

## B12A-0805 1330h POSTER

### The Influence of Physical Breakdown and Solute Transport on Chemical Properties of Permafrost Soils: Insights From Radiogenic (Sr and Nd) and Elemental Composition.

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This study in a continuous permafrost region investigated the influence of cold temperatures on soil formation, weathering, and solute transport by determination of radiogenic Sr and Nd isotopes in solid, labile, and dissolved reservoirs in the soil-vegetation system. The site is located in Caledonian belt of north-east Greenland with soils developed on glacial and colluvial deposits of metamorphic rocks of the Paleoproterozoic basement complex. Soils are well-drained Arctic Browns (Typic Haploturbels) characterized by an overall higher content of fines in upper soil horizons and accumulation of clay minerals in the B-horizon.

The Sr and Nd isotope ratios and element composition of bulk soil and grain size separates indicate enrichment of biotite, amphibole, and the accessory minerals apatite, garnet, and zircon in fine fraction of upper soil horizons. The higher abundance of these minerals in dark striae of gneiss suggests a higher susceptibility of mafic layers to physical break down that is enhanced in upper soil layers. Accumulation of biotite and its weathering products in the clay fraction of B-horizons is documented in high Sr isotope ratios. Lower Nd isotope ratios in B than A-horizons suggest that clay accumulation is related to mechanical rather than in situ weathering. The overall change in mineralogy decouples the chemical evolution of upper soil layers from lower soil layers.

To determine sources of dissolved materials and solute transport we measured Sr isotope ratios in the exchangeable complex (ammonium-acetate) and soil water collected with suction cups, and calculated the intercept of regressing Sr isotope ratios versus Al/Sr ratios of bulk upper soil horizons. Exchangeable Sr isotope ratios are uniform for each soil profile, higher than in bulk soil, and match isotope ratios in vegetation. They document that solutes extracted with this method give the composition of the plant available nutrient reservoir and indicates the strong influence of biotite. In contrast, Sr isotope ratios calculated from regression analyses are rather uniform and lower than observed in soil/exchange solution. The agreement with isotope composition of soil water indicates that this approach yields the longer-term Sr isotope signature of solutes that are exported by percolating water.

The difference in the isotope composition in these reservoirs point to different sources and limited exchange between both reservoirs. The accumulation of clay enriched in biotite and its weathering products in B-horizons may provide a preferential source for vegetation. A good correlation between organic carbon content and cation exchange capacity indicates that biomass cycling stabilizes the high Sr isotope signature. Lower Sr isotope ratios are observed in Na-rich feldspar, amphibole, and apatite that are abundant in sand and silt fraction of soils. Seeking these minerals as primary sources for Sr isotope ratio in percolating water suggest more rapid release of solutes to water. The difference between Sr isotope ratios of both solute reservoirs diminishes when soils are less well drained providing longer time for isotope equilibration.

## B12A-0806 1330h POSTER

### Landscape-Component Modeling of Permafrost Temperatures in Central Alaska

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Monitoring from 1997 to 2001 revealed that mean annual soil temperatures varied widely within a mountainous region in central Alaska, both at 5 cm below the soil surface (-2.6 to 3.3°C) and at 100 cm depth (-4.0 to 2.7°C). This variation was due primarily to differences in winter soil temperature among sites, which in turn were attributed mainly to the effect of elevation on winter air temperature. Thawing n-factors, which are ratios of soil temperatures to air temperatures, were similar among most landscape units (combinations of physiography and vegetation structure), in contrast, freezing n-factors were substantially lower in upland areas than in riverine or lowland areas. There was substantial variability in freezing n-factors was among years, with

the lowest values occurring in winter 1999-2001, when snow depths were greatest. Regression analyses indicated that successional stage, elevation, drainage, and snow depth all contributed to the variation in freezing n-factors. A spatially explicit model to simulate deep soil temperatures was developed based on regional climate, topography, vegetation, and soil properties. The model used climatic factors (air temperatures, snow cover) and n-factors to couple soil temperatures to atmospheric conditions, and thermal conductivity ratios of frozen and unfrozen soils to calculate temperatures at the base of the active layer. Model simulations indicate that 32% of the area has permafrost. Field verification revealed the model was highly accurate (84%) at predicting permafrost distribution and most (70%) predicted mean annual temperatures were within 1°C of measured temperatures.

## B12A-0807 1330h POSTER

### Modeling of Permafrost and Gas Hydrate Stability Zone Dynamics within Alaskan Arctic Shelves and Continental Margins

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A two-dimensional finite difference model was developed to simulate the influence of climate and sea level variations on the thermal regime of permafrost and gas hydrate stability zone (GHSZ) dynamics within the Alaskan Arctic Shelf. Unlike previous models, this model takes into consideration latent heat associated with formation (decomposition) not only permafrost but also the hydrates of natural gases. It employs the thermo-baric conditions where the hydrostatic pressure changes with depth and sea level. As a first step, to assess the importance of interaction between permafrost and GHSZ, we compared our results of simulations with previous model results, where latent heat associated with gas hydrates was neglected.

Calculations were carried out for the last glaciation - interglaciation cycle (120 Kyrs). Two sites were studied: Lonely and Prudhoe Bay. As upper boundary conditions we took paleotemperature curve developed by Romanovsky and Maximova and applied it with some adjustments to our sites. Also in this model we took into consideration sea level fluctuations during last 120 Kyrs. Temperature of water assumed to be constant (-1.5°C). Properties of rocks assumed to be constant along the entire cross section (one-layer structure) and the values of thermal conductivity and heat capacity were taken from literature. We assumed fine-grained soil structure for Lonely site. For Prudhoe Bay we took into account both possible cases: fine-grained and coarse-grained soils.

