

Introduction to special section: Land-Air-Ice Interactions (LAI) Flux Study

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The Arctic region covers 11% of the Earth's total land area. Large quantities of carbon (10–20% of the Earth's soil carbon inventory) are sequestered in the near-surface soils of this region. This stored carbon represents a significant potential source of carbon dioxide (CO₂) and methane (CH₄) to the atmosphere. What are the variables and processes controlling the fluxes of CO₂ and CH₄ from the Arctic ecosystems to the atmosphere, and how will these fluxes change in response to variations in climate? Answers to these questions were the goals of the NSF-sponsored Land-Air-Ice Interactions (LAI) Flux Study, an interdisciplinary study that focused on the Kuparuk River basin (8140 km²) and its subwatersheds on the North Slope of Alaska. The LAI flux study was conducted over a 4 year period (1993–1996) by a group of soil scientists, hydrologists, atmospheric scientists, biogeochemists, modelers, and ecosystem scientists.

The hypotheses addressed by flux study projects and by many of the papers in this section are as follows:

1. Arctic terrestrial and freshwater systems are presently a source for CO₂ and CH₄.
2. Climate-induced changes of air temperature and soil moisture will be large enough to provoke changes in trace gas fluxes in Arctic terrestrial systems.
3. Changes in trace gas fluxes will result in climate feedbacks that are comparable to or greater than albedo and vegetation feedbacks.
4. In the next 50 years, changes in soil moisture will exercise greater control over regional trace gas fluxes than either air temperature or vegetation; after 50 years, vegetation changes will contribute more significantly to Arctic climate feedback.
5. Climate change and the associated acceleration of soil organic decomposition will increase the nutrient flux to all water bodies.
6. Arctic trace gas feedbacks will be sufficient to impact climates beyond the Arctic.

Early results of the LAI Flux Study were presented in sessions entitled "Trace Gas Fluxes From Arctic Ecosystems" at the December 1996 American Geophysical Union meeting in San Francisco. The following papers are the result of the two 1996 sessions and are complemented with non-LAI Flux Study presentations that were relevant to the theme of trace gas fluxes from northern ecosystems. Of the 17 papers in this special section, over half deal directly with either the measurement of trace gas (CO₂ and CH₄) fluxes or the process and manipulation studies aimed at understanding environmental

controls on the fluxes. The carbon-water-energy linkage is especially important in the Arctic because of the importance of permafrost, of saturated/anaerobic soils, and the seasonality of snowfall, albedo, and stream discharge. Additional papers provide information on soils, carbon accumulation, dissolved organic carbon (DOC) in runoff, the surface energy balance, and permafrost and active layer behavior in the study area. Modeling papers compare land surface schemes in regional climate models, describe below ground thermal distributions, and project future conditions with an ecosystem model calibrated for Arctic tundra. An important framework for site selection and spatial extension of flux measurements from plots, towers, and aircraft transects to the watershed scale was provided by the hierarchic geographic information system (HGIS) of *Muller et al.* [1998], which also provided a vegetation map at several resolutions.

Ping et al. [this issue] summarize the chemical and physical properties of Arctic tundra soils along a longitudinal gradient. Topography varies along this north-south section from relatively flat on the northern coastal plain, with poorly drained soils, to moderately steep foothills with better drained soils. Variations in climate, topography, soil pH, and cryogenic processes result in soils with highly varying properties. Soil moisture content is a critical variable in soil decomposition processes and the partitioning between CO₂ and CH₄ trace gas fluxes. The carbon deposits on the Arctic coastal plain mirror the hydrologic, geomorphic, climatic, and vegetation patterns. *Eisner and Peterson* [this issue] report that there was rapid accumulation of peat between 8500 and 5000 years ago; however, the rate of accumulation of peat has slowed in the last 5000 years, and the vegetation has changed from mixed grass-shrub tundra to tussock-forming sedge vegetation. *Michaelson et al.* [this issue] examine the transfer of terrestrial carbon to aquatic systems during the following snowmelt. They report relatively high concentrations of dissolved organic carbon (DOC) in the melt runoff waters over a range of tundra types and show that this DOC is readily available to soil organisms.

McFadden et al. [this issue] examine the sub-grid-scale spatial variability of energy, water vapor, and CO₂ fluxes with a mobile eddy covariance tower. Variations in surface energy balance partitioning over different tundra vegetation types within a few kilometers distance were larger than differences reported for major climatic regions within the Arctic and of the same order as the contrast between Arctic tundra and boreal forest. Large-scale differences in energy partitioning were related to variations in soil moisture, while direct effects of vegetation were important in shrub tundra, where shading of the moss layer by the canopy reduced ground heat flux and increased sensible heat flux.

