

The Zotino Tall Tower Observatory (ZOTTO)

A Scientific Platform in the Centre of Siberia for
Observing and Understanding Biogeochemical
Changes in Northern Eurasia



There is increasing evidence that the climate of the Earth is warming, primarily as a consequence of the human induced increases in atmospheric greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). During the recent decades large warming trends in the near surface air temperature are being observed, in particular on the Northern hemisphere continents at high latitudes in the boreal and arctic zones. E.g. near surface summer temperature have increased by up to 2°C over large parts of Siberia during the last 45 years (Figure 1). According to numerical climate model simulations, the temperature growth in this region is expected to accelerate over the next 100 years.

What will be the consequences of this warming? The huge boreal and arctic landmass of Siberia constitutes an important “hot spot” in the global carbon cycle. Large forested areas

interspersed with bogs and partially with permafrost soils characterize the Siberian landscape. Siberian forests comprise approximately 10% of the global carbon stored in vegetation and soils, they contribute 5-10% of the global terrestrial net primary productivity, and 65% of the Siberian forests lie on permafrost. The anticipated warming is expected to trigger important feedback processes in the carbon cycle with potentially serious consequences. On the one hand, warmer temperatures imply longer vegetation periods leading to increased carbon uptake. On the other hand, this process will be offset by increased losses of soil carbon due to enhanced microbial activity under warming conditions. However, both of these effects depend critically on the available water and hence are subject to changing precipitation amount and distribution patterns. Additional critical processes, such as disturbances by fires and insects will also be affected by climate change. Finally Siberian permafrost contains huge quantities of organic carbon, of which by thawing a

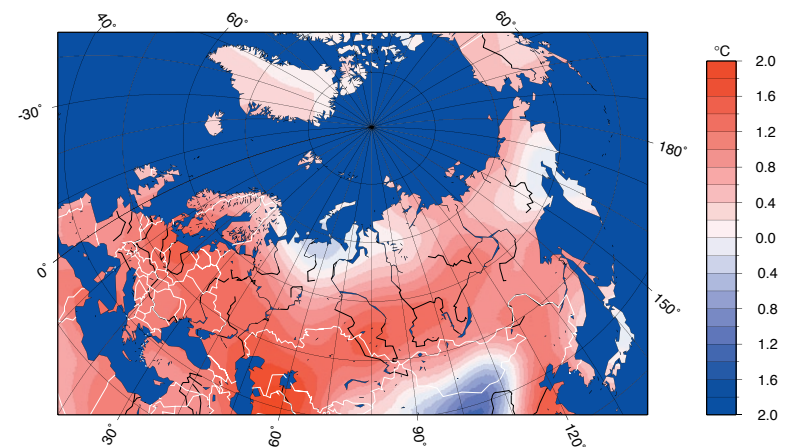


Figure 1. Observed changes in near-surface summer temperature (June to August) over the Eurasian continent during the 40 year interval 1960-2000. (After Chapin et al., 2005, NCEP reanalysis data).

significant fraction could be released to the atmosphere as carbon dioxide or methane. How fast and how strong these feedback processes operate and which of them will dominate is still an open and highly pressing scientific question. Furthermore, although direct anthropogenic impacts are at present still relatively modest, changes in land use and management may become increasingly important, e.g. by increased forest logging or rerouting of Siberian rivers for irrigation in agriculturally favourable areas further south. Such influences have the potential to seriously impact the boreal ecosystems and modify the regional emissions of greenhouse gases with probable global consequences.

Despite the large significance of the Siberian “hot spot” in the global carbon cycle and its sensitivity to global warming only few measurements representative for changes on large spatial scales and longer time-ranges exist for this region. Indeed, the global observation networks contain at present no station for continuous monitoring

of the full suite of greenhouse gases in the entire Siberian region north of 45° N. In the framework of the project “Observing and Understanding Biogeochemical Responses to Rapid Climate Changes in Eurasia”, a scientific platform, ZOTTO, the Zotino Tall Tower Observation Facility, is currently being constructed. It consists of a 300m tall measurement mast, a partially underground measurement laboratory and auxiliary infrastructure facilities located in the centre of the Siberian taiga, about 20km west of the river Yenisei (near 60°N, 90°E). At this site continuous measurements of CO₂, CH₄ and a suite of additional atmospheric gases as well as measurements of their isotopic composition will be performed on a routine basis. Complemented by additional measurements of meteorology, chemically active trace gases and aerosols, ZOTTO is to become a continental long-term atmospheric monitoring station which will document and help to quantify the anticipated changes in biogeochemical cycling in this important region of the globe.