As a result of our investigation we found that permafrost thickness at Lonely in the model with gas hydrate latent heat included is at least 10% smaller than in the model without this latent heat. The differences in the gas hydrate stability zone (GHSZ) volume can be even more (15%) with the thickness of the zone larger in the model without hydrates. For Prudhoe Bay, we obtained a difference of 9% in permafrost thickness and GHSZ for coarse-grained soil and 14% for fine-grained soil. Also, analysis of GHSZ dynamics during the last 120 Kyrs was carried out. It shows that the most significant changes in GHSZ volume was related to the largest sea transgression rates. The investigation also shows the presence of a gas hydrate stability zone on the continental slope underneath the seabed. The potential presence of gas hydrates on the slope may help to explain some slope processes that take place in this region.

## B12B MCC: Hall C Monday 1330h

### Water, Energy, and Carbon Exchange in Forest Systems IV Posters (joint with A, H, GC)

Presiding: B Law, Oregon State

University; P Thornton, National Center for Atmospheric Research; D Baldocchi, University of California, Berkeley

## B12B-0808 1330h POSTER

### Optimizing field methods for measuring C cycling in forests: A pilot test in the Delaware River Basin

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Recent work has demonstrated the utility of USDA Forest Service Forest Inventory and Analysis (FIA) data in large-scale assessment of forest C cycling rates. These FIA-based estimates have also been used to provide valuable large-scale comparison data for ecosystem process model predictions. However, the inventory-based techniques were not designed specifically to measure carbon stocks or NPP. Adaptation of FIA data is based on allometric relationships that predict biomass from tree dimensions such as height and diameter, and ecosystem models that predict NPP and other ecosystem carbon pools. The tree biomass component of forest C may be estimated with reasonable accuracy, but estimates of biomass increment, other ecosystem carbon variables, and NPP require measurements that are not made by FIA and may not be compatible with the FIA sampling design.

We are developing new sampling and measurement techniques for comprehensive monitoring of forest NPP in the Delaware River Basin (DRB), USA. Our methods for NPP estimation include development of an efficient sampling design and protocol, techniques for short-term measurement of tree diameter increment and litterfall production, and application of new generalized allometric equations for tree biomass that were designed for application at the continental scale. In order to estimate forest NEP, we will model coarse woody debris (CWD) dynamics and develop an approach to monitor soil CO<sub>2</sub> flux over large areas. Since 2000, we have installed 30 forest C monitoring plots at sites throughout the DRB and 13 independent validation plots. Measurement of C cycling rates is ongoing, though analysis of preliminary data suggests that NPP at our plots is consistent with expectations based on the literature.

## B12B-0809 1330h POSTER

### Estimating Canopy Leaf Area with Indirect Measurements: Comparison of Instruments and a Sensitivity Analysis in Alaskan Boreal Forest Stands

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Leaf area index (LAI) is a widely used variable for estimating a number of different processes associated with vegetation canopies, including light and precipitation interception, photosynthetic capacity, transpiration, and so on. LAI can be measured directly, but the process is tedious, expensive, and impractical over large areas. There are several methods for indirectly estimating LAI using methods that invert simple canopy models based on measurements of canopy light interception. These methods are useful because they allow efficient sampling of large areas, and relatively rapid and inexpensive data collection. We studied boreal forest stands in interior Alaska, at a range of successional stages, using two different instruments designed to estimate canopy LAI. A Decagon AccuPar Ceptometer and a Li-Cor LAI-2000 Plant Canopy Analyzer were used to provide unique measurements of canopy light interception, and then applied using specific theoretical inversions to estimate LAI. We tested both instruments' sensitivity to measurement conditions, and were able to estimate the uncertainty in the measurement based on the range of conditions allowed within our

measurement protocol. We also compared the instruments' estimates of LAI in matched measurement pairs at the same location. We found low sensitivity to many measurement conditions, and general comparability between the two instruments. The AccuPar instrument produced slightly higher LAI estimates than those of the LAI2000 (0.3 LAI), and this offset was consistent under various measurement conditions and stand types. Possible causes of the systematic offset are presented. The results suggest, however, that the instruments can be used interchangeably, provided specific conditions are met, and properties of each instrument may make one better suited than the other to various measurement conditions (e.g., non-uniform illumination). Similar sensitivity tests and comparisons should be conducted in an even wider range of sites.

#### B12B-0810 1330h POSTER

##### Spatial Heterogeneity and Inter-annual Variation in Ecosystem-Atmosphere CO<sub>2</sub>/H<sub>2</sub>O Exchange in the Southern Great Plains

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Spatial heterogeneity in mass and energy fluxes in the Southern Great Plains are controlled by a combination of driving variables (e.g. climate, topography and soil, vegetation, and land use and management). Accurate estimation of landscape-averaged ecosystem-atmosphere exchange hence suggests the need for predictive models tested with extensive ground based measurements and/or a measurement method with regional coverage. This is particularly true for estimation of regional responses of carbon and water cycles to changing climate, land use, or management because of the potentially strong interactions among the driving variables.

We report measurements of the spatial heterogeneity in land surface-atmosphere exchanges of carbon dioxide, water, and energy observed in three winter wheat fields and two mixed annual-perennial pastures during the spring 2002 growing season. Eddy covariance measurements of net ecosystem carbon exchange (NEE) and heat fluxes were made in fields surrounding the US-DOE Atmospheric Radiation Measurement Program central facility near Lamont, Oklahoma (36.605 N, 97.485 W). Additional measurements included soil microclimate; leaf area index; changes in plant biomass; and plant and soil carbon and nitrogen. The differences in time integrated NEE are approximately consistent with measured differences in accumulated above ground biomass. Initial consideration suggests that the differences in carbon uptake result from differing management practices because the fields are closely spaced and have very similar underlying soil properties and experienced similar micro-climate. A distinct inter-annual climate variation was also observed in which a large increase in early to mid summer precipitation and lower air temperatures (2002 vs. 2001) lengthened the summer growing season and increased pasture production.

