

## **EUROSIBERIAN CARBONFLUX (ENV4-CT97-0491)**

### **ANNUAL REPORT 1998**

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## Project Summary

### **Abstract**

EUROSIBERIAN CARBONFLUX is a feasibility study for the development of an observing system to quantify the regional (1-2000 km) and continental scale carbon dioxide and other long-lived biogeochemical trace gas fluxes over several years (up to a decade and more). EUROSIBERIAN CARBONFLUX includes a combination of surface flux measurements by means of the eddy covariance technique at selected stations together with atmospheric observations from aircraft of the CO<sub>2</sub> concentration and other atmospheric tracers linked to the carbon cycle (carbon isotopes, SF<sub>6</sub>, O<sub>2</sub>/N<sub>2</sub>, CH<sub>4</sub>). A hierarchy of nested models of atmospheric transport is developed, which will be used for forward and inverse simulations to infer and constrain surface sources and sinks over the target area based on the atmospheric observations.

### **Background**

What is the net carbon balance of a continental region, such as Europe or Eurasia? There are at least two major motivations to answer this question:

- An accurate quantification of regional surface sources and sinks of CO<sub>2</sub> is needed in the context of international negotiations to curb the emissions of greenhouse gases. Such a quantification can proceed bottom-up, i.e. by the compilation of local statistical inventories and flux estimates, which are then aggregated to the regional scale. Alternatively, a top-down approach may be feasible, in which atmospheric measurements of the concentration of the greenhouse gases are “inverted” to estimate magnitude and uncertainty of surface sources and sinks that are consistent with the observations.
- Very little is known about sign and magnitude of climatic feedbacks on the global carbon cycle. Observed variations in the atmospheric CO<sub>2</sub> concentration on all time scales demonstrate that climatic fluctuations significantly influence the exchanges of carbon between the various carbon pools. Many of these feedbacks, however, are still poorly understood and need to be quantified on the regional scale in order to determine the climate sensitivity of the global carbon cycle. This information is indispensable for the construction of comprehensive, geographically explicit, climate sensitive models of the global carbon cycle which are to be coupled to global climate models. The development of such models, necessitates process study data in order to correctly parameterise the modelled processes in the various ecosystem and climatic regions. In addition, the models have to be evaluated at the regional level by comparing the regionally integrated surface flux predictions to estimates of the regional budgets. Of particular interest are the interannually varying regional fluxes driven by climate fluctuations, which provide a means to assess the credibility of the models to depict the climate sensitivity.

One approach to determine the regional carbon budget proceeds by an integrative approach, whereby atmospheric CO<sub>2</sub> concentration measurements, together with surface flux measurements are used to constrain high-resolution surface models of carbon exchanges. In this approach a nested atmospheric meteorological transport model hierarchy is used to relate the atmospheric measurements to the surface fluxes.

## METHODOLOGICAL APPROACH

EUROSIBERIAN CARBONFLUX includes two observational work packages and an integrative modelling activity:

**WP1.** Establishment of a trace gas ( $\text{CO}_2$  and  $\text{CH}_4$ ) climatology of the planetary boundary layer up to the free troposphere (approximately 4000m) at three selected sites (Fyodorovskoye, 56°N, 33°E, Syktyvkar, 62°N, 53°E, Zotino, 60°N, 90°E) by bi-weekly continuous and flask sampling from aircraft.

### $\text{CO}_2$ Monitoring Networks, Europe and Western Russia

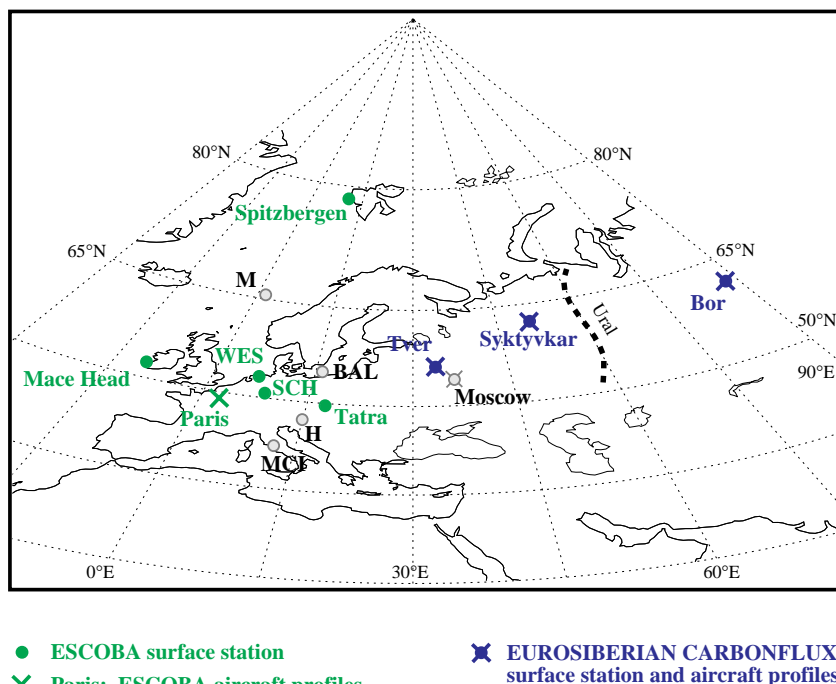


Figure 1. Monitoring stations in Europe and Western Russia  
EUROSIBERIAN CARBONFLUX study sites:

- Fyodorovskoye (near Tver, close to Moscow)
- Syktyvkar (only regular aircraft sampling)
- Zotino (near Bor in central Siberia)

**WP2:** The use of the Convective Boundary Layer (CBL) as integrator of surface fluxes in a series of intensive high-frequency intensive measurement campaigns: (1) to study daily changes in the structure and composition of the convective boundary layer (CBL) in relation to surface fluxes, (2) to develop models integrating surface fluxes at the regional level via changes in composition of the CBL and (3) to study the interaction between the CBL and the middle troposphere under continental conditions. This workpackage includes also surface flux measurements with the eddy-covariance method together with additional ground measurements (canopy and soil profiles) of meteorological and carbon cycle relevant parameters (a.o. temperature, humidity, windspeed,  $\text{CO}_2$  concentration,  $\text{CO}_2$  fluxes, isotopic composition etc.) over selected representative ecosystems in two primary observational areas: in the Central Forest Reserve near Tver (Fyodorovskoye, 56°N, 33°E) and in central Siberia near Bor (Zotino, 60°N, 90°E).

**WP3:** Development of a hierarchy of nested three-dimensional atmospheric models in conjunction with high resolution surface models based on remote sensing data to relate atmospheric observations to surface fluxes on different spatial and temporal scales using forward and inverse modelling techniques.

The measurement programme includes not only CO<sub>2</sub> but, besides the standard meteorological parameters, a whole series of long lived atmospheric tracers such as the isotopic composition (<sup>13</sup>C/<sup>12</sup>C, <sup>18</sup>O/<sup>16</sup>O) of CO<sub>2</sub>, CO, SF<sub>6</sub>, O<sub>2</sub>/N<sub>2</sub>, <sup>222</sup>Rn and CH<sub>4</sub>. The concurrent measurement of these tracers allows a separation of the measured signals into different source processes. E.g. CO and SF<sub>6</sub> allow an estimation of the contribution due to anthropogenic CO<sub>2</sub> from the burning of fossil fuels. The observations of tracers with known sources and sinks, e.g. <sup>222</sup>Rn and SF<sub>6</sub> provide also a tool for the critical evaluation of the modelled atmospheric transport.

### ***Project progress***

The official start of the EUROSIBERIAN CARBONFLUX project was January 1998. The continuous surface measurement field stations have been installed in spring (April/May) 1998; the regular monitoring programme by small aircraft has been initiated and the first intensive campaigns have been conducted in late spring and early summer of 1998. The continuous surface measurements and the regular aircraft flights have been running since without major interruptions. First scientific results are described in each of the participant reports below.

### ***Project management***

Major field campaigns and workshops in 1998 are listed in Table 1.

March 1998	Workshop and Laboratory on Eddy Correlation Measurements, Bayreuth, Germany. 30 participants from Russia, Germany, France, Italy
March 1998	Workshop and Laboratory on measurements and air-sampling by aircraft, Saclay, France.
Mid-May 1998	Installation of surface measurement equipment at Fyodorovskoye
Early June 1998	First intensive flight campaign in Fyodorovskoye and Zotino
Early June 1998	Installation of surface measurement equipment at Zotino
End of July 1998	Second intensive flight campaign in Fyodorovskoye and Zotino
August 1998	IGBP-workshop on the Eastern Siberian Transect. Krasnoyarsk, Russia.
September 1998	First Eurosiberian Carbonflux modelling workshop, Jena, Germany
December 1998	Training course for Russian participants on the processing of eddy correlation data, Jena, Germany.

### ***Perspectives***

EUROSIBERIAN CARBONFLUX has been designed as a pilot study to demonstrate the feasibility of estimating regional/continental scale carbon fluxes by means of a

combination of atmospheric measurements, surface flux measurements and mesoscale models. Since carbon flux variations driven by climate fluctuations clearly will influence the results obtained in a particular year, it is indispensable that the project will have to be extended beyond the present project lifetime of three years, and components of the observational programme, in particular the regular vertical aircraft sampling at Zotino eventually should become a fundamental component of a monitoring system for the global carbon cycle.

### ***Principal Investigators***

- Martin Heimann (Coordinator)  
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## **MPG.IMET: Max-Planck-Institut für Meteorologie, Hamburg, Germany**

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### ***Objectives***

- Development of meteorological model hierarchy for forward and inverse simulations of CO<sub>2</sub> over the project target region (jointly with IPSL/LSCE and IPEE).
- Development of inverse modelling strategy and tools for the determination of CO<sub>2</sub> surface exchange fluxes from atmospheric measurements.
- Determination of optimal sampling strategy.
- Development of project database (jointly with MPG.BGC).
- Overall co-ordination of EUROSIBERIAN CARBONFLUX.

### ***Methods***

#### **Development of model hierarchy**

In EUROSIBERIAN CARBONFLUX atmospheric models of three different resolution levels coupled in a nested fashion are employed:

- *Global scale*: Global scale models provide the necessary boundary and initial conditions for the simulations of the CO<sub>2</sub>-concentration over the smaller project target area.
- *Continental scale*: Domain of approximately 5000 x 5000 km encompassing the target area, i.e. Europe and western Siberia. This scale is covered both, by off-line transport models and by on-line transport simulations within the mesoscale atmospheric general circulation model REMO.
- *Regional/local scale*: For the interpretation of the measurements of the intensive campaigns a non-hydrostatic dynamic mesoscale model (GESIMA) is planned to be used to cover the target sites at Federovskoje and Zotino. This model will be applied with a horizontal resolution of approximately 4 km over a domain of

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about 300 by 300 km around the target sites. The time step is 5", and a typical simulation will cover an episode of a few days only.

### Inverse modeling strategy

This activity includes:

- The definition of the inverse model simulation targets, i.e. the specification of the a priori source information which is to be refined by the inversion simulations, and
- The development and preparation of the mathematical tools for inverse calculations by means of the adjoint technique.

### Determination of optimal sampling strategy

Together with the process oriented modeling work (WP1 and WP2) the hierarchy of models is to be used to address questions regarding cost effective sampling strategies for continental scale studies, by means of a detailed signal-to-noise analysis. This synthesis activity is scheduled for year 3 of the project.

## ***Performed work***

### Model development

Year 1 of the project included a detailed design and planning phase for the model system to be employed in the project. At a modeling workshop in Jena, September 1998 the design and the contributions of the project participants were defined. In a following planning workshop in Hamburg, January 1999, the design described below was adopted.

#### *Global Scale*

TM3 off-line model driven by ECMWF analyses for the years of the campaigns (1998,1999). Horizontal resolution: 4°x5°, 19 vertical layers. Time step of the analyses 6hr, numerical model time step: 40'. Datasets for 1998 have been ordered. A test version of this model configuration has been set up for 1993 driven by the ECMWF-reanalysis dataset.

#### *Regional Scale*

Off-line calculations:

TM3\_T106: Horizontal resolution: 1.125°x1.125°, 31 vertical layers. Datasets for 1998 have been ordered. A test version of this model configuration has been set up for two months in 1993 driven by the ECMWF-reanalysis dataset.

On-line calculations:

The regional scale is covered by two model resolutions of REMO in a nested fashion:

REMO\_30min: Horizontal resolution: 30' (i.e. approx. 25km) over a domain from 20°W to 140°E and 30°N to 85°N (see Figure 1). The actual model layout is somewhat distorted, because of the the rotated model grid in order to eliminate the convergence of the grid lines towards the poles.