Observation Strategy

Currently much of our understanding of the mechanisms of global change depends on models and theoretical approaches, primarily because observations, especially of the more complex biogeochemical processes, are still very sparse in many crucial parts of the world. Furthermore, many of the critical processes, e.g. permafrost melting, are occurring relatively slowly over decades and thus necessitate a long-term observing strategy. Available climate observations in northern latitudes show high rates of change that are widespread across the boreal and tundra regions of Eurasia and North America. These changes, while heterogeneous, are documented by surface meteorology, but are also witnessed from space, e.g. changes in the vegetation greenness [Myneni et al., 1997], and are also seen in the high-latitude atmospheric seasonal cycle of CO₂ [Randerson et al., 1998]. The changes may reflect the early impacts of greenhouse gas induced warming, although a sizeable fraction may also be associated with multi-decadal natural climate variability. In any case, trend analyses as well as model simulations indicate that observations, made over the next 5-30 years, very likely will witness the anticipated coupled changes to climate, the land surface and the carbon cycle (e.g. release and uptake of CH₄, CO₂, and CO) over the northern continents.

Conventional approaches to understand the connections between climate change and ecosystem-atmosphere interactions rely on a complementary top-down and bottom-up approach. The top-down perspective utilizes observations of the

atmospheric composition at remote locations (mostly oceanic islands or high mountains to minimize local effects), together with numerical models of large scale atmospheric transport in order to infer sources and sinks of the greenhouse gases at the surface. Conversely, the bottom-up approach is based on local in situ observations of fluxes or changes in ecosystem status, which then have to be extrapolated and scaled up in order to make inferences for the continental region. Bridging the huge gap in scale between the two approaches poses a tough scientific challenge. One possibility is the use of numerical models which describe the major processes involved in exchanges of biogeochemical trace gas exchanges between the terrestrial ecosystems and the atmosphere. These models are parameterized using in-situ relationships between environment, vegetation and soils, and they can also be evaluated and constrained with remote atmospheric observations. Alternatively, satellite remote sensing observations of the surface (greenness or biomass) can be used, but they do not “see” directly the gas exchange fluxes but necessitate additional process information and diagnostic models. Evidently, direct observation methods are needed to fill the spatial gap between the continental/global integrative approaches and the local, point wise process studies. This is where measurements on tall towers (200-600m) provide a promising new approach [Bakwin et al., 1998, 2004].





Why tall towers?

Tall tower observations bridge the gaps in scale by continuously observing the net exchange of large sub-continental regions and thus provide a key for focusing all three tools (atmospheric modelling, terrestrial modelling, and remote sensing) on the problem of understanding climate change interactions with ecosystems. Measurements of trace gas concentrations above 200-300 m above the earth's surface probe a relatively homogeneous part of the atmosphere (the mixed layer) (Figure 2). These mixed-layer observations of CO_2 combine the benefits of sensing surface flux processes integrated over a very large area and avoid the “noise” close to the earth's surface. Here, in the surface layer, the signals of the large respiration fluxes are amplified at night by the suppressed near-ground mixing, which traps and concentrates respired carbon within a shallow layer. But also

during daytime the heterogeneity of the terrestrial biosphere generates atmospheric concentration variations, which reflect the local flux patterns and surface wind circulation and mixing. Because of these effects, in vegetated areas the amplitude of diurnal signals of CO_2 next to the ground can be very large, reaching up to 300 ppm, or 50 times the large scale gradients associated with fossil fuel burning or other large scale source-sink processes. Therefore near ground measurements over vegetated land areas are very difficult to interpret in a regional or global context.