#### B12B-0811 1330h POSTER

##### Annual Soil CO<sub>2</sub> efflux Across Three Climatically-distinct Forest Chronosequences in Oregon.

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As advances in earth science and terrestrial ecology bring these fields closer together, the search for drivers underlying forest processes is being succeeded by a need to understand how these processes manifest themselves over broader spatial domains. Because 60-80% of all CO<sub>2</sub> released into the atmosphere by forests emanates from the soil surface, assessing global carbon cycles demands an understanding of how forest soil respiration is regulated not only at individual sites but also over broad spatial scales.

To assess soil CO<sub>2</sub> efflux over the full range of western Oregon's forest conditions, annual soil CO<sub>2</sub> efflux, and a suit of other physical and biological indices was

determined measured for 36 study plots arranged as three independent replicates of four age classes blocked by three climatically-distinct cover types. Forest ages range from 10 to 300 years and were subjectively classified as either initiation, young, mature or old. The three cover types spanned a 200 km transect and included 1) wet coastal hemlock-Sitka spruce 2) montane Douglas fir, and 3) rain shadow ponderosa pine. Annual soil CO<sub>2</sub> efflux for the year 2001 was computed by combining periodic chamber measurements with continuous soil temperature measurements, which were used along with site-specific temperature response curves to interpolate daily soil C-efflux between dates of direct measurement.

Results indicate significant cover type, age, and cover type x age interaction effects on annual soil CO<sub>2</sub> efflux. Average annual soil CO<sub>2</sub> efflux was 1232, 1805, and 666 g C m<sup>-2</sup> yr<sup>-1</sup> for the spruce, fir, and pine sites respectively. At the pine site, where root biomass averages 22% of belowground C, variation in annual soil CO<sub>2</sub> efflux among age classes is explained largely by aboveground production rates, with the youngest stands having the lowest rates and the mature stands having the highest rates. At the spruce site, where root biomass averages only 13% of belowground C, differences between age classes is related to soil C content, with the oldest stands having higher soil C and efflux rates than the other age classes. At the fir site, annual soil CO<sub>2</sub> efflux is highest at the youngest stands but appears uncorrelated with either aboveground production or soil C content.

Sensitivity analysis suggests that the regional variation in annual soil CO<sub>2</sub> efflux is most dependent on summer base rates (i.e. summer soil CO<sub>2</sub> efflux normalized to a common temperature) and much less dependent on the temperature response curve (to which annual rates are relatively insensitive) and soil degrees-days (which vary only 10% among sites).

Results from this study are consistent with a growing recognition that while the physical environment is important in driving soil CO<sub>2</sub> efflux at the plot level, variation in soil CO<sub>2</sub> efflux at regional scales may be more reliably coupled to biological indices.

#### B12B-0812 1330h POSTER

##### Effects of Stand age Structure on Regional Carbon Budgets of Forest Ecosystems

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This study has developed a two-stage modeling scheme to investigate the importance of age structure on regional carbon fluxes for the forests in the Pacific Northwest of the United States. In the first stage, an individual-based forest ecosystem carbon flux model (IntCarb) at stand scale is developed. IntCarb combines components from the ZELIG and CENTURY models to simulate forest growth and development, and heterotrophic respiration, respectively. Stand scale carbon fluxes simulated by IntCarb strongly depend on stand age. Due to its high variability over large areas, forest age structure has to be taken into account for realistic estimation of carbon budgets. The RegCarb model is developed to estimate regional scale carbon fluxes based on forest age structure and adjusting for the nonrespiratory carbon losses, such as harvesting. Our initial estimate with RegCarb for the Pacific Northwest of the United States found that this region was a tremendous carbon source to the atmosphere from 1890 to 1990 due to intensive logging of old-growth forest, and is becoming a carbon sink since the last decade. Projections for the role of forests in this region in the global carbon cycle in the future strongly depend on the amount of timber to be harvested, i.e. how the age structure of forests in this region is to be altered.

#### B12B-0813 1330h POSTER

##### Effects of Logging on Carbon Dynamics of a Jack Pine Forest Chronosequence in Saskatchewan, Canada

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The boreal forest covers ~10% of the world's land surface area and contains a disproportionately high amount of global terrestrial carbon (C). However, it is uncertain whether Canada's boreal forest is currently an annual net C sink or source and what role disturbance plays in determining this. The goal of this study was to calculate C budgets for a chronosequence of harvested jack pine (*Pinus banksiana* Lamb.) sites (1-y-old, 5-7-y-old, 10-12-y-old, ~29-y-old) and a ~79-y-old site established by wildfire. We measured total ecosystem C content (TEC) and above- and belowground net primary productivity (NPP) for each site. Total annual NPP (Mg C ha<sup>-1</sup> y<sup>-1</sup> ± 1 S.D.) from May 1999-April 2000 was 0.9 ± 0.3 at the 1-y-old site, 1.3 ± 0.1 at the 5-7-y-old site, 2.7 ± 0.6 at the 10-12-y-old site, 3.5 ± 0.3 at the 29-y-old site, and 1.7 ± 0.4 at the 79-y-old site. We measured soil surface CO<sub>2</sub> fluxes (R<sub>S</sub>) using an IRGA with chamber and correlated these measurements with soil temperature to estimate annual R<sub>S</sub>. To calculate net ecosystem productivity (NEP), we estimated heterotrophic respiration (R<sub>H</sub>) as 50% of total annual R<sub>S</sub>, and summed NPP and R<sub>H</sub>. NEP (Mg C ha<sup>-1</sup> y<sup>-1</sup> ± 1 S.D.) from May 1999 through April 2000 was estimated to be -1.4 ± 0.3 at the 1-y-old site, 0.1 ± 0.1 at the 5-7-y-old site, 1.1 ± 0.7 at the 10-12-y-old site, 0.6 ± 0.4 at the 29-y-old site, and 0.1 ± 0.5 at the 79-y-old site. The 1-y-old clear-cut was a source of C to the atmosphere; all other sites were either sinks or were essentially C neutral. We also calculated long-term annual NEP values based on the difference in TEC among the five differently-aged sites. These figures agreed well with the flux-based NEP estimates, except in the case of the 1-y-old site, which we determined had been a more productive site with greater forest floor carbon prior to harvest.