REMO\_10min: Horizontal resolution: 10' (i.e. approx. 15km) over the two key measurement domains near Fyodorovskoye and Zotino (see Figure 1):

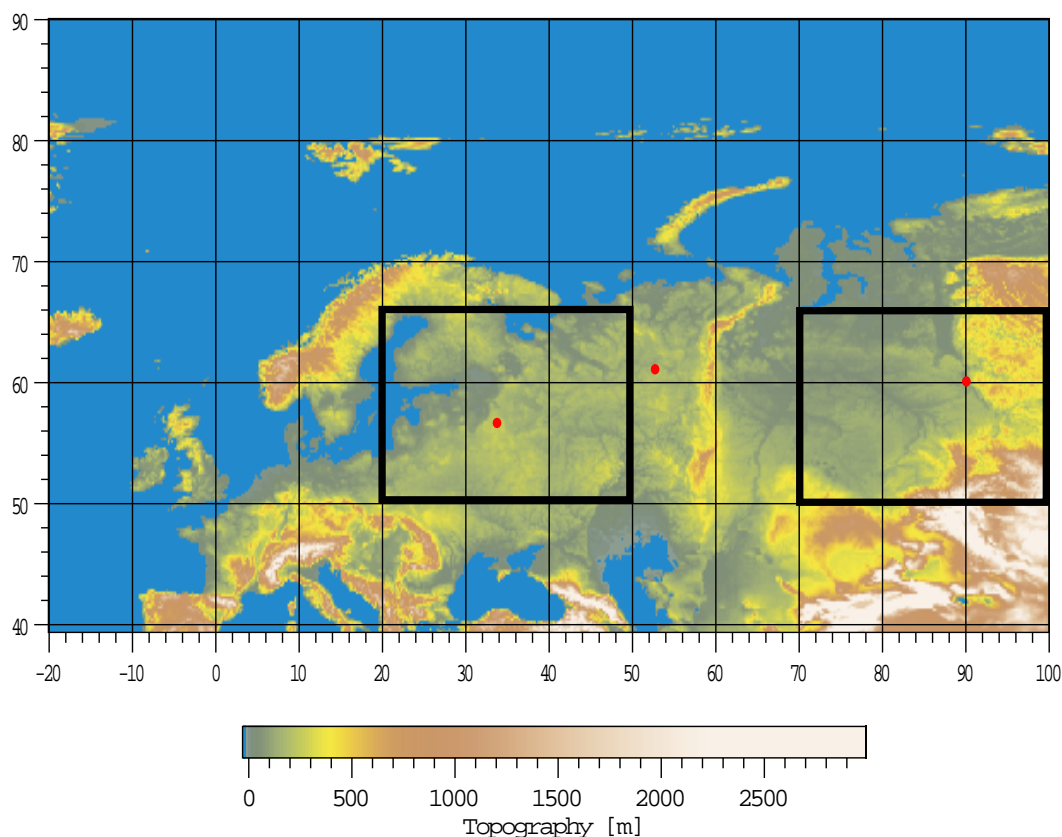


Figure 1: Approximate mesoscale model domain over the Eurosiberian target region and the two nested regions for which the REMO model will be implemented with a 10' resolution.

For this scale the computation of the atmospheric transport of CO<sub>2</sub> is performed off-line in the high-resolution transport model TM3\_T106 driven by analyses from the ECMWF, and alternatively on-line in the mesoscale model REMO, which computes the meteorology within the model domain in much higher spatial and temporal resolution than provided by the ECMWF analyses.

#### *Local Scale*

The setup of the GESIMA model for the local description of the transport in the immediate vicinity of the key measurement areas near Fyodorovskoje and Zotino has been deferred to year 3 of the project. The need for this model hinges on the outcome of the simulations with the coarser regional scale models.

#### **Inverse modeling strategy**

During 1998 the following studies have been performed:

- Completion of global scale inverse modeling study using the adjoint model to TM2 [Kaminski et al., 1999a, 1999b].

- An review of the inversion problem: How to scale-up local surface flux measurements and flux estimates and to regional and continental scales by means of atmospheric concentration measurements and transport models [Heimann and Kaminski, 1999].
- A detailed investigation on how to set up a high-resolution inversion system for the regional scale. In order to make this task computationally feasible, a global approach with an increasingly finer horizontal resolution in the target area has to be chosen. A first implementation within the very coarse global TM2 model has been tested. It could be shown that fundamental assumptions about the source structure within the not-resolved scales may influence considerably the inversion solution. The results of this study will influence the design of the inversion system for the Eurosiberian region, to be established within years 2 and 3 of the project.

### **Database development**

Because of the move of the coordinator to MPG.BGC, it was decided to establish the project database on the Jena computer systems. Since no qualified computing staff could be recruited in due time, the development of the database has been delayed to 1999.

### ***Workplan 1999***

- Completion of REMO-30min model implementation for Eurosiberian region
- Completion of REMO-10min model implementation for Tver and Zotino regions
- Forward mesoscale model simulations for measurement periods 1998
- Implementation of TM3\_T106.
- Development of adjoint model of TM3\_T106 for Eurosiberian region.
- Development and implementation of database

### ***Publications***

Heimann, M. and T. Kaminski, Inverse Modeling approaches to infer surface trace gas fluxes from observed atmospheric mixing ratios. In: Approaches to Scaling of Trace Gas Fluxes in Ecosystems, edited by A.F. Bouwman, pp. 275-295, Elsevier, Amsterdam, 1999.

Kaminski, T., M.Heimann, and R.Giering, A coarse grid three dimensional global inverse model of the atmospheric transport, 1, Adjoint model and Jacobian matrix, J. Geophys. Res., in press. 1999a.

Kaminski, T., M.Heimann, and R.Giering, A coarse-grid three-dimensional global inverse model of the atmospheric transport, 2, Inversion of the transport of CO<sub>2</sub> in the 1980s, J. Geophys. Res., in press. 1999b.

## **MPG.GBC: Max-Planck-Institut für Biogeochemie, Jena, Germany**

### ***Participant Summary:***

Principle Investigator: Prof. Dr. E.-D.Schulze  
Co-PI: Prof. Dr. Jon Lloyd  
Coworkers: Olaf Kolle (head of the field experiment section of the MPI)  
Karl Kübler (technician of Olaf Kolle paid by MPI)  
Julie Styles (Ph.D. Student of Jon Lloyd paid by MPI)  
Kirian Lawton (technician of Jon Lloyd paid by MPI)  
Alexander Knohl (Diploma student responsible for windthrow)  
The Russian partners are listed in the report IPEE  
A total of 26 scientists were working at the field sites in Siberia in 1998.

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### ***Objectives for year 1 (see proposal)***

- To carry out one campaign of high intensity data collection of air samples near Moscow and in central Siberia near Bor
- To carry out long-term eddy correlation measurements near Moscow (Central Reserve at Fyodorovskoye) and near Bor (Zotino)

### ***Performed work***

Set up of eddy correlation systems in spring after/at snow melt (in May):

- Fyodorovskoye:
  - 30 m tower in spruce forest,
  - 8 m tower above Sphagnum bog,
  - 12 m tower above windthrow
- Zotino:
  - 28 m tower in pine forest
  - 6 m tower above Sphagnum bog
- Organization and undertaking of flights for continuous measurements of CO<sub>2</sub> profiles and for air sampling during intensive campaigns
- Collecting associated data of stand biomass, growth and soil carbon in Siberia.

**Overview of results:**

The aircraft measurements have not been fully analyzed at this moment. The data indicate that the CO<sub>2</sub> concentrations in flasks agree with the CO<sub>2</sub> profiles by 0.1 ppm during regular flights and intensive campaigns. Especially in the free troposphere, the vertical structure of CO<sub>2</sub> is complex (Fig. 1)

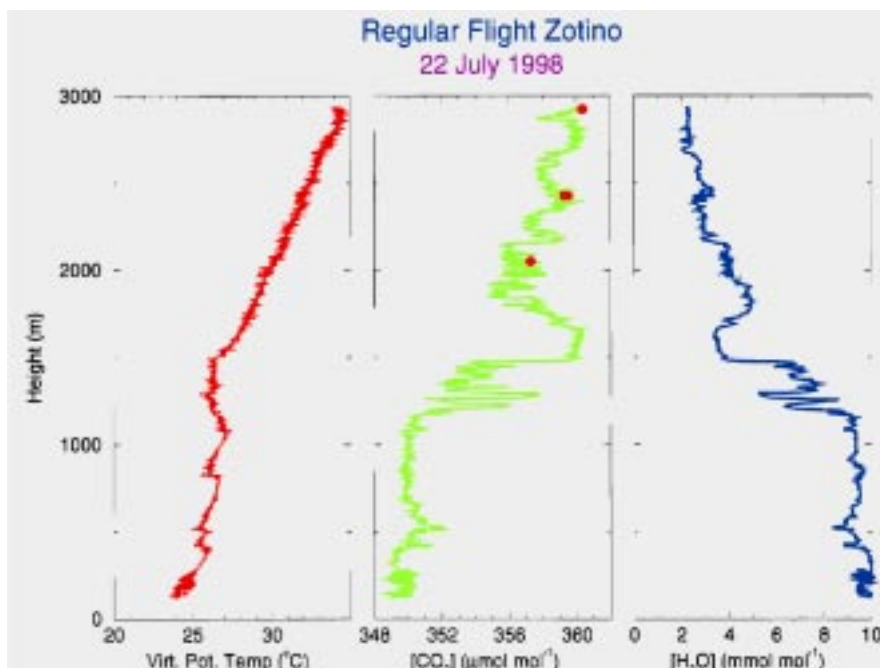


Figure 1. Vertical profiles of Temperature, CO<sub>2</sub> and water vapour measured on July 22, 1998 over Zotino.

The eddy correlation data show:

- The Siberian pine forest has a cumulative net ecosystem exchange (NEE) over the growing season that indicates a carbon sink capacity as high as in European spruce forest
- Sphagnum bogs are significant carbon sinks
- The Moscow spruce forest is a strong carbon source. Further investigations are needed in order to find out if this is a local or a regional effect.

The present data are published together with data which were taken in previous years when preparing for the Eurosiberian Carbonflux work.

**Main report****Objectives**

According to the Eurosiberian CarbonFlux proposal, the MPI for Biogeochemistry was responsible:

- to carry out one campaign of high intensity data collection of air samples near Moscow and in central Siberia near Bor

- to carry out long-term eddy correlation measurements near Moscow (Central Reserve at Fyodorovskoye) and near Bor (Zotino)

In preparing the actual work plan for 1998, the institute was also made responsible

- to assist the Russian participants in regular flights for the trace gas climatology
- to investigate net primary productivity and soil carbon

### **Methods**

Canopy and soil fluxes of CO<sub>2</sub> were measured using the eddy correlation technique. These measurements need to be supported by climatological measurements, especially with respect to various light parameters (diffuse, direct, long- and shortwave, photosynthetic). Power supply was generally planned by solar panels assisted by generator.

Eddy correlation systems were installed in forest and swamp vegetation which are typical for the variegated landscape of the boreal region.

Airplane measurements were performed above the sites where eddy correlation measurements took place. In these flights continuous profiles of CO<sub>2</sub>, water vapor and temperature were measured between ground and above the convective boundary layer (3000m). Air samples were taken above the CBL during flights concerned with the trace gas climatology, and in different heights (100 m, 500 m, 1000 m, 1500 m, 3000 m) during intensive campaigns.

Net primary productivity was measured by harvesting of sample trees and mensuration of whole stands. Soil carbon was collected at different depth, and black carbon will be measured after combustion in oxygen.

The maintenance of the eddy covariance measurements and the air sampling required more manpower than initially planned, mainly due to the very harsh climatic conditions:

- maintaining the eddy covariance system requires 2 permanent persons on site. It turns out that even Russian coworkers cannot stay longer than 4 to 6 weeks at maximum. Thus the measurements of 5 months required a total of 10 persons.
- Carrying out flights requires 2 persons at each flight

### **Problems and Experiences in carrying out Eurosiberian Carbonflux**

- A major problem exists with respect to the import of scientific instruments into Russia because the contract of scientific cooperation between EEC and Russia does not permit the import of instruments. Thus all instruments were imported on the basis of the German/Russian contract of scientific cooperation. The initial custom permit for import was issued for a 7 month period (December 28, 1998), and we hope that this permit has been extended on the basis of the above contract. It turns out, that the import by train, which was the preferential pathway in the past, is difficult. Solving customs was a major task that kept 2 Russian colleagues busy full time all summer.
- Problems exist also with respect to hiring airplanes. The Russian planes, as in any country, need a major service after a certain number of flight hours. There is no Russian funding to carry out such service. Thus, near Moscow, we used up the life-span of 4 planes, and it was necessary to hire planes from Moscow by the end

of the year. In Siberia, the problem is not as much the service, but the obtainability of gasoline. There are airports with planes but without gasoline. We had to fly from Krasnoyarsk by the end of the year.

