ATLAS field report
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Overview

In winter and spring, with considerable help from VECO and our Russian colleagues, we transported equipment for three flux towers to Cherskii on the lower Kolyma River in Eastern Siberia. It is a region of forest tundra near the arctic treeline, 100 km south of the Arctic Ocean. The purpose of the measurements was to extrapolate the research on ecosystem controls over land-atmosphere exchange from Alaska to a portion of the circumpolar Arctic where we have least confidence that our current understanding will apply. In this forest tundra region, the ground layer has a species composition quite similar to Alaska, but the tree species is a deciduous conifer (larch: *Larix gmelinii*). Soils are ice-rich loess sediments, with about a 70% ice content and are much more vulnerable than Alaskan soils to thermokarst in response to the regional warming that has occurred there over the past 30 years. The goals of the research program are to

1. measure physical environment and land-atmosphere exchanges of water, energy and CO2 in a recently disturbed (1984) and undisturbed (about 60-year) area of forest tundra and in a third site from which all Holocene organic matter is removed by bulldozer to follow the development of thermokarst and the carbon losses immediately following disturbance.
2. document the biomass, leaf area index, and species composition of the study areas for input to models of ecosystem change
3. document permafrost dynamics and their long-term response to disturbance.
4. document the role of thermokarst lakes and wetlands in the regional methane budget of the Kolyma lowlands.

In addition we are collecting samples or information for other groups on surface moisture (Hinzman, Kane, Nolan), soils (Ping), grid locations for vegetation sampling (Walker), and water samples for measurement of carbon flux from the Kolyma Lowlands to the Ocean (Randerson and Neff). The tower measurements will be continued for several years as part of a RAISE project (Randerson, Neff, and Chapin).

Land-atmosphere exchange and physical environment

Two tower sites (60-year-old and 15-year post-fire forests) were established in June 2001. These towers will be run for one full year as part of the ATLAS project and will maintained for an additional three years by the Randerson/Chapin RAISE project to determine the effect of disturbance and interannual variation in climate on fluxes of carbon, energy, and moisture. A third tower site will be initiated in July, after removing the Holocene organic mat. This will enable us to follow the immediate changes in carbon and energy flux after disturbance. Samples of CO_2 will be collected for isotopic analysis from all three sites. The 60-year forest tundra site will be monitored continuously. Instruments from the other two sites may be moved occasionally to other sites (mobile tower sites) to determine regional variation in fluxes among ecosystem types. The types that would be examined (in approximate order of priority) would be a lowland wet tundra (which is regionally widespread), a dense young forest tundra site (about 30 years), and an old forest tundra site (about 200 years). Continuous measurements to be made at tower sites include:

1. Fluxes of CO_2, sensible heat, latent heat, ground heat
2. Radiation (net radiation, incoming and outgoing longwave and shortwave)
3. Air temperature and relative humidity at 2 heights; wind speed at two heights; wind direction; precipitation; barometric pressure
4. In four vegetation microsites, soil temperature at 1 cm, 2 cm, 10 cm, 20 cm; soil moisture
5. Thaw depth weekly
6. Bulk density in soil horizons where soil sensors are located

We will continue to maintain records of meteorological data from the Cherskii airport weather data (daily averages of 4 daily measurements) of air temperature, wind speed, wind direction, temperature, precipitation. These records are currently maintained by the Northeast Science Station.

We will collaborate with a German research group (Detlef Schulze and Martin Hieman) by providing them with tower flux data in return for information they are collecting with Sergei Zimov on atmospheric profiles of trace gases and their isotopic composition. Zimov is collecting biweekly samples of vertical profiles (500, 1000, 3000m) of atmospheric $^{18}O_2$, $^{13}CO_2$, and $C^{18}O_2$ beginning winter 2001 for 3 years. These will be used in a modeling program to estimate regional CO2 fluxes from Eurasia.