#### B12B-0814 1330h POSTER

##### Interactive Effects of Time Since Fire and Tree Species Composition on Stand Transpiration and Canopy Conductance of Boreal Black Spruce Forest

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Fire is one of the most important disturbances in boreal black spruce forests. As part of a large investigation of carbon cycling of boreal black spruce forests, we quantified the effect of time since fire on canopy transpiration. Our hypotheses were that (i) canopy transpiration would be proportional to leaf area, and (ii) across tree species (paper birch, trembling aspen, jack pine, and black spruce) and tree sizes, the sensitivity of canopy average stomatal conductance (G<sub>s</sub>) to vapor pressure deficit would be proportional to a reference value of G<sub>s</sub> at low vapor pressure deficit. We measured sap flux using Granier and Kucera-type sensors in 84 trees across five different stands and the four tree species originating from fires in the years 1989, 1981, 1964, 1930, and 1870. We scaled the sap flux measurements to the whole-tree and stand level using measurements of radial and circumferential trends in sap flux and allometrically derived estimates of sapwood and leaf area. Leaf area index changed dramatically across the five stands (0.4, 1.4, 2.1, 8.1, and 6.7 for the 1989, 1981, 1964, 1930, and 1870 stands respectively), but stand transpiration was not proportional to leaf area index (24, 97, 224, 332, 183 mm per year for the 1989, 1981, 1964, 1930, and 1870 stands respectively). One explanation for the rejection of our first hypothesis was that transpiration per unit leaf area was significantly affected by tree species and thus by the changes in species composition across the five stands. We also rejected our second hypothesis because black spruce in the 1930 and 1870 stands had much lower G<sub>s</sub> sensitivity to vapor pressure deficit compared to black spruce in the 1989, 1981, and 1964 stands. The lower G<sub>s</sub> sensitivity in the largest and oldest black spruce trees (1930 and 1870 stands) is supported by tree hydraulic theory and leaf water potential and whole tree hydraulic conductance data. Our results show that models of future boreal forest water cycling must account for successional changes in response to fire.

## B12B-0815 1330h POSTER

## Biological and physical controls over carbon, water and energy exchange along a boreal forest chronosequence

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Tower-based eddy covariance measurements were used to quantify and explain patterns of whole ecosystem exchange of CO<sub>2</sub>, water vapor and energy exchange along a boreal forest age sequence near Thompson, Manitoba. Diurnal patterns of net carbon, water vapor and energy exchange in the four youngest stands in the chronosequence (burns 11, 18, 35 and 70 years in age) were made and compared directly to simultaneous measurements made in the oldest stand (150 year old Northern Old Black Spruce). The daily course of net CO<sub>2</sub> exchange in the youngest, primarily deciduous stands showed peaks early in the day, followed by afternoon declines. The older primarily coniferous stands started gaining C later in the morning and showed no significant damping of net CO<sub>2</sub> exchange later in the day. Stomatal conductance, and latent heat flux were highest in the youngest stands suggesting patterns may be explained by stand age differences in sensitivity to vapor pressure deficit, with the young deciduous stands being the most sensitive. Below canopy fluxes measured for one month in the growing season in the 35 year old and 150 year old stands were used to determine stand age differences in relative contribution of forest floor to whole canopy carbon, mass and energy exchange

## B12B-0816 1330h POSTER

## Spatial Variation of Soil Respiration Rate along a Latitudinal Alaskan Transect

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Dynamic chamber flux measurements were observed at representative sites of tundra and boreal forest along a latitudinal Alaskan transect (148° W) during the summers of 2000 and 2001. These observations were conducted to estimate soil respiration and net respiration rate by vegetations at surface soil, and to understand the effect of soil temperature determining soil respiration and net respiration rates, and to make a better spatial distributions of the contents of biomass, carbon and nitrogen. Average regional soil respiration rates in tundra and boreal forest stands were  $0.027 \pm 0.011$  GtC/season and  $0.056 \pm 0.014$  GtC/season for light and dark chambers during the growing period, respectively. Average regional net respiration rate by aboveground surface vegetation along Alaskan transect was  $0.007 \pm 0.005$  GtC/season in tundra and  $0.023 \pm 0.015$  GtC/season in boreal forests. These findings suggest that soil respiration and net respiration are one of the significant sources of atmospheric CO<sub>2</sub> in Alaska for the regional carbon budget. Soil respiration and net respiration showed remarkable soil-temperature dependence in the tundra and boreal forest soils during summer. Q<sub>10</sub> values (1.00 to 2.96) derived from the temperature at three soil depths (10, 20 and 30 cm) indicated considerable differences, suggesting that this results in the difference of soil physical characteristics. Spatial variation of biomass, carbon and nitrogen contents were remarkable in dry vegetations and soils of tundra and boreal forest.