The surface layer that extends to approximately 200 m above the earth's surface is characterized by turbulent motion caused by the frictional drag of the land surface on the flow of the atmosphere. In contrast, the dynamics of the mixed layer (200-2000 m above the earth's surface) is dominated by strong convective mixing during the day and the absence of turbulence and the decay of the layer during the night.

Because of vigorous mixing, the very large amplitude of the diurnal cycle of carbon signals within the surface layer is strongly smoothed and reduced within the mixed layer. The strong mixing within this layer is therefore an efficient integrator of both daily cycles and small-scale heterogeneity of the biosphere. Studies with measurements of the dry cleaning agent C_2Cl_4 , whose emissions are strongly tied to population density in North America, demonstrate that tower measurements indeed integrate atmospheric tracer signals over very large areas on the order of 10^6 km^2 [Gloor, 2001]. The reason for the coherence between trace gas emissions and measurements over large distances is the comparably slow exchange between the mixed layer and the free troposphere caused by entrainment of air by “overshooting convection”

and by passing weather systems.

In addition to the benefits of taking measurements at very large heights, tall towers also permit measurements of vertical concentration and flux profiles of trace substances and meteorological variables. These observations allow the quantification of mixing within the surface layer and the processes responsible for mass exchange between the surface and mixed layer, as well as more local ecosystem-atmosphere exchange processes.

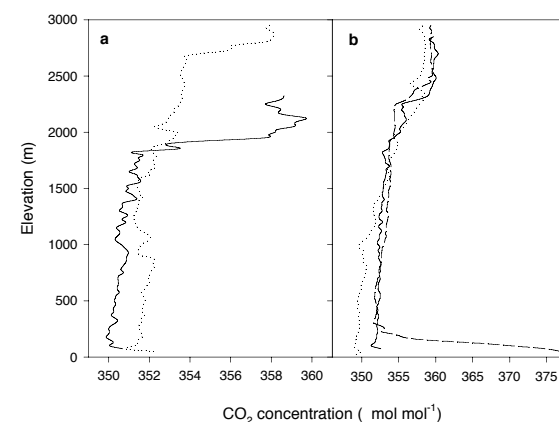


Figure 2: Observed profiles of the CO_2 concentration on (a) 23 July 1998 and (b) 24 July 1998 near Zotino using chartered light aircraft. Concentration was monitored continuously and averaged over each 50-m height interval. The solid line is the afternoon profile (1400 h on each day), the dotted line is the evening profile (2100 h on 23 July, 1900 h on 24 July) and the dashed line is the morning profile (0730 h on 24 July). The effects of the surface layer (below approx. 200m) as well as the mixed layer (200-2000m) are clearly discernible. (Styles et al., 2002)



ZOTTO - The Site

A tall tower of 300m height with adjacent laboratory and housing facilities, The Zotino Tall Tower Observation Facility (ZOTTO), is currently being established in the centre of the Siberian taiga near approximately 60°N, 90°E, about 20km west of the river Yenisei. It is a vast region of forests and bogs, still relatively undisturbed by anthropogenic influences and relatively inhospitable because of its continental climate. The population density is low but a moderate human impact on vegetation, e.g. by logging activities, is already visible. The harsh climate is dominated by the large seasonal temperature cycle reaching minima below -55°C in winter and maxima above 30°C in summer. Differences in climate within Siberia are comparably small and the composition of the ecosystem, which is the world's largest contiguous forested area, is quite homogeneous. The regionally

