominated by the history of land management. Interactions among these major regulators may be as important as the single-factor effects.

As emphasis on CO_2 and climate as the sole or dominant explanation for terrestrial sinks has faded, a number of new potential mechanisms have emerged, including, (1) climate change, (2) CO_2 fertilization, (3) nitrogen fertilization, (4) the regrowth of previously harvested forests, (5) the abandonment of agricultural land, (6) changes in agricultural management, (7) increasing woodiness of grassland and savanna vegetation, (8) fire suppression, (9) accumulation in landfalls, and (10) accumulation in durable products. None of these mechanisms produces an indefinite sink. For some mechanisms, the potential is influenced primarily by the interaction between ecosystem processes and the trajectory of climate and atmospheric change. For others, the historical pattern of human actions is the dominant influence. These two classes of regulators interact for all of the mechanisms.

B52A-06 1445h INVITED

Measuring the Human Footprint on Ecosystem Function

R. S. DeFries[1,2] (301 405 4884; rd63@umail.umd.edu)

[1]Department of Geography, 2181 Lefrak Hall University of Maryland, College Park, MD 20742, United States

[2]Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD 20742, United States

Major questions for the biogeosciences concern the consequences of human transformation of landscapes for biogeochemical cycling and other ecosystem functions. While it is clear that the footprint of humans extends to almost all corners of the world, there is no single measure of the anthropogenic effect on ecosystems. Unlike the "Keeling curve" representing anthropogenic carbon dioxide emissions in a single atmospheric measurement, the spatial and temporal heterogeneity of ecosystems and the patchy nature of human activities on the landscape make such a measurement impossible. Here we present two approaches for assessing the consequences of human modification of the landscape on ecosystem processes: the effects of past and future land use change on net primary production at the global scale and analysis of satellite observations over the past 18 years to quantify the carbon dioxide emissions from tropical land use change. Key issues for quantifying human influences on ecosystem function include accounting for natural variability on a variety of time scales and incorporating spatial heterogeneity in landscape-level analysis.

B52A-07 1500h

Human Activity and a Changing Biosphere – A Review

Jonathan A Foley (jfoley@facstaff.wisc.edu)

Center for Sustainability and the Global Environment, University of Wisconsin 1225 West Dayton Street, Madison, WI 53706

As we take a more complete and synthetic view of the biosphere, we must also recognize the important human dimensions affecting the planets ecosystems. The use of ecosystems as sources of food, fiber, freshwater, and other ecosystem services has radically transformed the nature of the biosphere.

In this presentation, I will attempt to review some of the human activities affecting ecosystem processes on regional and global scales. In addition, examples of how human activities can be directly incorporated with ecological models will be illustrated.

B52B MC: 122 Friday 1530h

Synthetic Analyses of Large Scale Ecological Processes: The North American Carbon Sink as a Case Study

Presiding: **C Potter,** NASA-Ames Research Center**; J Coughlan,** NASA Ames Research Center

B52B-01 1530h

Observational Evidence of a Large CO2 Sink in North America?

Pieter P Tans[1] (303 497 6678; ptans@cmdl.noaa.gov); James W White[2]; Thomas J Conway[1]; Patricia M Lang[1]; Kenneth A Masarie[1]; Bruce Vaughn[2]

[1]NOAA/CMDL, 325 Broadway, Boulder, CO 80305, United States

[2]Univ. of Colorado/INSTAAR, 1560 30th Street, Boulder, CO 80303, United States

The concentration of atmospheric CO2 over the North Atlantic basin, downwind from the continent of North America, is on average somewhat lower than over the North Pacific basin. The reason could be unexpectedly large uptake of CO2 on the North American continent, larger "local" uptake of CO2 by the North Atlantic than by the North Pacific, or some combination of the two. Our analysis of these hypotheses is strongly data-oriented. Use is made of spatial gradients of other atmospheric species, namely the isotopic ratio 13C/12C of CO2, CO, SF6 in order to arrive at an estimate of a sink in North America. The 13C/12C ratio of CO2 is enriched over the North Atlantic relative to the Pacific, suggesting the presence of a biological sink upwind of the Atlantic. Sampling stations in both basins are not located at the same latitudes, so that the contamination of the (small) east-west differences by the (larger) north-south gradient has to be removed. Statistical uncertainty of the concentration differences is estimated by a Monte Carlo technique in which observation stations are added and removed.