## B12B-0817 1330h POSTER

## Boreal black spruce and soil carbon exchange along an elevation gradient

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In a warming climate, the temperature sensitivity of organic matter decomposition will accelerate soil carbon loss via soil respiration from cold boreal soils. Increased decomposition may also increase nutrient availability, plant productivity, and organic inputs to soils. We studied the relationship between decomposition

and aboveground vascular increment, total soil respiration and heterotrophic respiration near Fairbanks, AK. Our sites consisted of three similarly structured black spruce feathermoss forests that varied in aspect, elevation, and depth to permafrost. These characteristics drive complex differences in annual temperature at the soil surface and through the soil profile. For example the two "warmer" sites are warmer during the summer but are much colder during the winter, resulting in permafrost aggradation to within 50 cm of the soil surface. We hypothesized that ecosystem CO<sub>2</sub> uptake (aboveground increment) and loss (total soil respiration and soil heterotrophic respiration) both increase with decomposition rates of black spruce needles and two litter proxies. Although both aboveground tree increment ( $418-548 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$ ) and heterotrophic respiration from trenched plots ( $122-137 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$ ) were significantly correlated to the decomposition indices, total soil respiration was not. These results imply either that black spruce at the warmer sites allocates less carbon belowground or that the warmer soils sequester more. Which of these processes dominates will determine whether black spruce forest soils alter their soil carbon balance in a warmer climate.

## B12B-0818 1330h POSTER

## Using Data on Vegetation Height Structure to Improve Model Estimates of Carbon Stocks and Fluxes

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Two recent developments, one in remote sensing technology, the other in ecosystem modeling, are combined and evaluated for their potential to improve carbon stock and flux estimates. The first is airborne lidar remote sensing, which is capable of measuring fine-scale heterogeneity in the vertical structure of vegetation. The second is a new height-structured terrestrial ecosystem model (the Ecosystem Demography model, ED), which is capable of calculating the consequences of fine-scale heterogeneity in vegetation structure in larger-scale analyses carbon stocks and fluxes. Used together, reliable model estimates of above-ground biomass are shown to be produced at several study sites. In addition, lidar data are shown to provide substantial constraints on model estimates of above-ground carbon fluxes. The continued development and combination of these two technologies is shown to be a promising approach for improving large-scale carbon stock and flux estimates.

## B12B-0819 1330h POSTER

## Verification of Satellite Radar Remote Sensing Based Estimates of Boreal and Subalpine Growing Seasons Using an Ecosystem Process Model and Surface Biophysical Measurement Network Information

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We employ daily surface Radar backscatter data from the SeaWinds Ku-band Scatterometer onboard Quikscat to estimate landscape freeze-thaw state and associated length of the seasonal non-frozen period as a surrogate for determining the annual growing season across boreal and subalpine regions of North America for 2000 and 2001. We compare these results with estimates of growing season length derived from a network of surface stations, utilizing BIOME-BGC stand-level ecosystem process model simulations, site sap flow and tower eddy flux net CO<sub>2</sub> exchange measurements for a network of mature evergreen coniferous forest stands. Remote sensing based estimates of spatial patterns in the timing of seasonal freeze-thaw vary by more than 8 weeks, while associated estimates of growing season length span more than 14 weeks across the region. Inter-annual variability between 2000 and 2001 is found to be on the order of 1-4 weeks. Remote sensing estimates of growing season initiation and length are found to be well correlated with both site measurements and model simulations. Remote sensing measurements of the end of the seasonal non-frozen period are also found to be consistent with site based temperature measurements, but not with site based estimates of growing season termination. These findings are attributed to a relatively strong dependence of the onset of the growing season to snowmelt and associated soil thaw in spring and the relative importance of additional factors such as light availability and day length in controlling growing season termination.

This work was performed at the University of Montana, and at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

## B12B-0820 1330h POSTER

## An Investigation of Multi-Sensor Radar Backscatter Sensitivity to Spring Thaw Dynamics With Respect to Landscape Complexity

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We investigate radar backscatter characteristics as measured by ERS (C-band, VV polarization, 200m resolution) and JERS-1 (L-band, HH polarization, 100m resolution) Synthetic Aperture Radars (SARs) during spring thaw transitions in boreal landscapes for three regions in Alaska and Canada. We perform multi-scale analyses to assess trade-offs in spatial and temporal resolution between these SARs and spaceborne scatterometer measurements from Quikscat (Ku-band, 25km spatial resolution). We compare the time series SAR and scatterometer data series for available contemporary data. ERS and JERS SAR backscatter characteristics observed during seasonal transitions are examined with respect to landscape complexity, exploring areas of varying landscape and topographic character. An assessment of sub-25 km variability is explored, examining the dynamics in the spring thaw transition occurring at high spatial variability which may not be observable with the lower resolution scatterometer.

We classify the time series radar imagery according to landscape freeze-thaw state, employing a temporal change discriminator based on seasonal differences in backscatter relative to wintertime frozen and summertime thawed conditions. Scaling assessments of the relationship between the SAR and SeaWinds backscatter and derived freeze/thaw state maps provide a means for determining sub-grid spatial variability in land cover, terrain and spring thaw processes, based on semi-variogram analyses.

Results show that JERS and ERS backscatter are sensitive to the spring thaw transitions. However, JERS exhibits a larger transitional dynamic range than does ERS and is more sensitive to varying land cover classes. These findings demonstrate the importance of landscape heterogeneity when considering development of remote sensing techniques for monitoring phenological processes in boreal ecosystems.

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

## B12B-0821 1330h POSTER

## Monitoring Boreal Ecosystem Phenology with Integrated Active/Passive Microwave Remote Sensing

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The important role of the high latitudes in the functioning of global processes is becoming well established. The size and remoteness of arctic and boreal ecosystems, however, pose a challenge to quantification of both terrestrial ecosystem processes and their feedbacks to regional and global climate conditions. Boreal and arctic regions form a complex land cover mosaic where vegetation structure, condition and distribution are strongly regulated by environmental factors such as moisture availability, permafrost, growing season length, disturbance and soil nutrients. The timing of spring thaw in particular, can influence boreal carbon uptake dramatically. With boreal forests accumulating 1% of their annual total accumulated carbon each day of the growing season, variability in timing of spring thaw can trigger total interannual variability in carbon uptake on the order of 30%.