Permafrost is addressed in two papers. *Nelson et al.* [this

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issue] intensely monitored the depth of thaw of the active layer at the end of summer for 2 years at seven representative sites in the Alaskan Arctic. They concluded that topographic position had the highest autocorrelation with depth of thaw; but soil moisture is also highly correlated with topographic position. The spatial prediction of the active layer depth of thaw and near-surface temperature profiles is required for spatial models of trace gas fluxes. *Hinzman et al.* [this issue] developed a spatially distributed thermal model and present results of simulated thermal processes for the Kuparuk River basin. The surface energy balance equations were solved simultaneously to predict the surface temperature, and this surface temperature was used in a finite element formulation to calculate the temperature profile and depth of thaw.

Fluxes of CO_2 and CH_4 were measured over a range of spatial and temporal scales. *Oechel et al.* [this issue] report large-scale estimates of net CO_2 and energy exchange from a study involving chamber as well as tower and aircraft-based eddy covariance measurements. They report good agreement between these approaches, in spite of spatial distribution problems in comparing spatial and temporal averages, underestimation of nocturnal net CO_2 exchange, and periodic appearance of a CO_2 plume from Prudhoe Bay. *Reeburgh et al.* [this issue] estimated annual CH_4 emission from the Kuparuk River basin with a straightforward application of the *Muller et al.* [1998] vegetation map and three years of annually integrated methane flux measurements from a representative range of vegetation types. Inundated wetlands and open waters are the major methane sources, but comparisons of this emission estimate with global models suggests that the Kuparuk River basin may not be typical of the entire Arctic. The areal extent of inundated wetlands is probably underestimated by remote sensing, raising the possibility that several large wetlands may account for the majority of high-latitude wetland CH_4 emission. *Christensen et al.* [this issue] investigated environmental controls on CO_2 emission with measurements on soils from a Eurasian tundra transect and comparative experiments in northern Sweden and northeast Greenland. Temperature and depth of water table were the most important controls. Field observations and experiments involving nitrogen and phosphorus additions showed that soil N status is of minor importance in controlling decomposition rates.

Two papers describe gas fluxes during and after winter. *Fahnestock et al.* [this issue] reported elevated subnivean CO_2 concentrations and added support to the hypothesis that early and deep snow accumulation insulates microbial populations from extreme cold, allowing sites with early snow cover to sustain higher levels of microbial activity throughout the winter. *Phelps et al.* [this issue] reported measurements of methane in ice-covered lakes. Methane trapped by the ice cover accumulates and is released as a pulse during breakup and spring turnover.

Two papers deal with regional climate models, and one uses an ecosystem model to project future ecosystem behavior. *Lynch et al.* [this issue] investigated the spring seasonal transition and mechanisms controlling snowmelt with ARCSYM using BATS and LSM land surface schemes. Both schemes deviated from the observed results; both snow albedo formulation and the partitioning of ground heat flux explained the differences between the two land surface schemes. *Tilley and Lynch* [this issue] compared three land surface schemes (BATS1E, NCARLSM, and CLASS) in simulations of the 1992 summer season at Barrow and Imnavait Creek in the

Kuparuk River basin. They found CLASS and LSM schemes with multilayer diffusion schemes to be superior to BATS1E for capturing the seasonal behavior at the two sites. Calibration of the Marine Biological Laboratory General Ecosystem Model (GEM) for an Arctic tussock tundra system is described by *Hobbie et al.* [this issue]. A 150-year simulation of carbon storage under a slow doubling of CO_2 and 3.5°C temperature change showed that carbon storage increased under conditions of both increased and decreased soil moisture. This model result suggests that warming is unlikely to enhance carbon loss to the atmosphere and a greenhouse feedback.

Process studies and site-scale environmental manipulations provide information on the sensitivity of tundra systems to environmental changes as well as the mechanisms. *Oberbauer et al.* [this issue] extended the growing season of tussock tundra by early and late season snow removal and by heating with resistance wires. These treatments tended to increase below ground respiration but did not differ significantly from controls. *King et al.* [this issue] studied CH_4 fluxes and below ground CH_4 distributions at sites where vegetation had been manipulated by removal of either sedges or mosses. Methane emission was greatest from plots with intact sedges. Insertion of arrays of gas-permeable silicone rubber tubing into the soil indicated that these "rubber plants" are reasonable physical analogs for gas transport through plants. *Moosavi and Crill* [this issue] report measurements of CH_4 oxidation using methyl fluoride as a selective inhibitor. They suggest that CH_4 oxidation, a significant preemission sink, might consume a near-constant fraction of available CH_4 .

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