Permafrost dynamics

Soil profiles of temperature and moisture will be established in the three tower sites to document the impact of disturbance on permafrost dynamics and thermokarst. These measurements will be used to test soil thermal models developed in Alaska. Measurements to be made over the next several years include

1. Soil temperature and moisture from surface to 2 meters at the two tower sites
2. Horizontal variability in soil temperature
3. Deep temperature profile (20-30 meters) in the site from which the organic mat will be removed to follow thermal consequences of thermokarst. This will be coordinated with tower and chamber measurements of CO_2 flux and isotopic measurements of carbon to determine the contribution of Pleistocene carbon to CO_2 fluxes that occur after disturbance.

Vegetation and carbon fluxes

We are making measurements at both tower sites of parameters needed to model the role of plant functional types in Siberian carbon fluxes. Our comparison of recently disturbed and undisturbed sites will also enable us to document how these functional types change after disturbance. Measurements at the two tower sites (n=10 samples per site) include:

1. Aboveground biomass separated into major plant species, including NPP (new leaf, new stem) and old growth (old stem, old leaf); minor species grouped by plant functional types.
2. Plant nitrogen concentrations to estimate the quantity of nitrogen in plants and the quantity of nitrogen absorbed by plants every year. Samples will be taken to Alaska for analysis.

3. Leaf area index (leaf area per unit ground area) using Licor canopy analyzer. These measurements will be made every ten days.

4. Tree cores or cross sections to determine age since burn

5. If time is available, some measurements might be made in wet tundra to give a picture of the other major regional vegetation type and in a 30-year and a 160-yr forest-tundra site to make a more complete picture of the chronosequence

Other vegetation measurements being made at the Northeast Science Station include

1. Seasonal and diurnal patterns of ecosystem CO_2 flux using chamber measurments in a late-successional forest-tundra site at the science station (continuation of the 10-year record of measurement); occasional measurements at the tower sites to compare tower and chamber measurements

2. Litterfall in the forest behind the station (continuation of a 3-year record of measurement (n=12)

Skip Walker will make additional measurements of vegetation at the tower site in August of species composition as well as documenting regional variation in vegetation as a basis for improving of the current vegetation map that Chapin and Davydov developed.

We are collecting additional samples for other research groups, including:

1. (Jim Randerson) Time course of dried plant leaf samples (one site; n=5) for ^{13}C and ^{14}C to document the isotopic signature of photosynthesis and respiration, for comparison with the German atmospheric measurements. Species to be measured are:

Salix lanata
Betula exilis
Calamagrostis neglecta
Tomenthypnum nitens
Larix dahurica
Ledum decumbens

2. (Michelle Mack) Peak season collections of leaves, stems and soils along a soil fertility gradient of the same species listed above for ^{15}N analysis.

Soils

We are collecting soils for several research groups who will do analyses in the United States. These analyses include:

1. (Chien-Lu Ping) Soil samples from the two tower sites for comparison with data collected at other ATLAS tower sites in Alaska. Samples will be analyzed for standard soil parameters (including carbon quality). Two organic depths (fibric and sapric) and three mineral depths (organic-stained; mineral above permafrost; mineral below pemafrost) will be compared.

2. (Chien-Lu Ping) Soil samples from two Pleistocene soil profiles (40 m soil depth; same parameters). These will be collected from sites where Sergei Zimov has made field measurements and laboratory incubations of CO_2 flux.

3. (Michelle Mack) Soil samples for ^{15}N analysis; same design as Ping.

4. (Mark Hines) Permanantly frozen yedoma sediments from Cherskii will be analyzed for pore-water volatile fatty acids, sulfate, nitrate/nitrite, phosphate, total organic carbon, nitrogen, ^{13}C, pH, etc.

5. (Kathleen Tresider) Frozen permafrost soils for microbial community analysis.

Other measurements being made at the station include soil CO_2 flux from yedoma and grassland sediments incubated aerobically at two temperatures to document variations in organic matter quality and their impact on CO_2 flux.

Methane flux

We initiated a program of methane flux measurements to document regional methane flux and the role of lakes and wetlands in this flux. The Siberian lowlands are globally important methane sources, so an improved understanding of the regional patterns and factors controlling these fluxes seems important. We initiated the following measurements.