We utilize active and passive microwave remote sensing measurements from spaceborne scatterometers and radiometers to examine interannual variability and multi-year trends in seasonal freeze/thaw cycles across the pan-boreal landscape. Ku-band backscatter data are available from the SeaWinds scatterometer on Quikscat for June 1999 to the present, and from the NASA scatterometer (NSCAT) from late 1996 through June 1997. Contemporary brightness temperature measurements are available from SSM/I, while SMMR brightness temperature measurements extend from the late 1970s. These data allow investigation of the synergistic use of active/passive microwave measurements, as well as longer-term assessments of the timing of spring thaw and associated growing season initiation in the boreal high latitudes. We extend our on-going work in applying spaceborne radars for monitoring boreal growing season dynamics to include application of contemporary and historic brightness temperature measurements from SSM/I and SMMR. We investigate the synergistic use of the active/passive measurement suite and we assess interannual variability in growing season initiation and length. Providing a useful measure for estimates of growing season timing, these data sets enable examination of historical spatial and temporal patterns in boreal growing season.

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract to the National Aeronautics and Space Administration

## B12B-0822 1330h POSTER

## Retrieval of Biomass and Structural Information of Forests From Lidar Waveforms Using Time-Dependent Radiative Transfer Theory

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Climate change, carbon sequestration policies and wood industry are three principal motivations for quantifying the magnitude and rates of change of the carbon content of forests. Globally, forests cover approximately 3870 million hectares and contain about 350 giga tons of carbon in their wood. Any activity that changes the amount of forest biomass has the potential to sequester carbon from, or release carbon to, the atmosphere. Ground measurements of biomass are expensive, limited to small areas, time consuming, prone to error and difficult to repeat. Remote sensing estimates of biomass have the advantages of high spatial resolution, temporal consistency, mapping remote areas and known uncertainty. Large footprint waveform recording laser altimeters (lidars) have demonstrated a potential

for accurate remote sensing of forest biomass and structure. Presently, the lidar-based methods of biomass estimation require intensive ground measurements to develop relationships between the amount of biomass and the specific indices extracted from lidar waveforms, such as quadratic mean canopy height. These methods are useful only for forest stands where the density of stems and foliage and the content of species are approximately the same over large areas. Moreover, they are based on the simplifying assumption that only single scattering contributes to the return signal, which can lead to large errors at near-infrared wavelengths. A new method based on the combination of time-dependent radiative transfer theory and probability approach used in cloud remote sensing, has been developed to retrieve crown radius, gap probability and foliage density from lidar waveforms without corresponding ground measurements. The method describes multiple scattering events and allows for realistic representation of forest structure including forest clumping and gaps. It was tested with SLICER data collected over deciduous and coniferous forest stands. The retrieved parameters were compared with those measured on the ground. This is a fundamental research in support of lidar remote sensing of forest structure and biomass, and can underlie physically based algorithms for biomass estimation from future space-based sensors.

URL: <http://cybele.bu.edu/download/ms.html>

## B12B-0823 1330h POSTER

## Quantitative Estimates of Biomass and Forest Structure in Temperate Rainforests Derived from Multi-return Airborne Lidar

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Obtaining accurate measures of biomass and forest structure in the primary temperate rainforests of southeast Alaska from traditional remotely sensed data has been hampered by the complex stand structure of these productive rainforests and variability of canopy illumination in steep topography that occurs at high latitudes. We evaluated the utility of lidar (Light Detection and Ranging) in estimating biomass and forest structure at High Island, southeast Alaska. Forest structure attributes were measured for 12 plots 0.12 - 0.78 ha in size, representing a range of naturally occurring seral stages and structural attributes. High density (>2 pts per m<sup>2</sup>) lidar data was then collected using a second generation airborne multi-return digital airborne topographic imaging system scanner (DATIS 2). Variables which could be used to predict forest structure attributes were then developed from the lidar data within pixels of varying resolution. Backward stepwise multiple regression was then used to develop a statistical relationship between lidar-derived variables and field-observed stand attributes such as aboveground biomass, basal area, stem diameter and stand density. The influence of sampling effort (lidar point density) on prediction was evaluated by randomly removing data (to produce a lower point density) and constructing regression equations each time. The relationship between observed and lidar predicted forest structure attributes were significant (>0.7 R<sup>2</sup>, P<0.01). The three-dimensional aspects of the canopy measured by the lidar sensor were able to accurately estimate complex aspects of the diameter distribution, such as the standard deviation of diameter at breast height. We conclude that multi-return lidar can be used to accurately predict biomass and other forest structure attributes over large areas in coastal temperate rainforests, although problems associated with dense understorey and complex topography still present difficulties for lower intensity sampling efforts.

## B12B-0824 1330h POSTER

## Testing The Feasibility of Estimating Forest Evapotranspiration From Visible/Infrared Imaging Spectrometer (AVIRIS) Data

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Remotely sensed data acquired using the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) at two irrigated hybrid poplar plantation sites located in Oregon and Washington States were used to assess the feasibility of using AVIRIS retrieved column water vapor as a measure of forest evapotranspiration (ET). AVIRIS data collected on four different days in the summers of 1996, 1997 and 1998, were used to derive column water vapor over the sites. To relate column water vapor to poplar ET, we developed a hypothesis, which was used to infer the relationship between the two variables. The approach tested consisted of delineating homogenous vegetated patches and averaging the column water vapor to determine the down-wind spatial distribution pattern (trend) in the water vapor signal. The results indicate that the poplars were transpiring at rates characteristic of vegetation under unlimited soil moisture conditions and that the vertical distribution of water vapor was chiefly driven by forced convection. The concentration and the observed trends in the column of water vapor over the vegetated patches were related to the moisture condition of the land cover up-wind of their location, and the trends were best described by linear or quadratic functions. To give an idea of the strength of moisture flux in the AVIRIS vapor signal, latent heat fluxes were estimated, based on the slope of the trends. Comparison of the AVIRIS values with flux estimates at the Boardman site lend credence to the potential for AVIRIS retrieved column water vapor in fields such as ecology, hydrology, agriculture and meteorology.