B52B-02 1545h

Estimating North American Carbon Sink with Process-Based Ecosystem Modeling and Satellite Observation

Jenny Small[1] (301 405 7891; jsmall@glue.umd.edu)

Mingkui Cao[1] (301 405 7891; mkcao@glue.umd.edu)

Stephen D Prince[1] (301 405 4062; sp43@umail.umd.edu)

[1]University of Maryland, Dept of Geography, College Park, MD 20742, United States

Atmospheric inverse modeling and direct inventories of the carbon on the ground indicated that Northern America is a substantial carbon sink, however, the sink size, spatio-temporal variation, and causes remain uncertain. In this study, we used two models - a biogeochemical model, CEVSA, driven with ground meteorological data and a production efficiency model, GLO-PEM, driving with remotely sensed NDVI and climate variables from NOAA/NASA AVHRR satellites-to quantify the changes in net primary productivity (NPP), heterotrophic respiration, carbon stocks in vegetation and soils, and net ecosystem production (NEP) in North America between 1981 and 1998. The results show NPP and NEP fluctuated interannually in response to the climate variability associated with the El Ni?o Southern Oscillation (ENSO) cycle, particularly in the middle and southwestern United States. Despite the high variability, both NPP and NEP increased consistently during the 1980s and 1990s, but the estimated annual carbon sink was much smaller than that estimated with atmospheric inverse modeling and the carbon accumulation occurred mainly in vegetation with litter changes in the carbon stocks in soils. The changes in NPP were closely correlated with climate variability, but the increasing trend seems to be driven mainly by the fertilization effect of increasing atmospheric CO2. The estimates with the two independent methods agree generally well, but the biogeochemical model predicted larger increases in NPP and weaker responses to the ENSO cycle than the production efficiency model did.

B52B-03 1600h

The North America Carbon Sink From 1982-1998 Estimated Using MODIS Algorithm Products

Steven Klooster[1] (steve@gaia.arc.nasa.gov)

Christopher Potter[2] (cpotter@mail.arc.nasa.gov)

Ranga Myneni[3] (rmyneni@crsa.bu.edu)

[1]California State University Monterey Bay, Earth System Science and Policy, Seaside, CA 93955, United States

[2]NASA Ames Research Center, Mail Stop 242-4, Moffett Field, CA 94035, United States

[3]Boston University, Department of Geography, Boston, MA 02215, United States

To make direct assessments of terrestrial ecosystem exchange of carbon for North America, we simulated net primary production (NPP) and soil heterotrophic respiration (Rh) for the years 1982-1998 using the NASA-CASA (Carnegie-Ames-Stanford) Biosphere model. This model is driven by observed surface climate and monthly estimates of vegetation leaf area index (LAI) and fraction of absorbed PAR (FPAR) generated at 0.5 degree spatial resolution from the NOAA satellite Advanced Very High Resolution Radiometer (AVHRR). Land surface AVHRR data processing using modified MODIS (Moderate-resolution Imaging Spectroradiometer) radiative transfer algorithms includes improved calibration for intra- and inter-sensor variations, partial atmospheric correction for gaseous absorption and scattering, and correction for stratospheric aerosol effects associated with volcanic eruptions. Our NASA-CASA model results for net ecosystem carbon fluxes (NPP-Rh) suggest that large areas of the western United States and Mexico, northwestern Canada, and interior Alaska have acted as fairly consistent sinks for atmospheric carbon dioxide over the past 17 years, whereas much of the mid-western United States and eastern Canada were more variable as interannual source-sink areas. We estimate that the sink from net ecosystem exchange of atmospheric carbon dioxide in North American has been on the order of 0.1 to 0.2 Pg C annually, in comparison to our separate estimate of the forest regrowth sink in North America of 0.09 Pg C annually.

URL: http://geo.arc.nasa.gov/sge/casa

B52B-04 1615h

Featured Presentation: Mechanisms Affecting Carbon Sequestration in North America

Jerry Melillo (508-289-7494; jmelille@mbl.edu)

The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA 02543, United States

There is no abstract available for this presentation.