1. Seasonal sampling of a floodplain and an upland yedoma lake and wetlands near the margins of these lakes. Each lake is being sampled near sites of thermokarst erosion, near aquatic plants, and in zone of emergent aquatic plants. Parameters measured include methane diffusion flux (from chamber measurements or calculated from surface water CH_4 concentration), and vertical profiles of pH, temperature, dissolved oxygen, redox potential, and light. In the emergent aquatic plants CH_4 and CO_2 midday flux and aboveground biomass are being measured.

2. Extensive survey of 3 yedoma and 3 floodplain lakes for same parameters as in point 1. $^{13}CH_4$ from ebullition flux in lakes and wetlands to determine pathway of methanogenesis.

3. Laboratory incubation of surface sediments from 3 yedoma and 3 floodplain lakes (stratified into sediments near thermokarst and sediments near aquatic plants) to measure methane production potential at two temperatures. Frozen yedoma sediments will also be sampled because these are important organic matter inputs to these lakes.

4. Study of a recently drained floodplain lake to document the impact of lake drainage on CO_2 and CH_4 fluxes.

5. Decomposition rate of aquatic and terrestrial plants in anaerobic (lake bottom) and aerobic (drained lake basin) sediments.

6. Examination of aerial photographs and maps, use of tree rings, and benchmark monitoring of thermokarst erosion to estimate rate of lake migration.

Water samples

We are collecting a range of water samples that will provide preliminary information for documenting carbon flux from the Siberian terrestrial landscape to the Arctic Ocean. Samples include:

1. Survey of 10-12 streams that will be analyzed for dissolved organic carbon and particulate organic carbon

2. Soil pore water from tower sites and wetlands.

3. Sample Kolyma River water every two weeks for direct measurement of the carbon input to the Arctic Ocean.

4. Sample potential water supplies (tap water, lab distilled water) 2 or 3 times over summer to check for water quality

5. Rain or snow water for ^{18}O analysis occasionally through year

6. Snow depth and water equivalent each month at the two tower sites

7. (Mark Hines) Lake and wetland sediment pore water for volatile fatty acids, sulfate, nitrate/nitrite, phosphate

Additional data available from the Northeast Science Station in Cherskii

Climate and physical environment

1. Daily air temperature, precipitation 1989-2001 at Cherskii airport; occasional data on atmospheric pressure, wind speed; daily and monthly summaries available for each year in excell spread sheet. Data available from Ambarchik on the Arctic Coast for some years.

2. Soil temperature and active-layer depth beneath different microsites in the forest behind the station; also floodplain, steppe, disturbed places

3. Effect of experimental addition of sugar and flour on soil temperature and thaw depth (test of the effect of microbial respiration on soil temperature)

4. Soil temperature in boreholes in the Cherskii region (Gilichinksy, Fukuda)

5. CALM grid (100 x 100 m grid) of maximum active layer depth in shrub tundra on Rodinka mountain. Seasonal measurements 1 year; maximum thaw depth 3 years

6. Discharge of Kolyma River

Maps and remote sensing

1. 1973 map (US DoD)

2. Aerial photograph 1:500,000; Davidov is looking for photography from other dates to look for changes in positions of lakes and dates of fires over time

3. Satellite false color infrared 1:1,000,000 and 3 enlargements

4. 1 km resolution NDVI and vegetation maps (86-72˚N; 150-166˚E) (Mike Fleming and Terry Chapin unpubl.)

5. Vegetation maps of the region exist (Yakutian atlas)

Vegetation

1. Understory aboveground biomass (i.e., all species except trees) on altitudinal transect from the Panteleja River to Rodinka Mountain (1985; n=42 places). Also 20 locations of floodplain. In each site, biomass was collected in 50 x 50 cm quadrats and separated by plant functional types. % cover by species; soil profiles, thaw depth. Soil temperature at 5, 10, and 40 cm. These sites have been revisited to observe vegetation recovery over time.