- In operating the Eddy-systems fuel supply is a problem by the end of the year, when solar energy is not sufficient to power the measuring systems. Since we were not sure about the behavior of our instruments in the Siberian winter (-60°C) we cut off the eddy system in October, and maintained the climate system only. It turned out, that all solar batteries cracked by frost and will need replacement in 1999.
- The cost for running Eurosiberian Carbonflux was much higher than anticipated. The Schulze team used all money for travel and running cost. It was not possible to employ a Ph.D. student from EEC money. The MPI for Biogeochemistry supported the project by paying all flight operations (totaling 120 DM), as well as a Ph.D. student (Julie Styles).

## **Results**

The measuring systems were installed mid May (Moscow) to early June (Zotino). At that time snow covered the ground, and bud-break of *Betula* started when all systems were running

Measuring systems were installed above spruce (Moscow) or pine (Zotino) forest and these were compared with spruce forest in Germany. All forest stations were additionally equipped with an eddy system close to the ground. In addition measurements were carried out above Sphagnum bogs. An additional system was installed above a windthrow area at the Fyodorovskoye forest area. In total, 10 eddy correlation systems were operating.

The operation of the eddy systems was shared between Russian and German scientists.

Intensive flight campaigns were undertaken early June and end July. It was not possible, due to very difficult weather conditions to carry out intensive flights in September or October.

Regular flights were undertaken on a 2- to 3-weekly basis at Fyodorovskoye, at Syktyvkar and at Zotino (see Moscow report). These flights were operated mainly by Russian scientists, and with MPI help when needed.

The Russian colleagues were instructed for running eddy-correlation measurements and taking air samples during a workshop (laboratory class) in March 98 (two weeks).

The data analysis of eddy correlation measurements was trained to the Russian colleagues in a two-week course in December 98. It was decided during this course that the Russian students will very actively participate in the data analysis and in writing scientific papers.

It is clear that only some aspects of the information has been worked up. At present,

- the canopy eddy data are processed, but not analyzed for publications
- the ground eddy data are not yet processed
- the trace gas concentrations of the Zotino intensive flights are analyzed 50%

The year 98 was also used to integrate the new data into the existing data from previous measuring campaigns, and to develop the theory for budgeting the CBL measurements.

Following main results are apparent (Fig.1):

- the Siberian pine forest exhibits a cumulative growing season NEE that is a carbon sink similar to that in German spruce forest, and despite large differences in NPP
- the bogs in European Russia and in Siberia are very similar C-sinks, about half as strong as the forest.
- The spruce forest in Fyodorovskoye is a C-source. This result is a great surprise, because this stand has the highest day-time NEE, and the negative ecosystem balance is due to high soil respiration. We are not sure if this results from two heavy summer rainfalls that partially flooded the stand. However in this case, daytime NEE should have been low, which was not the case. Thus, the high respiration must result from decomposition of the peat layer underneath the roots. We are uncertain, if this result represents local conditions or if it is a regional phenomenon. This will be clear from the intensive flight campaigns. Also, we will have to study an additional, well grained forest in 1999.
- Windthrow exhibits a massive C-loss that is equivalent to the uptake of Siberian forest.

#### Uncertainties

- We have not measured winter respiration, and it is quite clear that a large proportion of the C-gain will be lost in winter.
- the CBL-budgeting will clarify if our ground observations are representative at a regional scale.

#### ***Publications (containing new theory but in part old unpublished data)***

Lloyd J, Francey RJ, Sogachev A, Byers JN, Kelliher FM, Mollicone D, Raupach MR, Wong SC, Arneth A, Rebmann C, Valentini R, Schulze E-D (1999) Vertical profiles, boundary layer budgets and regional flux estimates for CO<sub>2</sub>, its <sup>13</sup>C/<sup>12</sup>C ratio, and for water vapor above a forest/bog mosaic in Central Siberia. Global Biogeochemical Cycles (in preparation)

Schulze E-D, Lloyd J, Kelliher FM, Wirth C, Rebmann C, Lohker B, Mund M, A.Knohl, Milukova I, Schulze W, Ziegler W, Varlagin A, Sogachov A, Valentini R, Dore S, Grigoriev S, Kolle O, N Tchepakova, Vygodskaya NN (1998) Productivity of forests in the Eurosiberian boreal region and their potential to act as a carbon sink - A synthesis. Global Change Biology (in press)

#### Examensarbeiten

A. Knohl: Flußmessungen von CO<sub>2</sub> und H<sub>2</sub>O über Windwurf-Flächen im zentralen Waldgebiet bei Nelidovo. Diplomarbeit Jena 1999

**Meetings:**

March 1998: Workshop and Laboratory on Eddy Correlation Measurements. 30 participants from Russia, Germany, France, Italy

March 1998: Workshop and Laboratory on measurements and air-sampling by aircraft

August 1998: IGBP-workshop on the Eastern Siberian Transect. Krasnoyarsk.

December 1998: Training course for Russian participants on the processing of eddy correlation data



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### ***Summary:***

Within the first years contribution to EUROSIBIRIAN CARBONFLUX we could establish continuous measurement devices for CO<sub>2</sub> and <sup>222</sup>Radon observations at the Federovskoye forest reserve tower site. During the intensive summer campaign, a flask spot sampling program for the analysis of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O concentrations and CO<sub>2</sub> stable isotopes was performed with a time resolution of 2 hours. Simultaneously, chamber flux samples of soil emanation CO<sub>2</sub> near the tower were taken every 4 hours. These samples were also analysed for stable isotopes in CO<sub>2</sub>. Due to the very high humidity at the forest sampling site the *in situ* measurements as well as the analysis of CO<sub>2</sub> and stable isotopes on the flasks turned out to be difficult. Consequently, improvement of the air drying procedure is necessary under these conditions. Nevertheless, diurnal variations of CO<sub>2</sub> and its stable isotopic ratio showed prominent features which, as derived from the <sup>18</sup>O/<sup>16</sup>O ratio, seem to indicate that the soil and leave respiration layers in the forest can sometimes be effectively separated during stable night time situations.

The continuous atmospheric <sup>222</sup>Radon measurements which have been maintained at the forest site, although surprisingly low (about 2 Bq m<sup>-3</sup>), show prominent diurnal variations during the summer months. During autumn these diurnal features disappear, and longer term <sup>222</sup>Radon events with activities up to 8 Bq m<sup>-3</sup>, lasting for several days, become more frequent.

### ***Objectives:***

1. Establish intercalibrated analytical facilities for high precision atmospheric trace gas concentrations (CO<sub>2</sub>, CH<sub>4</sub>, SF<sub>6</sub>, <sup>222</sup>Radon) and stable isotope ratios of CO<sub>2</sub> (WP1)
2. Implementation of regular air sampling and first analysis of samples over Eurosiberian Region (WP1)
3. Completion of one intensive campaign at the Tver site including sample analysis and preliminary data evaluation (WP2)

**Methods:****Continuous atmospheric  $^{222}\text{Rn}$  daughter measurements**

Under most meteorological conditions, the short-lived  $^{222}\text{Rn}$  daughters are in secular radioactive equilibrium with atmospheric  $^{222}\text{Rn}$ , hence the atmospheric  $^{222}\text{Rn}$  (gas) activity can be determined via its short-lived daughter activity. With the Heidelberg Radon Monitor  $^{222}\text{Rn}$  is measured with the so-called static filter method: ambient air is continuously pumped through a quartz fibre filter, where the  $^{222}\text{Rn}$  daughters which are attached to aerosols, are quantitatively collected. The flow rate is measured with a mass flow meter. The  $\alpha$ -decay of the  $^{222}\text{Rn}$  daughters  $^{218}\text{Po}$  ( $\alpha_E = 6.0 \text{ MeV}$ ) and  $^{214}\text{Po}$  ( $\alpha_E = 7.7 \text{ MeV}$ ) is counted in situ, and the net atmospheric  $^{214}\text{Po}$  activity is then calculated from the  $^{214}\text{Po}$  activity on the filter. The maximum time resolution of atmospheric  $^{214}\text{Po}$  (and  $^{222}\text{Rn}$ ) measurements with the filter method is 0.5 to 1 hour, due to the time lag between changes in the radon daughter activity and  $^{222}\text{Rn}$ , respectively. The mean atmospheric disequilibrium between  $^{222}\text{Rn}$  and its daughters has been determined for the Heidelberg observation site (20m above ground) through parallel direct  $^{222}\text{Rn}$  measurements with a slow-pulse ionization chamber to  $0.704 \pm 0.081$  [Cuntz, 1998]. This value is also used in the case of the Federovskoye forest site where parallel measurements have been made at two heights, 16.3m and 26.3m above ground during the intensive summer campaign. Measurements at the lower level have been discontinued after the end of the summer campaign whereas the 26.3 m level measurement is still ongoing.

During the Paris EUROSIB Intercomparison campaign in spring 1998 the Heidelberg Radon Monitor was compared to an instrument developed by the Paris group which uses a filter band and two scintillation counters to measure the  $\alpha$ -decay of the  $^{222}\text{Rn}$  daughters. Over the period of intercomparison, from March 30 to April 3, 1998, ambient  $^{214}\text{Po}$  activity showed a range of about  $1\text{--}11 \text{ Bq m}^{-3}$ . For the whole intercomparison period, the mean ratio of the  $^{214}\text{Po}$  activities measured by the two systems was Paris/Heidelberg =  $0.96 \pm 0.14$  (for details, see "Paris Test Campaign Report"). The agreement between the two independently developed and calibrated  $^{222}\text{Rn}$  monitor systems is excellent, particularly taking into account all possible intrinsic effects when measuring aerosols, such as loss of particles in the system. This is also true in view of the uncertainty of more than 15% in the final determination of the atmospheric  $^{222}\text{Rn}$  gas activity due to not aerosol attached daughter atoms or variations of the radioactive disequilibrium between  $^{222}\text{Rn}$  and its daughters.

**Continuous atmospheric  $\text{CO}_2$  concentration measurements**

For continuous  $\text{CO}_2$  concentration measurements during the summer campaigns a new NDIR gas analyzer (LiCor LI-6251) has been set up, using an automated gas inlet system. This allowed switching of three calibration gases (338.73 ppm, 387.23 ppm and 436.86 ppm) every hour for five minutes each into the sample cell, as well as two ambient air inlets alternating between two heights (16.3 and 26.3 m above ground) during the remaining 45 minutes. All system components were stored in a temperature controlled ( $\pm 1^\circ\text{C}$ ) aluminium box. Air drying was through magnesium perchlorate. The drying agent was renewed every two to three days, depending on its visible humidity. After the summer campaign, data evaluation showed, however, in some cases that the perchlorate's drying capacity seemed to be exhausted earlier than expected. Data logging (concentration, sample gas flow, sample cell temperature and

pressure, wind speed), calculation of mean values with standard deviations, and valve control was performed by appropriate software using a portable PC.

#### Flask sampling of atmospheric air and analysis of CO<sub>2</sub> and stable isotope ratios, CH<sub>4</sub> and N<sub>2</sub>O

The flask sampling setup during the intensive summer campaign was installed at the forest tower where the air was sampled from the lower air inlet only (16.3 m). Two preconditioned (for details of the preconditioning procedure, see “Paris Test Campaign Report”) glass flasks (1.2 liter volume each) were flushed (air flow about 2 l/min) with atmospheric air for about 10 minutes and finally pressurised to 2 bar. Condensation of water vapour within the flask can lead to an isotopic change of the sampled  $\delta^{18}\text{O}$ -CO<sub>2</sub> signal via the exchange of oxygen atoms between water and carbon dioxide. Therefore, the air was dried with magnesium perchlorate, which was renewed before every sampling. During the whole intensive campaign period, a time resolution of 2 hours for flask sampling was performed. The stable isotopes were analysed in the Heidelberg laboratory with a Finnigan MAT 252 mass spectrometer, combined with a multiport trapping box for CO<sub>2</sub> extraction [Neubert, 1998]. CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O concentrations were measured with an automated HP 5890 series II gas chromatograph equipped with a flame ionisation detector (FID) for detection of CO<sub>2</sub> and CH<sub>4</sub> and an electron capture detector (ECD) for N<sub>2</sub>O [Bräunlich, 1996].