B52B-05 1630h INVITED

Patterns of Carbon Source and Sink Distribution in Canada's Forests Resulting From Disturbance and Climate Change

Jing M. Chen[1] (chenj@geog.utoronto.ca); Josef Cihlar[2]; Brian Amiro[3]; Weimin Ju[3]; David Price[2]; Jane Liu[2]; Jianjun Pan[1]

[1]University of Toronto, 100 St. George St, Room 5047, Toronto, Ont M5S 3G3, Canada

[2]Canada Centre for Remote Sensing, 588 Booth St, Ottawa, Ont K1A 0Y7, Canada

[3]Canadian Forest Service, 5320-122 St, Edmonto, Alb T6H 3S5, Canada

Major forest disturbance includes fires, insetinduced mortality, and timber harvest. The direct release of carbon from Canadas forests due to disturbance amounts to 150 Mt/y in some years, which is about 1.5 percent of the net primary productivity (NPP) of all Canadas forests (420 Mha.). The mean carbon release due to disturbance in 1990-1998 was about 60 percent of net ecosystem productivity (NEP) of all undisturbed Canadas forests. The disturbance effects have been estimated in previous studies, either based on eco-region disturbance statistics in 5 year time steps, or Canada-mean values in annual time steps. However, large improvements in the estimation are still possible when spatially explicit information is used. For this purpose, 10-day cloud-free synthesis images of VEGETATION onboard SPOT-4, acquired in June-August, 1998, are used to derive a Canada-wide fire scar age distribution for up to 25 years. The spatial resolution of the fire scars is 1 km. This information is combined with gridded forest inventory of forest stand age at 10 km resolution to complete the age distribution at 1998. Forest regeneration is assumed to start 1 year after disturbance, but the regrowth is slower at locations with lower annual temperatures. An ecosystem model, named InTEC, is used to assimilate satellite-derived land cover and leaf area index maps, gridded climate (1901-1998) and soil data, and this forest stand age map, and to calculate NPP, NEP and net biome productivity (NBP) for each 1 km pixel at annual time steps. Both direct carbon release and forest regrowth after disturbance are modeled. The NBP maps of Canada in recent years show: (i) large spatial variations corresponding to patterns of recent fire scars and forest types, and (ii) a general south-to-north gradient of decreasing sink strength and increasing source strength. This gradient results mostly from different effects of temperature increase on growing season length, nutrient mineralizaton, and heteorotrophic respiration at different latitudes and the uneven nitrogen deposition. These data sets and the modeling framework produced new statistics of the disturbance effects and carbon balance in Canadas forests.

B

B52B-06 1645h

Soil Carbon Storage, Present and Future, in Temperate Forests of The Eastern United States

Julia B Gaudinski[1] (831 426 6541; gaudinsk@socrates.berkeley.edu)

Susan E Trumbore[2] (setrumbo@uci.edu)

[1]University of California Berkeley, Integrative Biology VLSB 3060, Berkeley, CA 94720-3140, United States

[2]University of California Irvine, Earth System Science, Irvine, CA 92697, United States

Soil organic matter (SOM) stocks reflect a complex milieu of inputs from leaf litter, root litter, and woody debris that have turnover times ranging from days to millennia. Knowledge of C stock sizes and their average cycling rates allows for evaluation of the potential for SOM to accumulate or lose C over the coming centuries under potentially different climate change scenarios. Using the amount of $bomb\ -^{14}\ C$ incorporated into SOM pools in three temperate forests along a latitudinal gradient from Maine to Tennessee, USA, we calculate current soil C storage rates of 5-50 $gCm^{-2}yr^{-1}$.

Storage is occurring primarily in low density, non-mineral associated SOM in the O and A horizons, which contain significant C stocks cycling on decadal and centennial times scales. The deeper B horizons, which are dominated by high density carbon stocks with low input rates and long turnover times (200-2000 years) can store significant amount of C (hundreds of grams Cm^{-2}) only over several centuries. Future increases in net primary productivity potentially associated with climate change would increase current C storage rates only on the order of tens of $gCm^{-2}yr^{-1}$.