2. Litterfall in larch forest behind station (1998-2001) and at selected other sites (Sergei Davidov)

3. Successional studies; qualitative observations of species composition in many kinds of disturbances; profiles, thaw depths (Sergei Davidov)

4. Vegetation and soils studies (Dima Davidov Feoderov)

5. Experimental study of transpiration rate (lysimeters) by major steppe and tundra species (Zimov et al. 1995)

6. Model of vegetation composition based on light and water competition among plant functional types (mosses, grasses, and shrubs), driven by climate, loess inputs and herbivory (Zimov et al. 1995).

7. Biomass and soil profiles from a variety of tundra sites.

Soils

1. Carbon content of yedoma for Siberian lowland based on vertical profiles of organic C at tundra, forest tundra, and forest sites (Zimov et al. Submitted). Frozen subsamples of many of these profiles have been archived.

2. An expedition of high-latitude soil scientists visited the Cherskii area and described 12 soil profiles along 3 transects: (1) an altitudinal transect from Rodinka Mountain, (2) a transect across yedoma and drained lakes at Duvani Yar, and a couple sites in high-arctic tundra at the mouth of the Kolyma River (Smith et al. 1995). All soils were on yedoma sediments. They describe the general vegetation and vertical soil properties and conclude that there are important reasons to establish a gelisol soil order in the US taxonomy. The US and Canadian taxonomy of soils give similar classifications of soils. The Rodinka transect was close to the vegetation/soil transect of the Cherskii group, but was not in the same place (closer to the road).

3. Resin-extractable ammonium, nitrate, and phosphate from disturbed vs. undisturbed sites in several places (Zimov and Chapin unpubl.)

4. Permafrost studies of temperature, permafrost microbes, etc. from deep boreholes (Puschino): Gubin, Gilichinsky and others

CO_2 flux

1. Chamber measurements of CO_2 flux in old forest behind station in different microsite types (disturbed vs. undisturbed). Measurements are made about every 10 days during summer; less frequently in winter; diurnal CO_2 flux is measured about once a month, 1991-2001. Initial data 1991-94 is published (Zimov et al. 1993a, Zimov et al. 1993b, Zimov et al. 1993c, Zimov et al. 1996).

2. Chamber measurements of CO_2 flux in paired disturbed and undisturbed sites from Cherskii (shrub tundra, cottongrass alas, riparian meadow, young and old forests, high arctic tundra [Ambarchik]). Measurements have been made through the annual cycle at noon and midnight, 1995-96 to describe the effect of disturbance on the annual cycle of carbon exchange (Zimov et al. 1999). Detailed data on daily net flux [NEP], photosynthesis [GPP], and carbon flux in the dark [ecosystem respiration] have not yet published. Data on air and soil temperature and light intensity were recorded at time of measurement. Occasional measurements have continued.

3. Winter CO_2 flux in response to experimental carbon additions to estimate winter microbial activity

4. Grids of subsurface CO_2 concentration to study role of soil convection in winter CO_2 flux (1999-2001)

5. CO_2 flux from yedoma (field measurements). Laboratory incubations (2 temperature regimes) of vertical profiles of ice-rich yedoma, yedoma beneath formerly drained lakes, and modern grassland soils (Zimov et al. Submitted). Measurements were made intensively for two years and have been continued less frequently for an additional two years . These measurements are being repeated for a new set of samples (2001); subsamples of this new set have been archived in frozen condition (see soils).

CH_4 flux

1. Seasonal cycle of CH_4 flux from thermokarst lakes; ebullition and diffusive flux; ^{14}C age of winter and summer ebullition flux (Zimov et al. 1997)

2. Survey of 19 lakes, streams, the Kolyma, and the coastal ocean of vertical profiles of dissolved CH_4 concentration to estimate diffusive flux (unpublished manuscript).

3. Lab incubation of yedoma and modern grassland soils (to be initiated in 2001)

4. Summer wetland CH_4 flux (Japanese group, published)

5. CH_4 concentration in permafrost ice (and its ^{13}C and ^{14}C content) Fukuda, Gilichinsky, Archangel, Vasilchuk, Zimov, Davidov, etc.

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