#### Flask and bag sampling and analysis of soil emanation gas for CO<sub>2</sub> and stable isotope ratios, CH<sub>4</sub>, and <sup>222</sup>Rn

During the intensive part of the summer campaign, regular flask samples have been collected from soil respiration gas collected with the inverted cup method at two sites close to the tower at a time resolution of 4 hours. Stainless steel frames have been permanently installed and covered with a Silicon-oil-sealed top for the actual soil flux measurement. Samples at start and stop of the flux measurement were collected into 300 ml pre-evacuated glass flasks using magnesium perchlorate as drying agent. In the laboratory, CO<sub>2</sub> and CH<sub>4</sub> mixing ratios were measured by gas chromatography [Born *et al.*, 1990]. Stable isotope ratios were analysed with the same system as the atmospheric samples.

After the intensive part of the summer campaign two transects along a hydrological line were collected for <sup>222</sup>Rn emanation measurements. Samples were collected with the same stainless steel inverted cups as used for the CO<sub>2</sub> soil emanation samples but were collected into 500ml aluminium bags. After transportation to Heidelberg they were measured as quickly as possible for their <sup>222</sup>Rn activity in a set of slow pulse ionization chambers.

### **Results:**

#### Preliminary results from canopy air and chamber measurements at the Tver forest site during the intensive campaign

Figure 1 shows a typical diurnal cycle of trace gas observations at the Federovskoye tower site at the 16.3 meter level: Depending on the meteorological conditions in the surface layer, CO<sub>2</sub> and <sup>222</sup>Rn show strong diurnal variations with maximum concentrations in the early morning and minima during the afternoon.  $\delta^{13}\text{C}$ -CO<sub>2</sub> shows the well-known correlation with CO<sub>2</sub> mixing ratio leading to a mean source

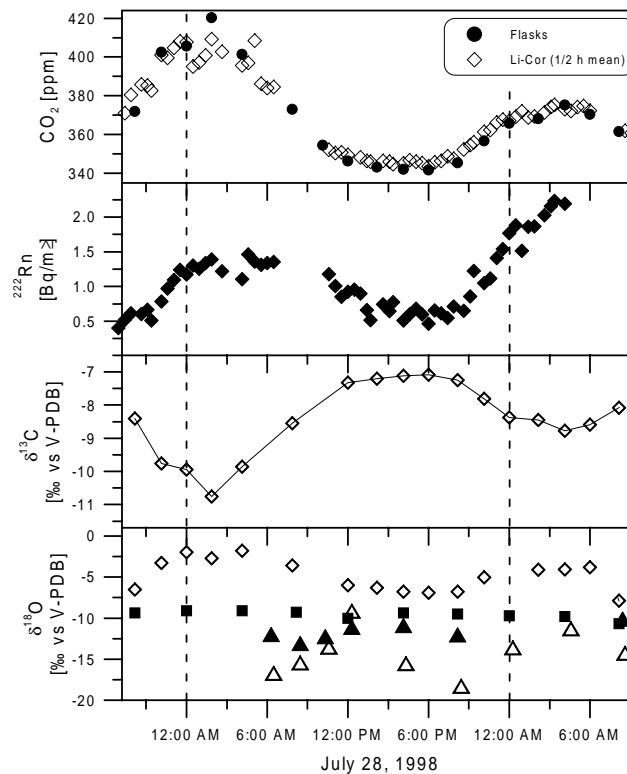


Figure 1: Typical diurnal cycle of  $\text{CO}_2$  (flask samples and Li-Cor),  $^{222}\text{Rn}$ ,  $\delta^{13}\text{C}\text{-CO}_2$  during the intensive summer campaign at Federovskoye forest site within the canopy (16.3 m above ground). The lowest panel also shows calculated values of  $\delta^{18}\text{O}\text{-CO}_2$  equilibrated with water collected at the soil surface (black squares) as well as the  $\delta^{18}\text{O}\text{-CO}_2$  of the chamber flux measurements (open triangles: chamber 1 with green mosses, black triangles: chamber 2 without vegetation).

signature of  $-25.63 \pm 0.2$  ‰ (Figure 2). In contrast,  $\delta^{18}\text{O}\text{-CO}_2$  is strongly anti-correlated to  $\delta^{13}\text{C}\text{-CO}_2$  and shows maximum values (around  $-2$  ‰) during  $\text{CO}_2$  maxima. This  $\delta^{18}\text{O}$  signature is close to measurements from the free troposphere or, likewise to  $\text{CO}_2$  which is in equilibration with leaf water. During the day,  $\delta^{18}\text{O}\text{-CO}_2$  decreases and approaches values close to what would be expected from soil  $\text{CO}_2$  which is in equilibrium with soil water (measured values of the saturated soil water were between  $-9$  and  $-10$ ‰).

One tentative explanation of the  $\delta^{18}\text{O}\text{-CO}_2$  diurnal cycle may be that during the nights a stable layer builds up within the forest separating the soil source from the leaf layer where samples are collected. During the day, this layering is broken up and soil emanating gases penetrate higher up in the canopy. An indicator for this behaviour may be the low  $\delta^{18}\text{O}\text{-CO}_2$  values observed in the vertical aircraft profiles around noon (see report by IPSL/LSCE).

#### Continuous atmospheric $^{222}\text{Rn}$ observations at the Federovskoye forest site

Figure 3 shows our continuous  $^{222}\text{Rn}$  daughter observations at the Federovskoye forest site for the six month period of July to December 1998 (note that the 16.3 m level has been removed on August 9, 1998). For the period where we have

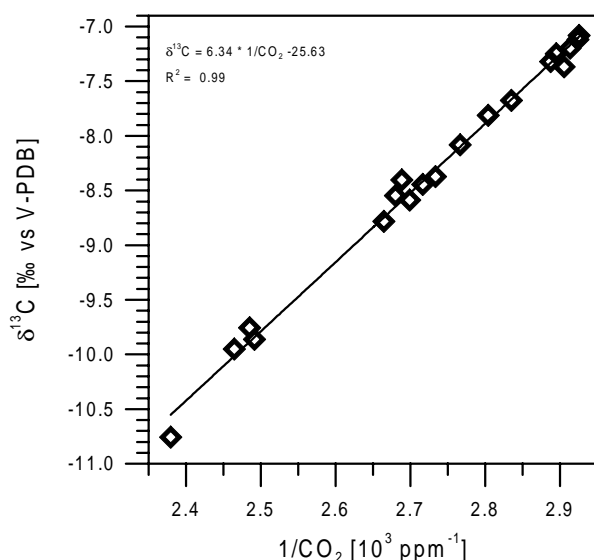


Figure 2:  $\delta^{13}\text{C}$ - $\text{CO}_2$  versus  $1/\text{CO}_2$  („Keeling plot“) of the diurnal cycle shown in Figure 1. The signature of the apparent source is  $\delta^{13}\text{C} = -25.63 \pm 0.2\text{‰}$

measurements at both heights, we observe a night time difference only occasionally. A similar behaviour is observed in the continuous  $\text{CO}_2$  measurements. Obviously, the canopy air is well-mixed between 16 and 26 meters. The frequency of strong diurnal cycles as observed in July, August and September decrease towards the autumn season. From October onwards, longer term Radon events originating from large scale continental air masses become dominant.

### **Work Plan for 1999:**

#### Technical improvements:

The biggest problem for the continuous  $\text{CO}_2$  observations with the LiCor system during the summer campaign was the very high humidity at the site. The chemical drying system used, turned out to be not efficient enough to eliminate all water vapour. For future campaigns we plan to develop a two-stage drying system with a peltier cooler running at close to zero temperatures and extracting the major amount of the water vapour from the air stream. A chemical dryer will be installed in

### <sup>222</sup>Radon daughters at Federovskoye Forest Reserve

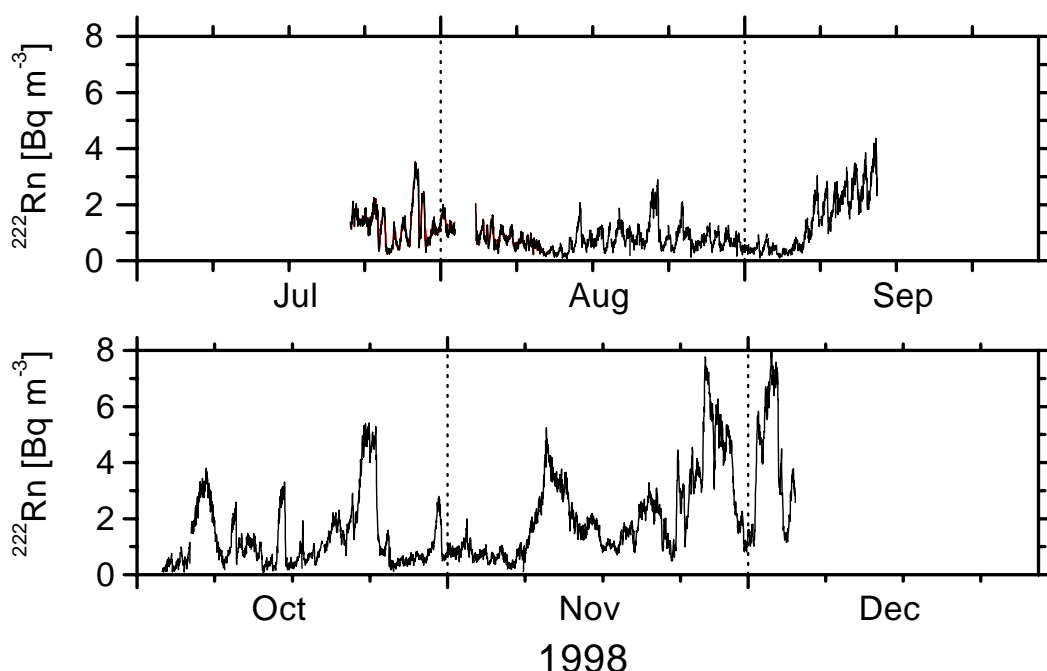


Figure 3: Continuous atmospheric <sup>222</sup>Radon observations at the Federovskoye forest site at 26.3 m above the ground.

sequence to reduce the vapour pressure to a dewpoint of less than  $-40^{\circ}\text{C}$ . A similar system has to be set up for the flask sampler to avoid condensation of water in the flasks and possible  $^{18}\text{O}$  isotopic exchange. In addition, we are working on a reliable second drying system to be connected to our GC inlet for flask analysis. During analysis of flasks from the campaign samples as well as from the regular flights it turned out that also the flight flasks contained absolute water vapour concentrations in the order of 1-2 % which have to be removed before analysis.

In this context we are also thinking of an economic way to possibly combine the drying system with a sampling device for atmospheric water vapour. The solution will depend on available resources (power supply at the site as well as project money).

### Campaigns:

With the experience gathered during the first summer campaign at the Tver forest site we plan to repeat the measurement program of ground-based sampling (atmospheric flasks, chamber samples) and *in situ*  $\text{CO}_2$  and  $^{222}\text{Rn}$  observations in one summer and one autumn campaign (possibly at two heights, but with the second height closer to the ground). This work will be closely coordinated with the Paris group which will collect frequent vertical profiles and vegetation samples in the canopy.

### Regular Flights:

All flasks from regular flights at Syktyvkar will be analysed for trace gases in Heidelberg. In addition, if logistically possible,  $\text{SF}_6$  analyses will be made on flask samples from the other two sites, Tver and Zotino.

### Intercomparisons:

A number of intercomparison exercises have been started in 1998 which will be continued during the whole period of the project, namely

1. Regular exchange of flasks with Paris
2. Regular exchange of flasks with CSIRO Australia (todate analysing the Jena flasks)
3. Pure- $\text{CO}_2$  intercomparison: Heidelberg – Paris – Groningen (– Jena)
4. Ongoing whole-air intercomparison for concentration and isotopic ratios: Heidelberg – Paris – Groningen – Stockholm (– Jena)

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### ***Objectives.***

To continue measuring CO<sub>2</sub> at 3 sites in Western Europe. To help establish and measure low frequency regular aircraft soundings (flasks) at 3 sites of the project, in collaboration with MPG-Jena and Uni-HD. To establish a computer database for all flasks move and analysis. To carry on an intensive air sampling campaign at the Tver site in summer 1998. To help initiate a regional model development with MPI-Hamburg.

All of the above stated objectives have been achieved (see below for a detailed description).