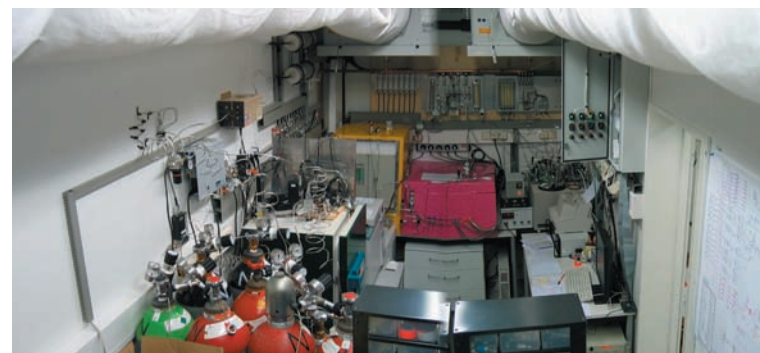
dominant vegetation type is needle-leaf evergreen forest (e.g., *Pinus sylvestris*), which surrounds sphagnum peat bogs and river meanders. In this area, temperature is the most important environmental control on large-scale vegetation patterns and activity [Churkina and Running, 1998]. A second relevant factor is natural fires [Isaev, 2002]. This high latitude region also contrasts with Western Europe because it contains significant wetlands, which hold large amounts of slowly accumulated carbon in soils. Due to the remote location of ZOTTO, pollution is minor and contamination of measurements by local emissions therefore minimal. Finally, because of the continental setting and large-scale homogeneity of the landscape, the atmospheric circulation is less complex than in Central Europe.

The measurements

The core observations to be made on this tower include continuous measurements of the mixing ratio of CO₂, CH₄, CO, N₂O and of the O₂/N₂ ratio, continuous flux measurements of CO₂ and latent heat by the eddy correlation method at various heights, and the standard meteorology (wind, temperature, humidity, and pressure). In addition, the isotopic composition of air samples will be analyzed via flask sampling (a.o. ¹³C/¹²C D/H, ¹⁵N/¹⁴N, ¹⁸O/¹⁶O stable isotope ratios on the different gases, as well as ¹⁴C and ¹⁸O on CO₂ and CH₄). Furthermore, a host of additional trace species of biogeochemical interest (e.g. aerosol density and size spectra) will be measured by various partner groups. The measured data are incorporated into comprehensive modelling frameworks comprising advanced atmosphere-biosphere exchange formulations, regional atmospheric models and 4-dimensional data assimilation techniques. This allows to combine the tower data both with satellite measurements of the atmosphere and land surface and also with in situ forest biomass inventory data. Atmospheric and biogeochemical

process modelling will serve to interpret atmospheric observations and relate them to seasonal and inter-annual vegetation and land surface variability.

Climate change and their associated changes in biogeochemistry necessitate a long-term observing strategy. This is especially important in the case of continental climates, which exhibit a strong seasonal and interannual variability. In order to detect longer-term trends, sufficient statistical sampling has to be made, which implies measurements over more than one decade. The ZOTTO project is intended to serve the scientific community for up to 30 years or more as a continental long-term observatory, similar to the renowned Mauna Loa observatory on Hawaii established almost 50 years ago.



Organization and Core Partners

The project partners:

- Max Planck Institute for Biogeochemistry, Jena, Germany, performing continuous biogeochemical trace gas measurements, eddy covariance flux measurements, meteorology observations and local ecosystem process studies;
- Max Planck Institute for Chemistry, Mainz, Germany, performing measurements of aerosols and CO concentration and isotopes;
- V.N. Sukachev Institute of Forest of the Russian Academy of Sciences, Krasnojarsk, Russia, responsible as local host institution for the maintenance of the station logistics and the measurements, as well as local ecosystem process studies.

Currently associated partners:

- The Institute for Tropospheric Research, Leipzig, performing continuous aerosol measurements
- The National Institute for Environmental Studies (NIES), Tsukuba, Japan, performing CO₂ concentration measurements
- The Institute of Atmospheric Physics of the Russian Academy of Sciences, Moscow, performing measurements of chemically reactive species and long-range pollution transport.

ZOTTO is a partner project of the International Science and Technology Center (ISTC #2757p).

ZOTTO in a wider context

ZOTTO is not an independent research project, but is embedded in an international effort for the establishment of a global system for the monitoring of carbon and related biogeochemical tracers (Integrated Global Carbon Observations - IGOS-Carbon Theme Report, Ciais et al., 2004). As part of this effort a high quality level of the measurements is mandatory. It is anticipated that most of the measurements at ZOTTO will be performed according to the standards of the Global Atmosphere Watch program (GAW) of the World Meteorological Organization, and that ZOTTO will become a certified GAW baseline station.



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Jena, August 2006