## B12B-0825 1330h POSTER

Recent Interannual Variations in Exchanges of CO<sub>2</sub> with the Atmosphere: Inverse Model Results and Consistency with Bottom-up Approaches

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We have inferred regional biospheric and oceanic exchanges of CO<sub>2</sub> with the atmosphere by an inverse calculation from measurements of the concentration and C13/C12 isotopic ratio of atmospheric CO<sub>2</sub>. Over the last 20 years, tropical biospheric fluxes have been primarily responsible for El Niño scale variations in atmospheric CO<sub>2</sub>. The magnitude We have inferred regional biospheric and oceanic exchanges of CO<sub>2</sub> with the atmosphere by an inverse calculation from measurements of the concentration and C13/C12 isotopic ratio of atmospheric CO<sub>2</sub>. Over the last 20 years, tropical biospheric fluxes have been primarily responsible for El Niño scale variations in atmospheric CO<sub>2</sub>. The magnitude and timing of biospheric fluxes from our inversion are only broadly consistent with results from terrestrial biospheric process models. However, in order to reliably predict future changes in atmospheric CO<sub>2</sub>, we must accurately characterize the role of biological processes which requires agreement between the atmospheric inverse calculation and biospheric models. We will present results from a biological model and an examination of the the spatial and temporal patterns of primary climate drivers and of new time series of the satellite greenness index, NDVI, as a step towards resolving current discrepancies between the "top-down" and "bottom-up" estimates of biological CO<sub>2</sub> fluxes.

## B12B-0826 1330h POSTER

## Assessing Photosynthetic Capacity From Canopy Biophysics: A Test Of A Generalized Model Using Eddy Flux Data

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Knowledge of the magnitude and seasonality of photosynthetic capacity (A<sub>max</sub>) is essential to understanding and modeling the dynamics of ecosystem-atmosphere CO<sub>2</sub> exchange. Typical methods of prescribing A<sub>max</sub> on the basis of biome type are limited by the accuracy of ecosystem classifications, variability within ecosystem types, and the assumption that photosynthetic capacity does not change during the growing season. Alternative methods for assessing A<sub>max</sub> that can be incorporated into global models and remote sensing applications are needed, particularly those that rely on readily available plant measures (e.g. LAI, FPAR, NDVI) and standard meteorological variables (e.g. temperature, radiation, humidity).

From an ecophysiological perspective, canopy *Amax* should scale with absorbed radiation and this relationship should be conservative because of the conservative variation in the quantum yield of photosynthesis. That is, the magnitude and seasonality of canopy *Amax* can be explained by acclimation to growth irradiance, temperature and moisture. Specifically, *Amax* can be modeled using the functional constraint of co-limitation between light-limited (electron transport) and light-saturated (carboxylation) rates of photosynthesis. In contrast to optimality approaches, this allows for resource use efficiency rather than carbon gain to be maximized in a given environment. Further, this constraint is functionally more realistic, consistent with observations, and testable at leaf to landscape scales.

Based on eddy flux data in arctic, boreal, temperate, and tropical ecosystems, the magnitude and seasonality of canopy *Amax* is consistent with acclimation to absorbed radiation in a wide range of ecosystems as predicted by the functional constraint of co-limitation by electron transport and carboxylation. A unique aspect of the approach is the use of a recursive filter for calculating photosynthetic acclimation based on the temporal integration of environmental conditions. Overall, the model provides a process-based link between canopy physiological status and canopy biophysics (e.g. FPAR). As such, the model can be applied at canopy to global scales using remote sensing observations of absorbed photosynthetically active radiation (APAR).

## B12B-0827 1330h POSTER

### Solar Radiation, Microclimate, and Water Balance in Complex Terrain

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Incoming solar radiation (insolation) is the major source of energy at the earth's surface, and is a primary driver of water flux. In particular, insolation directly affects local temperature, which in turn affects evapotranspiration rates. Three components of topography determine local insolation: 1) elevation, with greater insolation at higher elevations; 2) surface orientation, with decreased insolation at larger angles of incidence; and 3) surrounding obstruction, with decreased insolation when sky obstruction increases. We are using GIS-based approaches to evaluate landscape patterns of insolation, microclimate, and water balance for the Los Alamos National Environmental Research Park and surrounding lands. Using an upward-looking viewshed insolation model (the Solar Analyst), which requires a digital elevation model (DEM) and estimates of transmissivity for input, we calculated variation in direct and diffuse insolation as a function of landscape position and time of year. Then we used an insolation-modified adiabatic model, calibrated with ground-based meteorologic measurements, to calculate climatic surfaces (temperature, precipitation, potential evapotranspiration, and actual evapotranspiration) for the study site. In keeping with findings for other topographically diverse sites, topography has a strong and predictable influence on evapotranspiration through its effect on insolation.