### ***Objectives***

LSCE-Paris, together with Uni-HD is the leader of workpackage 1 in the EUROSIBERIAN CARBONFLUX programme (low frequency aircraft measurements). Our group is also committed to continue CO<sub>2</sub> measurements over western Europe that are not specifically part of the EUROSIBERIAN CARBONFLUX programme, but that will be necessary in the integration/modelling part. In addition to this, it has been decided that LMCE-Paris will lead the workpackage 2 (aircraft intensive soundings) at the site of Fedorovskoye. All these objectives for 1998 have been reached.

## **Methods and results**

### **Contribution to low frequency aircraft soundings**

LSCE has built and designed three pump units for air sampling aircrafts. These pump units have been completed in April 1998. Our group has organized a test flight campaign in Paris before the air sampling programme in Siberia. This campaign's aim were (1) to compare the CO<sub>2</sub> analysers Ultramat 5F operated for the continuous measurements sites by Uni-HD and LSCE, (2) to test the airborne licor [CO<sub>2</sub>] analysis system developed by MPG-Jena, and (3) to compare the two <sup>222</sup>Rn monitors (using two independent techniques) of Uni-HD and LSCE-Paris. Planning of the summer 1998 campaign was also discussed during that 5 days meeting in Paris. A technical report with the preliminary intercomparison results for CO<sub>2</sub> and <sup>222</sup>Rn is in preparation. Since April 1998, we have measured flasks from 4 regular flights from Syktyvkar (flasks collected by Russian groups) and 2 flights from Fedorovskoye. We also have set up a computer database to archive all flasks moves and measurements (collaboration with P. Tans and K. Masarie, from NOAA/CMDL, USA). This database has been operated successfully with the help of other partners and has allowed to track all the flasks history.

### **New laboratory analytical developments**

In our flask analysis laboratory, new developments have been made that increase our analytical capacity. The [CO<sub>2</sub>] measurements system has been entirely automatised and its capacity has increased from 20 flask samples per day to 70 samples per day. The technique used is NDIR and uses about 500 cc per analysis. In the mean time, we have developed CO and CH<sub>4</sub> measurements, using GC. The routine precision of our measurements is 5 ppb for CO and 7 ppb for CH<sub>4</sub>. The CH<sub>4</sub> analytical system is being automatised. Several conservation tests (Gros et al. 1998) have shown no alteration in the [CO] concentration of air sampled using the same technique as the one used in the aircraft and stored for 3 months. This suggests that the Pyrex glass flasks used in the EUROSIBERIAN CARBON FLUX project are suitable for [CO] measurements. However, when the flasks were exposed to light, significant differences in [CO] have appeared between the two members of each pair (up to 50 ppb after 6 months).

### **Intensive campaign over Fedorovskoye (Tver) in July 1998: Aircraft measurements.**

LSCE-Paris carried out the summer intensive aircraft sampling campaign in Tver, that took place between July 24<sup>th</sup> to July 31<sup>st</sup>. Three persons from LSCE participated to this campaign. We have sampled vegetation and soil material for 5 consecutive days, in the vicinity of the flux tower installed and operated by MPG-Jena in the Fedorovskoye forest site. Aircraft measurements have completed the ground sampling programme, using an AN-2 airplane rented for the whole campaign duration. We flew 3 times per day between dawn and dusk to record CO<sub>2</sub> vertical profiles (from 50 m to 3000 m) using an in-situ operated LICOR and to sample flasks, right at the vertical of the flux tower. Given the relatively remote location of the flux tower from the nearest airport, a total number of flights of 3 per day was the maximum feasible. We had planned to measure <sup>222</sup>Rn in the aircraft and brought a battery-operated filter sampling system in the field, which could not operate in a satisfactory manner (possibly due to interference with the aircraft radio and instruments).



Flask samples (150 total) have been analyzed in  $\text{CO}_2$ ,  $^{13}\text{CO}_2$ ,  $\text{C}^{18}\text{OO}$ , and  $\text{CO}$  at LSCE.  $\text{CH}_4$  analysis are still underway. A subset of these samples were analyzed for  $\text{SF}_6$  in Uni-HD. Flasks were also sampled at 100 m and 3000 m for  $\text{O}_2/\text{N}_2$  analysis at CIO-Groningen. The results are shown in Figure 1 A-C. The measured  $\text{CO}_2$  concentration at 3000 m does not vary significantly over the entire campaign ( $< 2$  ppm), whereas substantial diurnal changes occur in the atmosphere's boundary layer (ABL). We observe a  $\text{CO}_2$  build up in the early morning near the surface, resulting of night time respired  $\text{CO}_2$  accumulated in the canopy and in the stable air shed overlying the vegetation, known as nocturnal boundary layer (NBL). Connecting the aircraft data with  $[\text{CO}_2]$  profiles within the canopy at two different heights (Uni-HD and MPG-Jena) will enable us to budget  $\text{CO}_2$  from the ground to the free troposphere. Around noon,  $[\text{CO}_2]$  is observed to be more uniform along the vertical between the top of the canopy and 3000 m.  $\text{CO}_2$  uptake by the vegetation depletes the air column, but daytime convective mixing tends to dilute this signal higher up. At dusk, it is apparent that the entire air column has been depleted in  $\text{CO}_2$ .

The  $\delta^{13}\text{C}$  measurements made on the same flasks analysed for  $\text{CO}_2$  are represented in Figure 1B.  $\delta^{13}\text{C}$  mirrors  $\text{CO}_2$  with a  $\delta^{13}\text{C}$  increase consecutive to uptake by the vegetation and a  $\delta^{13}\text{C}$  decrease as a resulting from the addition of  $\text{CO}_2$  respired by plants and soils to the canopy air and to the overlying ABL. Figure 2 shows the correlation between  $\delta^{13}\text{C}$  and  $1/[\text{CO}_2]$ , the intercept of which provides the equivalent isotopic composition of  $\text{CO}_2$  added/removed to the atmosphere,  $\delta^{13}\text{C}_s$  (Table 1). Table 1 indicates that on average among the 4 consecutive days that have been measured,  $\delta^{13}\text{C}_s$  at dusk time was lower than in the day. This tentatively indicates that the  $^{13}\text{C}$  discrimination by plant photosynthesis was smaller than the difference between soil respired and ABL  $\text{CO}_2$  during the intensive campaign. A difficulty in interpreting these data is the up-scaling between local flux measurements (footprint of 1  $\text{km}^2$ ) and ABL budgets (footprint of 10-100  $\text{km}^2$ ).

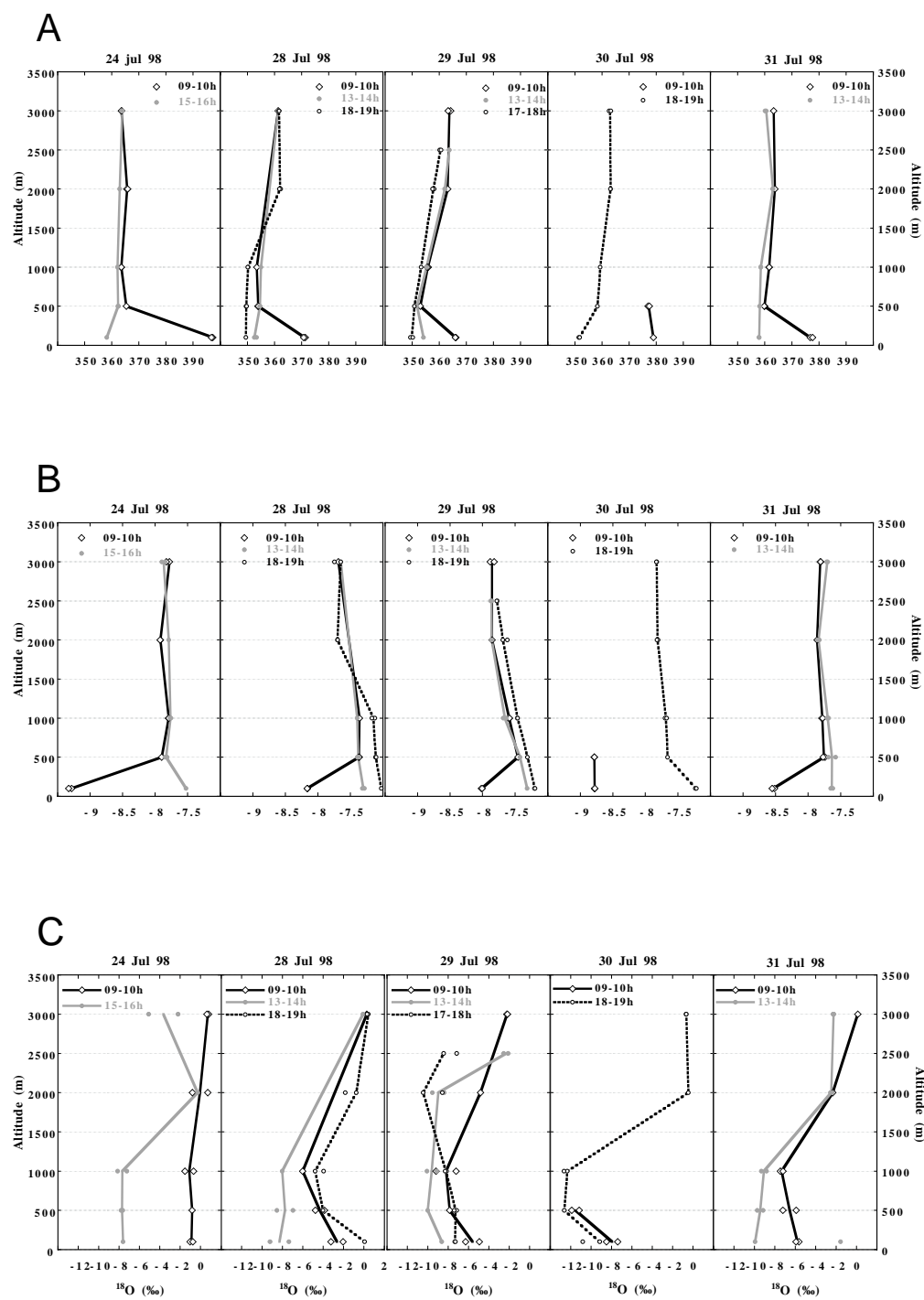
Figure 1. Vertical profiles of  $\text{CO}_2$  (A),  $\delta^{13}\text{C}$  (B) and  $\delta^{18}\text{O}$  (C), over Fedorovskoye.

Table 1. Equivalent  $\delta^{13}\text{C}$  added to the atmosphere by the vegetation during the Fedorovskoye intensive campaign.

Date	Time	$\delta^{13}\text{C}_s$
24-07	9h	-25
	18h	-29.8
28-07	9h	-24.4
	12h	-22.3
	18h	-25.0
29-07	9h	-21.9
	12h	-22.8
	18h	-26.3
30-07	9h	N/A
	18h	-25.5
31-07	9h	-25
	18h	N/A

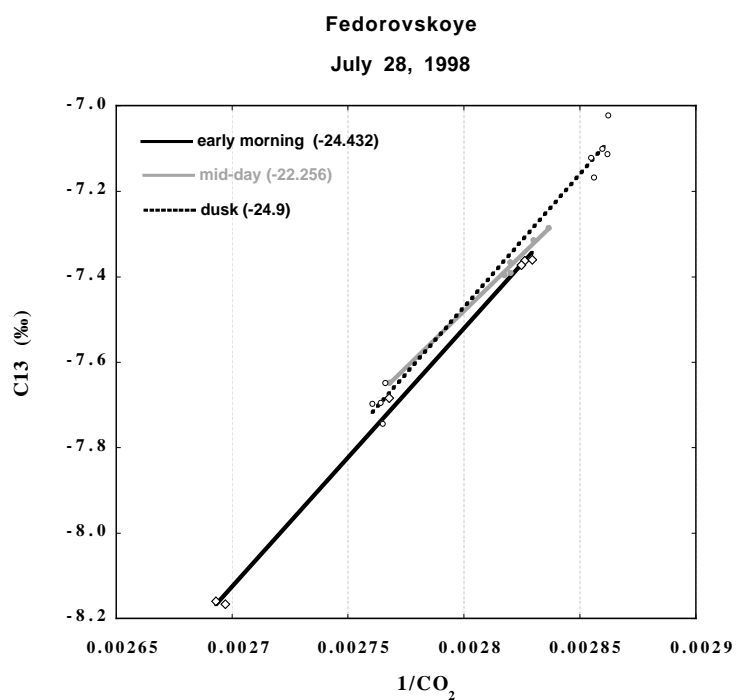


Figure 2. Typical  $\delta^{13}\text{C}$  as a function of  $1/\text{CO}_2$  for the ABL flights over Fedorovskoye

## Intensive campaign over Fedorovskoye (Tver) in July 1998: Vegetation and soil measurements

In parallel to aircraft measurements during the intensive campaign, we have sampled leaf and soil material over the course of 4 consecutive days with a frequency of about 4 hours. The schedule of the ground sampling with the aircraft flights is given in Figure 3. The objective is to characterize the  $^{13}\text{C}$  and  $^{18}\text{O}$  isotope composition of  $\text{CO}_2$  fixed/emitted by leaves and respired by soils. Of special importance are the  $\delta^{18}\text{O}$  values because  $\delta^{18}\text{O}$  in  $\text{CO}_2$  has been proposed to estimate separately photosynthesis from respiration. Further aircraft measurements of  $\delta^{18}\text{O}$  in  $\text{CO}_2$  (Figure 1C) indicate enormous changes in  $\delta^{18}\text{O}$  over the course of the day in the ABL, with  $\delta^{18}\text{O}$  values as low as  $-8\text{‰}$  at the end of the morning (compared to a tropospheric background of about 0 to  $-1\text{‰}$  within this latitude band and close to the 3000 m value).

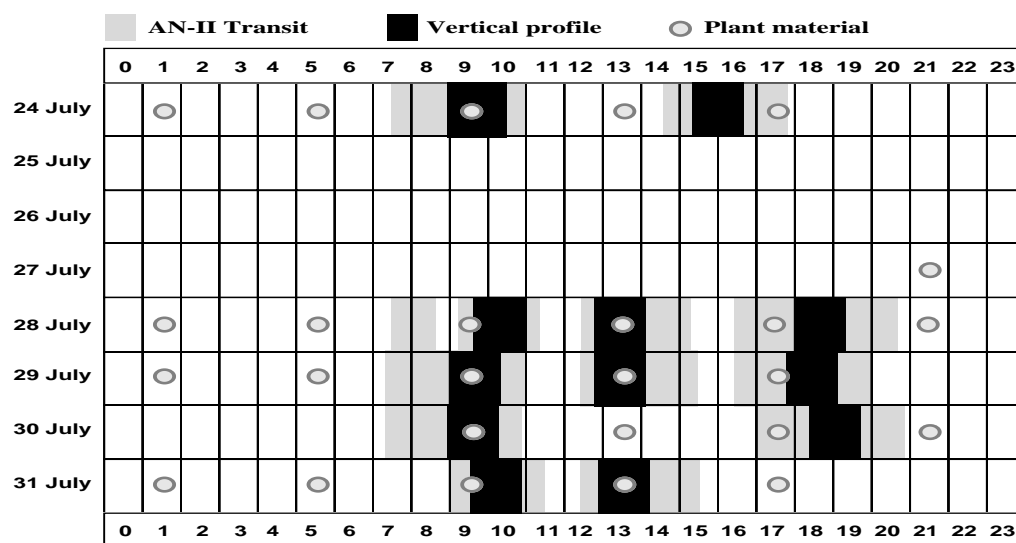


Figure 3. Schedule of the ground sampling and the aircraft flights.

The data presented in Figure 4, for the first day (day 0 is 24-07-98) show the diurnal evolution of the  $\delta^{18}\text{O}$  in plant material, including trees (conifers and aspen) and understory plants (blueberries, mosses). Soil litter has been measured as well (not shown in Figure 4). Conifer needles have been sampled near the flux measurement tower at two different levels inside the canopy (15 m and 20 m). Duplicate sampling were made for each sample (error bars in Figure 4). Also shown is the average  $\delta^{18}\text{O}$  of the source water utilized by the conifers (taken as the collar water extracted from a core drilled in the tree on 23-06-98 at 22:00 PM). Sampling the collar water instead of the soil moisture has the advantage to average the isotopic signature of water taken up by the root system (shallow and deep roots) to smooth out its spatial variability. There is a substantial enrichment of needles compared to the water at the collar due to evaporative enrichment in the leaves. The lower level conifer needles are enriched by on average 12.3 ‰ compared to the source water, and the higher level ones by 11 ‰. The conifer needles did not show a strong diurnal cycle in  $\delta^{18}\text{O}$ . In contrast aspen leaves sampled on the same patch has a pronounced diurnal cycle. In comparison, mosses and blueberries show a lesser degree of  $\delta^{18}\text{O}$  enrichment in their leaves.

**Work plan 1999**

LSCE-Paris plans to pursue its contribution to workprogramme 1 (analysis from low frequency soundings). In 1999, the interpretation of the data using 1D model of CO<sub>2</sub> and isotopes transfer will be started, in strong collaboration with Uni-HD and MPG-Jena. We also intend to make two intensive campaigns in the Federovskoye/Tver site, if possible in July and October 1999. The design of these campaigns will be similar to the one performed in July 1998, with aircraft vertical profiles (3 times a day, 5 consecutive days) and plant material sampling. Clearly more analysis are needed to link the scales between the flux measurement site and the ABL, for CO<sub>2</sub> and isotopes. Sampling of water vapor will be added for  $\delta^{18}\text{O}$  characterization. Four persons from LSCE will participate to each campaign. Interpretation of the observed vertical profiles will be developed in cooperation with MPI-Hamburg. A suite of regional models will be used to study the variability and the mean gradients of [CO<sub>2</sub>] over the Siberian domain.

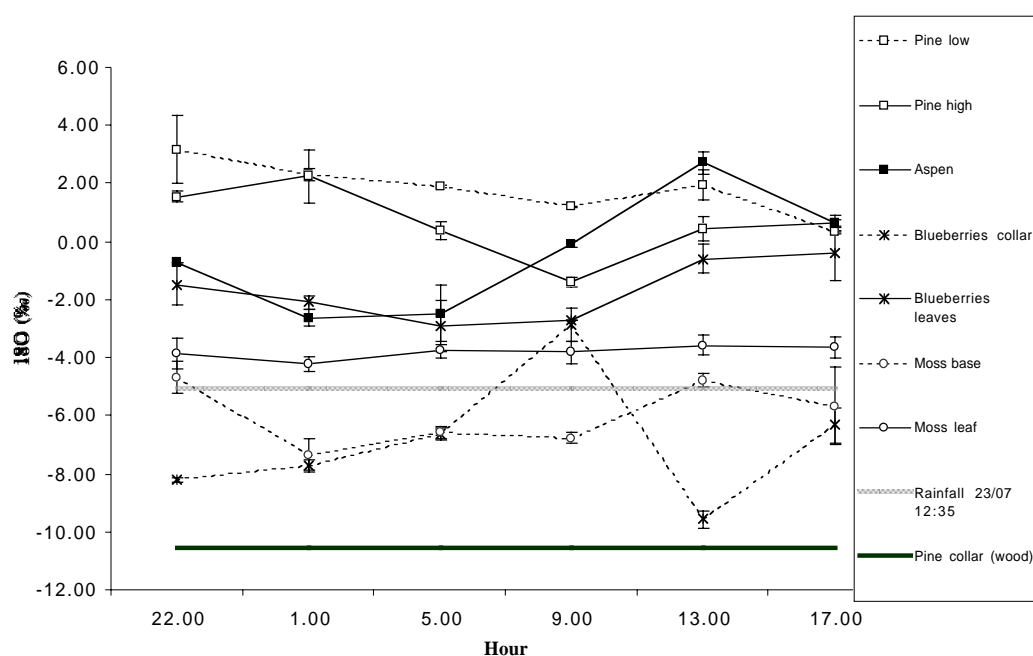


Figure 4. Diurnal evolution of the  $\delta^{18}\text{O}$  in plant material (23/24 July 1998).



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### ***Summary***

CESBIO is in charge of the development of high resolution surface CO<sub>2</sub> flux parameterization (WP 3-1). The goal is to estimate the uptake and release of carbon by vegetation and soils at the temporal and spatial scales suitable for the analysis of atmospheric measurements. Satellite data and models are used to estimate vegetation Net Primary Productivity (NPP), heterotrophic respiration (soil and litter respiration, R<sub>h</sub>), and Net Ecosystem Productivity (NEP) at a weekly time step. We also process satellite data to monitor snow cover and surface temperatures monitoring, and to establish land cover maps. Due to delivery time, current results are based on data acquired between 1989 and 1997. Processing of 1998 data started by early 1999.

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## OBJECTIVES

CESBIO is in charge of the development of high resolution surface CO<sub>2</sub> flux parameterization (WP 3-1). This parameterization will be used together with high-resolution atmospheric models in order to quantify regional scale surface flux (WP 3), and to relate atmospheric observations to surface fluxes on different spatial and temporal scales using forward and inverse modeling techniques.

The goal is to estimate the uptake and release of carbon by vegetation and soils at the temporal and spatial scales suitable for the analysis of atmospheric measurements. Satellite data and models are used to estimate vegetation Net Primary Productivity (NPP), heterotrophic respiration (soil and litter respiration,  $R_h$ ), and Net Ecosystem Productivity (NEP) at a weekly time step. This task is performed in close collaboration with LET (L. Kergoat), LEV (B. Saugier) and LSCE (N. Viovy).

In addition, secondary objectives are to improve, as needed, vegetation phenology characterization, snow cover and surface temperatures monitoring, and land-use and land cover maps. These variables are derived from satellite data.

## METHODOLOGY

### Net Primary Productivity

Net Primary Productivity is inferred using the TURC<sup>6</sup> model developed by Ruimy et al. (1996) in the framework of ESCOBA-Biosphere. TURC is a diagnostic model, driven by low resolution ( $\geq 1$ km), high repetitivity satellite data acquired in the shortwaves.

TURC computes NPP as the difference between carbon uptake by vegetation (or gross primary productivity GPP) and carbon released by autotrophic respiration  $R_a$ . Only GPP is dependent on solar radiation, while  $R_a$  has a maintenance component that depends on biomass and temperature, and a growth component that depends on C availability for growth :

$$NPP = GPP - R_a = e' f c S - R_a$$

where  $S$  is the incoming solar radiation (300-4000 nm),  $c$  is the fraction of this radiation that is available for photosynthesis ( $cS$  is called PAR or photosynthetically active radiation),  $f$  is the fraction of incoming PAR that is absorbed by vegetation, and  $e'$  is the photosynthesis efficiency.  $f$  is derived from satellite vegetation index (NDVI or Normalized Differential Vegetation).

To get estimates of  $e'$  we compiled over one hundred relationships between CO<sub>2</sub> flux measured above plant canopies (from micrometeorological or chamber methods) and incident solar radiation  $S$  (Ruimy et al., 1995). For closed canopies a single relationship may be used as a first approximation for all vegetation types (crops, grasslands and forests).

To compute  $R_a$ , a large number of respiration measurements (expressed per unit biomass) have been used with a separation into various plant organs : leaves, fine roots, wood. Thus average maintenance respiration rates have been computed at 20°C

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<sup>6</sup> Terrestrial Uptake and Release of Carbon



and found to be  $10.7 \text{ mg}_C \text{ g}_C^{-1} \text{ day}^{-1}$  for leaves, 6.6 for fine roots and 0.5 for sapwood (same units). Sapwood is the living part of wood, and has to be estimated. In our case, we started from a map of vegetation biomass derived by Olson, derived leaf biomass from NDVI data, took fine root biomass equal to leaf biomass and calculated wood biomass as the remainder. Sapwood was then derived from total wood biomass using regression lines established on a few forest stands. The temperature dependence of maintenance respiration was taken as a linear one, rather than as an exponential for there is ample evidence that the  $Q_{10}$  values - often used in respiration - decreases markedly with increasing temperature.

Finally, available carbon for growth was computed as the difference between GPP and total maintenance respiration, and growth respiration was taken as a constant fraction (0.28) of this available carbon.

We run the TURC model globally for the years 1989 and 1990. The incoming solar radiation,  $S$ , is provided by the GEWEX-SRB global dataset. Monthly means of  $S$  are derived from meteorological satellites and mapped at a  $2.8^\circ$  resolution. The fraction of incoming PAR absorbed by vegetation,  $f$ , is derived from calibrated and atmospherically corrected AVHRR datasets (Berthelot et al., 1997).

### Heterotrophic respiration

In a first step, heterotrophic respiration ( $R_h$ ) is estimated by using a simple parameterization that relates carbon release to temperature :

$$R_h = V_0 Q_{10}^{(T(t)-T_0)/10}$$

Where  $Q_{10}$  is the factor applied on  $R_h$  fluxes for a  $10^\circ \text{ C}$  increase in monthly temperature  $T(t)$  and  $V_0$  is the rate of carbon decomposition at the cut-off temperature  $T_0$  below which no respiration occurs. We set  $Q_{10}$  to a constant value of 2.3, and  $T_0$  to  $5^\circ \text{C}$ . By now, we assume that over one or several years  $R_h$  balances  $NPP$  (zero net ecosystem productivity) for each grid cell of the model through a calibration of the  $V_0$  parameters.