URL: <http://gislab.lanl.gov>

## B12C MCC: 132 Monday 1330h

### Using Microbial Community Structure, Activity and Reaction Modeling to Evaluate Biogeochemical Cycles in Sediment and Soil Environments II (joint with H, OS)

**Presiding:** L Proctor, University of Maryland Biotechnology Institute and U.S. Geological Survey; E Roden, University of Alabama; W Burgos, Pennsylvania State University

## B12C-01 1335h INVITED

### Structure and diversity of functional guilds in the microbial nitrogen cycle of estuarine sediments

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Denitrification is a major flux of nitrogen in Chesapeake Bay, an estuary with a long residence time and high organic and inorganic nutrient inputs from the large surrounding watershed. The estuarine system spans a complex gradient of salinity and many correlated chemical constituents, from its upper bay and river freshwater end members to its nearly full strength seawater lower bay. Denitrification rates in sediments, computed from net nitrogen fluxes in simulated *in situ* core incubations, show distinct reproducible patterns along the Bay. Highest rates are observed in sediments from the low salinity, high nitrate upper stations in the Bay and Choptank River. Lower rates occur in the low nitrate, oxygen depleted mid bay sediments and in the metabolically less active south Bay sediments. Gene sequences for nitrite reductase, the key enzyme in denitrification, show very high diversity in Bay and River sediments. On the basis of clone library sequences alone, however, there are distinct clades and patterns indicating highest diversity in the upper Bay and River sediments and lower diversity in the lower Bay sediments. Using a DNA microarray containing many individual nitrite reductase sequences, we investigated the population structure of denitrification genes along the estuarine gradient. Evaluation of gene expression patterns, in addition to presence/absence or abundance of individual genes, will allow a direct assessment of the links between diversity and biogeochemical transformation rates for particular functional guilds. The rate of denitrification and its regulation by environmental variables may be reflected in patterns of guild composition and activity.

## B12C-02 1350h INVITED

### The Role of Reactive Transport Modeling in Understanding Biogeochemical Processes Associated With Iron Oxide Reduction

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In a series of column and batch experiments, we are investigating mineral phase transformations during microbially mediated reduction of the iron oxide ferrihydrite. Quantification of the solid phase over time, using XAS and HRTEM, indicates that the primary sinks during iron oxide reduction, for both Fe (II) and Fe (III), are the secondary iron phases goethite and magnetite. While goethite is the dominant secondary phase when dissolved Fe (II) concentrations are low, magnetite is the dominant sink at higher concentrations. The specific secondary mineral phase assemblage changes with time and is very sensitive to initial conditions. Reactive transport modeling using MIN3P has been an essential tool in our interpretation of the experimental data and has assisted in developing and testing of our conceptual model of this system. Early simulations highlighted the potential importance of dissolved Fe (III) (a parameter often ignored in aqueous systems at near neutral pH) and helped to guide later experimental design. In particular, simulations illustrated the necessity of rapid aqueous mass transfer of dissolved Fe (III) from ferrihydrite to goethite, despite very low dissolved Fe (III) concentrations. These observations have implications for mechanisms of microbial iron reduction, secondary phase formation, the availability of ferric iron to reduction, and the sequestration of metals and nutrients. The modeling results were realized prior to achieving simulations that closely matched the laboratory data, emphasizing the utility of reactive transport modeling as a research tool.

## B12C-03 1405h

### Bacterial Production and Enzymatic Activities in Deep-Sea Sediments of the Pacific Ocean: Biogeochemical Implications of Different Temperature Constraints

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The deep-sea bed, acting as the ultimate sink for organic material derived from the upper oceans primary production, is now assumed to play a key role in biogeochemical cycling of organic matter on global scale. Early diagenesis of organic matter in marine sediments is dependent upon biological processes (largely mediated by bacterial activity) and by molecular diffusion. Organic matter reaching the sea floor by sedimentation is subjected to complex biogeochemical transformations that make organic matter largely unsuitable for direct utilization by benthic heterotrophs. Extracellular enzymatic activities in the sediment is generally recognized as the key step in the degradation and utilization of organic polymers by bacteria and a key role in biopolymeric carbon mobilization is played by aminopeptidase, alkaline phosphatase and glucosidase activities. In the present study we investigated bacterial density, bacterial C production and exo-enzymatic activities (aminopeptidase, glucosidase and phosphatase activity) in deep-sea sediments of the Pacific Ocean in relation with the biochemical composition of sediment organic matter (proteins, carbohydrates and lipids), in order to gather information on organic matter cycling and diagenesis. Benthic viral abundance was also measured to investigate the potential role of viruses on microbial loop functioning. Sediment samples were collected at eight stations (depth ranging from 2070-3100 m) along two transects located at the opposite side (north and south) of ocean seismic ridge Juan Fernandez (along latitudes 33° 20' - 33° 40'), constituted by the submerged volcanoes, which connects the Chilean coasts to Rapa Nui Island. Since the northern and southern sides of this ridge apparently displayed small but significant differences in deep-sea temperature (related to the general ocean circulation), this sampling strategy allowed also investigating the role of different temperature constraints on bacterial activity and biogeochemical processes and to define possible scenarios dealing with climate induced changes in deep-sea conditions.

## B12C-04 1420h

### Relationships Between Denitrifier Abundance, Denitrifier Diversity and Denitrification in Gulf of Mexico Hypoxic Zone Sediments.

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The largest zone of anthropogenic bottom water hypoxia in the Western Hemisphere occurs seasonally in the northern Gulf of Mexico. This hypoxic zone reaches its greatest extent in the summer months and is a consequence of seasonal stratification of the water column combined with the decomposition of organic matter derived from accelerated rates of primary production. The enhanced primary production is driven by inorganic nitrogen input from the Mississippi River and these conditions would seem ideal for supporting high levels of denitrification. Yet sediment denitrification exhibited a wide range, even at the height of the seasonal hypoxia. Therefore, we compared benthic denitrifier abundances and denitrifier diversity at several stations over two seasons exhibiting extremes in denitrification to evaluate the relationship between abundances, diversity and denitrification levels. Sediment denitrification ranged from 20 to 100  $\mu\text{mol m}^{-2} \text{h}^{-1}$ , with rates in July, 2000 approximately half that observed in July, 2001. The highest rates were generally observed at stations with bottom water DO concentrations between 1 and 3  $\text{mg l}^{-1}$ . Relative denitrifier abundances, using *nirS* and *nirK* as proxies for denitrifiers, suggested a direct relationship between abundances and denitrification while denitrifier diversity, measured by