### Characterization of snow cover and surface temperature

We used measurements acquired by the SSM/I instrument onboard the US DMSP F-11 satellite. SSM/I is a passive microwave radiometer that measures radiances at 19, 22, 37 and 85 GHz, with both horizontal and vertical polarization (except at 22 GHz, where only the vertical polarization is available). The spatial resolution is low, of the order of 25 to 50 km depending on the wavelength. The main interest of these measurements is to be unaffected by solar elevation and relatively unaffected, depending on wavelength, by cloud cover or rainfall. The data have been processed to obtain a weekly time sampling with 0.5 degree resolution, for the years 1989 to 1996. Processing of 1997 and 1998 is in progress.

These data are being used to derived snow cover maps and snow cover periods, equivalent snow water content, and surface temperature.

Monitoring of snow cover using microwave radiances is based on the scattering properties of snow, that depends on the structure of snow crystals (Mätzler, 1987).

Snow water content,  $SD$ , estimation is based on the semi-empirical algorithm proposed by Chang and Chiu (1986, see also Chang et al., 1987). This algorithm uses the scattering difference at 19 and 37 GHz :

$$SD (mm) = 15.9 (T_{19h} - T_{37h})$$

This algorithm applies only for flat terrain and for snow depth lower than 1m. Brightness temperature,  $T_{19h}$  and  $T_{37h}$  (K), are derived from radiance measurements, assuming a black body emission.

Snow cover transition dates, i.e. first snow or snow thawing, are determined when estimated snow water content becomes negligible.

Surface temperature,  $T_s$ , estimate is computed according to the following empirical algorithm (Hiltbrunner et al., 1994) :

$$T_s = (1.95 T_{19h} - 0.95 T_{37h})/e_x$$

where  $e_x$  is an empirical coefficient, set to 1.

The accuracy of the retrieved surface temperature is of the order of 3K. Thus, the retrieved temperature is certainly not as accurate as those derived from thermal infrared sensor. However, it is not perturbed by cloud cover. The SSM/I surface temperature can be used to define the periods when the temperature is above freezing which corresponds to the period when vegetation can be active and, probably, when heterotrophic respiration occurs.

#### Land use and land cover

We used the classification algorithm developed by Viovy (in press). This algorithm, called ACTS (Automatic Classification of Time Series), is based on both hierarchical and dynamical clustering principles. The method is really "automatic" since it determines, automatically, the number of clusters. The method is very fast and does not show a degradation of the results with large dimension and datasets. Application to synthetic data sets shows that in most of the cases ACTS is able to retrieve all the clusters of the image independently of the dimension of the problem. ACTS has been applied to one year (1993) of vegetation index (NDVI) sampled every 10 days and provided by the IGBP-DIS global 1km AVHRR data set. Resulting vegetation classes correspond to pixels that present similar NDVI time profiles.

### Results

#### Net Primary Productivity and heterotrophic respiration

Two years (1989-1990) of weekly NDVI derived from atmospherically corrected AVHRR data were used to drive the TURC model and produce weekly global NPP maps at a  $1^\circ \times 1^\circ$  resolution (fig.1). The original resolution of the AVHRR dataset we used (GVI) is of about 15 km, but the increase of the spatial resolution of NPP maps to 15 km is questionable due to the lack of high resolution weather datasets. However, in order to develop the needed software and test the procedure for future work, we applied the TURC model to one year of global AVHRR data at 1km resolution (results not shown here).

Time evolution of net primary productivity (NPP), heterotrophic respiration ( $R_h$ ) and net ecosystem productivity (NEP) for the two sites of Tver (Nedlidovo,  $56^\circ 18' N$ ,  $32^\circ 54' E$ ) and Bor (Vorogovo,  $61^\circ 04' N$ ,  $89^\circ 30' E$ ) are shown in figs. 2 and 3, for 1989 and 1990. Table 1 presents the annual values. The heterotrophic respiration is assumed to balance NEP over the two years. The Tver site appears slightly more productive than Bor, the difference coming from a lower solar irradiance in Bor. For

both sites, NPP and moreover Gross Primary Productivity (GPP) are slightly higher in 1989 than in 1990. The NPP satellite estimates we obtained are higher than in situ preliminary estimates. This issue will be further analysed during the course of the project.

	Tver (56°27' N, 32°55' E)		Bor (60°45' N, 89°23' E)	
	1989	1990	1989	1990
Gross Primary Productivity	915	889	834	775
Autotrophic respiration	461	448	461	444
Net Primary Productivity	454	441	373	331

Table 1 : results of the TURC model for  $1 \times 1^\circ$  cells centered on Tver and Bor sites. Unit :  $\text{g(C).m}^{-2}.\text{y}^{-1}$ .

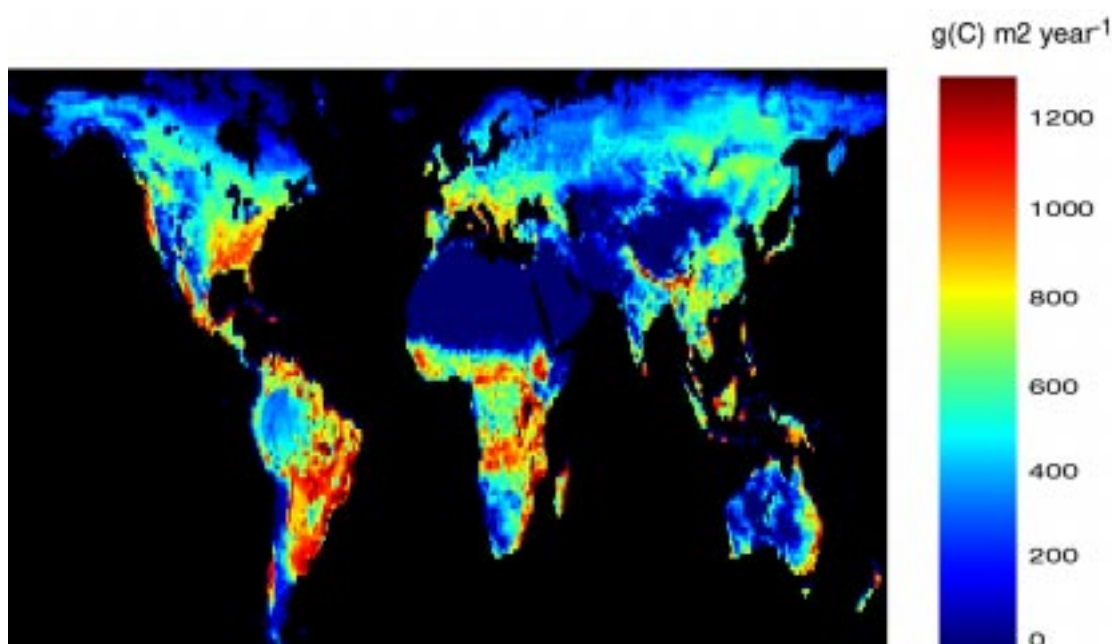
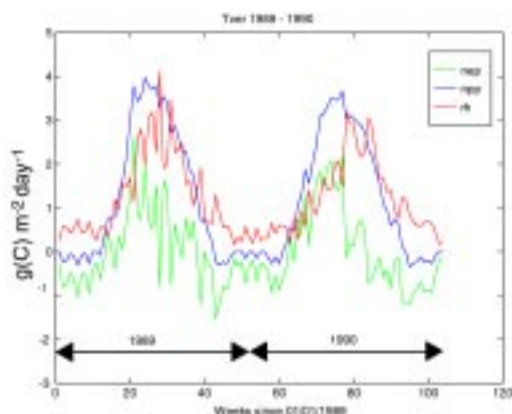
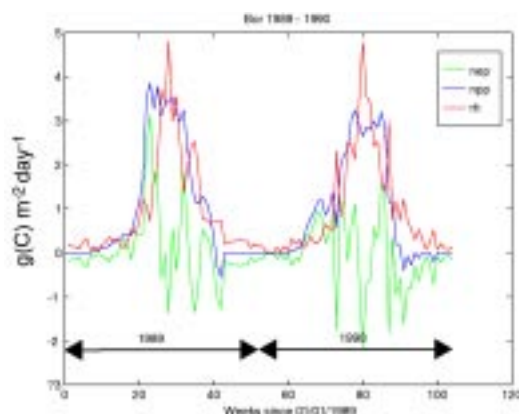


Figure 1 : global yearly net primary productivity for 1990.



**Figure 2 :** Time evolution of net primary productivity (NPP), heterotrophic respiration (Rh) and net ecosystem productivity (NEP) for the Tver site (Nedlidovo, 56°27' N, 32°55' E)



**Figure 3 :** same as figure 2, but for and the Bor site (Vorogovo, 60°45' N, 89°23' E)

### Characterization of snow cover and surface temperature

We applied the algorithms described in section 2 to weekly SSM/I data for the period 1989-1996. We only present here a few examples of the results. Time evolution of snow water content during the 1992-1993 winter is mapped in figure 4. Weekly maps of snow water content are used to estimate the date of first snow (fig. 5) and of snow thawing (fig.6). The algorithm of Hiltbrunner et al. (1994) was used to monitor surface temperature. From this temperature, we mapped the duration of summer by assuming that summer corresponds to positive temperature (fig.7).

This results will be used first to analyse and possibly explain some of the temporal variations of CO<sub>2</sub> atmospheric concentration over large areas, since snow cover probably regulates the release of carbon respired by soil. In addition, together with surface temperature estimates and other data and models, they could allow us to improve the modeling of soil respiration and carbon release.

### Land use and land cover

We applied the ACTS classification algorithm to 1km AVHRR vegetation index for 1993. Land cover map for the Tver area is presented in figure 8 (left). ACTS is an automatic procedure that does not label classes. We compared our results to the IGBP 1km land cover map in order to label classes. Knowledge of colleagues who visited the site, aerial photographs, Landsat quicklooks, and NDVI time evolution were also taken into account. This labeling is preliminary and will be improved on the basis of existing maps, high resolution satellite data and ground truth. Figure 8 (right) shows the typical NDVI time profile for every class. The various forest types with similar names correspond to different age or density forest classes. According to the classification, about 39% of the area is covered with forests, and more than 16% by crops.

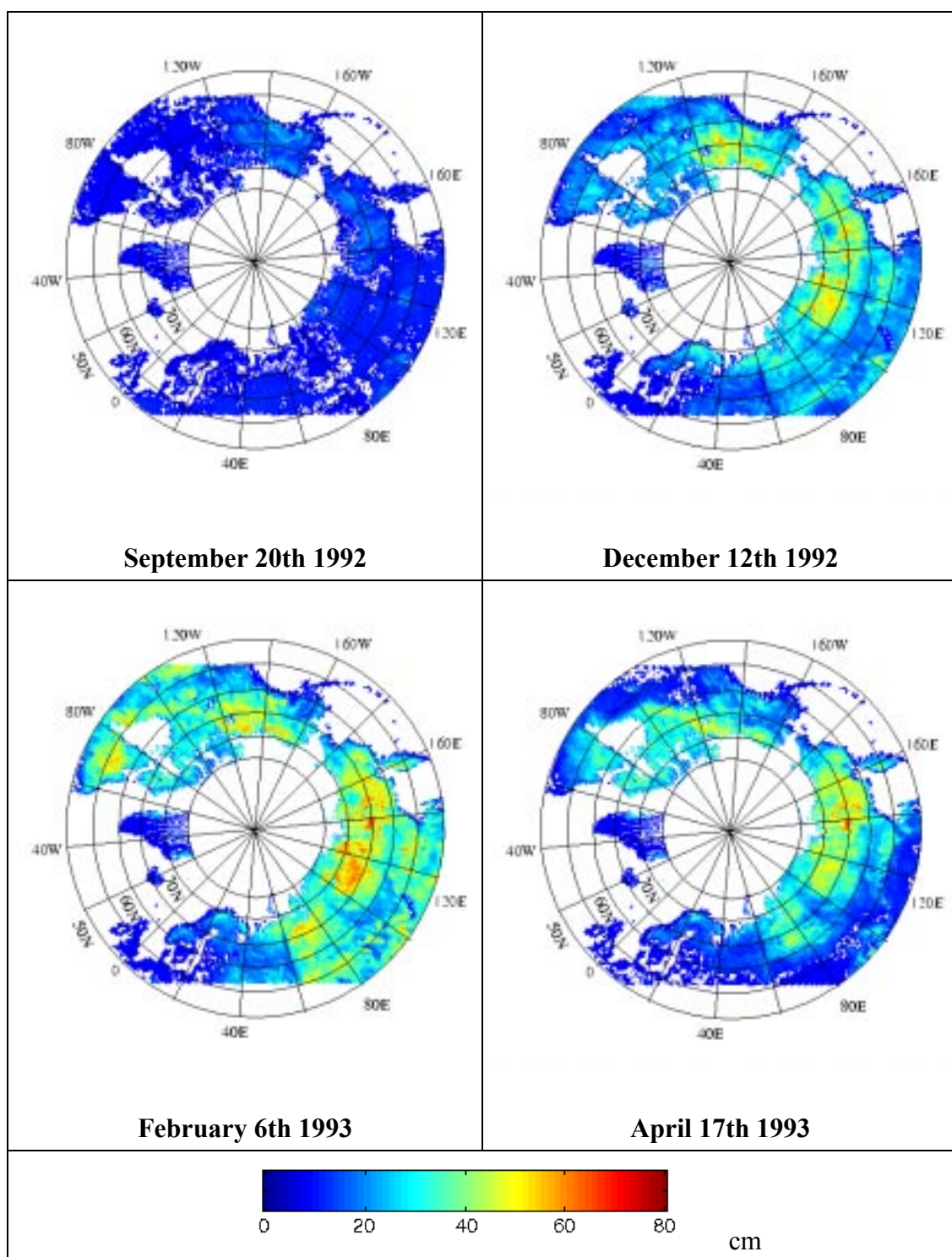


Figure 4 : snow water content equivalent derived from passive microwaves measurements (SSM/I) for some dates of 1992-1993 winter. Unit is centimeter of water.



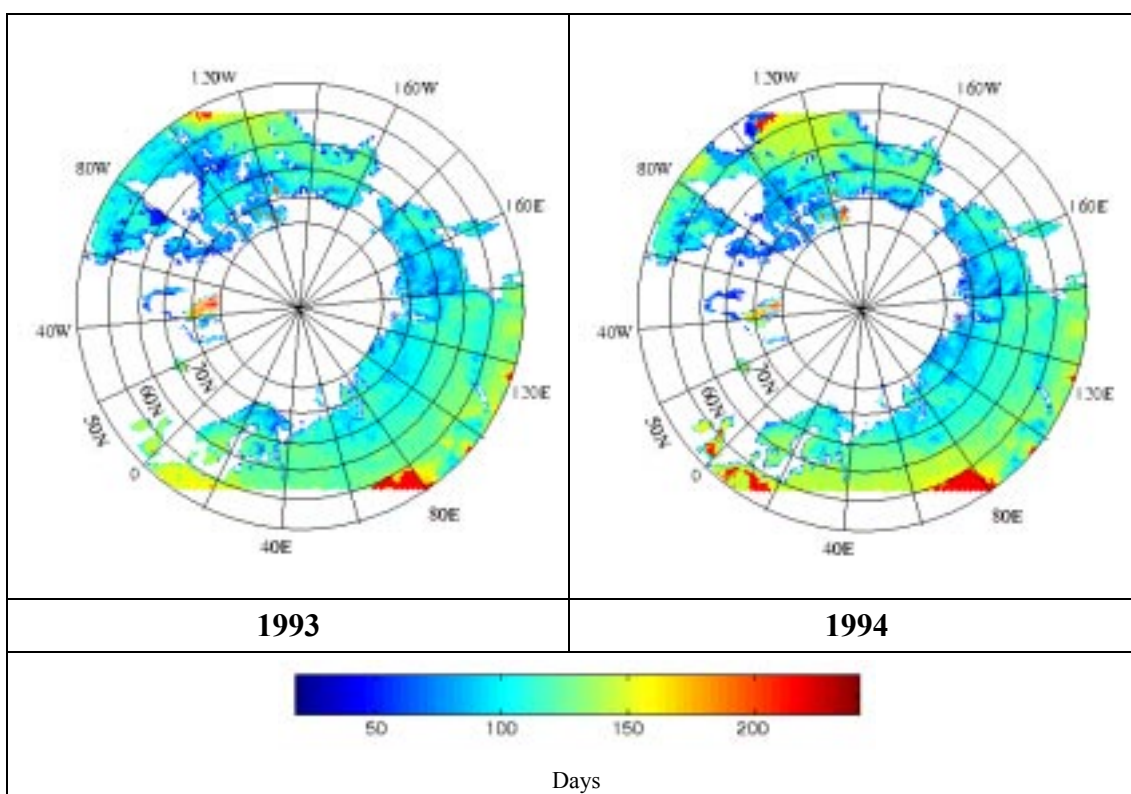
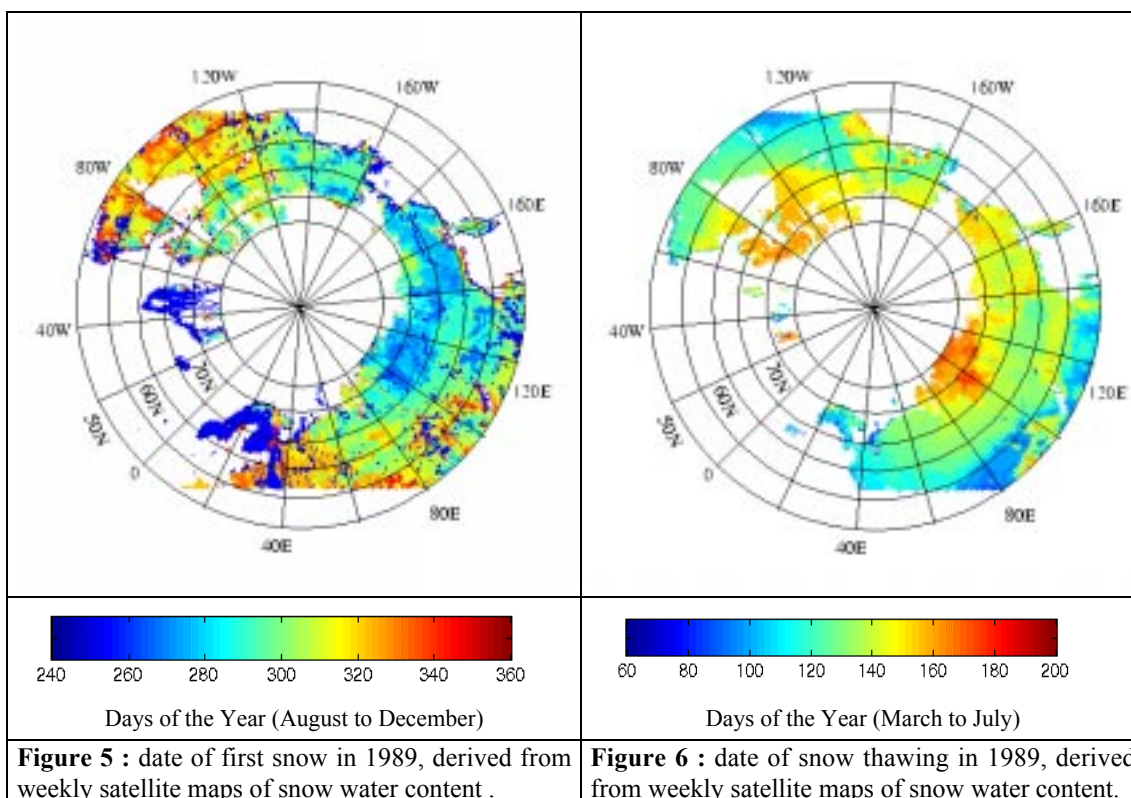


Figure 7 : summer duration in 1993 and 1994, derived from weekly satellite maps of surface temperature. Summer is assumed to correspond to positive temperatures.

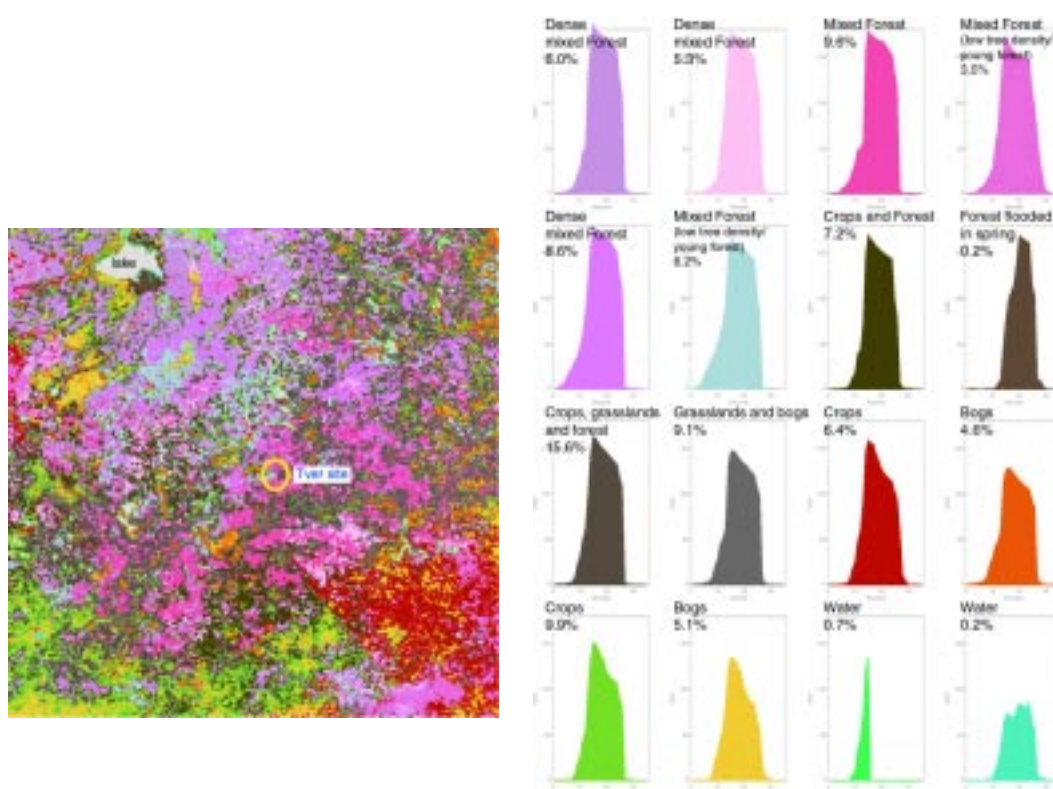


Figure 8 : Left : 1km resolution map of land cover of the Tver area (400x400 km<sup>2</sup>) in 1993. Colors correspond to the ones used in the right figure. Right : NDVI as a function of time for every class as identified by the ACTS algorithm. The relative surface covered by each class is mentioned. Class labels are preliminary. The grey area (1.7% of the surface) in the north-west of the map is a lake masked in the original dataset, not presented on the right hand side figure.

### **Work plan for 1999**

Results achieved in 1998 were based on the use of historical satellite data. In 1999, the algorithms and models will be applied to the 1998 data we acquired. Satellite data acquisition will continue in 1999. We plan the following activities :

- improvements of the TURC model, mainly by including a water balance submodel to account for water stress effect on photosynthesis. We also plan to improve the heterotrophic respiration modeling.
- The TURC model will be driven by 1km SPOT4-VEGETATION data, instead of AVHRR. TURC will be run over 1000x1000 km areas centered on Tver and Bor sites. In order to test the results, the model will be also run over smaller areas centered on measurement sites, using local weather data as inputs. Global runs of TURC will also be performed when global synthesis of VEGETATION data become available. This activity will also provide some by-products such as fAPAR.
- Estimation of snow cover characteristics in 1998 will be performed, and results will be tested against in situ data.
- VEGETATION data will also be used to derive land cover maps of the two sites. We plan to improve class labeling by using high resolution satellite images, existing maps and ground truth.

- The use of our results for the assessment of carbon budget will be defined in detail during the project meeting to be held in april 1999.

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### ***Activities***

As a logistical base, in 1998 the set of glass flasks dedicated for O<sub>2</sub>/N<sub>2</sub> air sampling was completed, accompanied by special transport-cases.

For the aircraft sampling at Fedoroskoye and Zotino two flask sampling suitcases were built up, to allow filling with dried atmospheric air to 100 kPa absolute, which is necessary for the storage of O<sub>2</sub>/N<sub>2</sub> samples, but differing from the standard CO<sub>2</sub> sampling flask model, filled to 200 kPa.

Atmospheric air sampling in diurnal cycles for O<sub>2</sub>/N<sub>2</sub> measurements started at our near-by station Kollumerwaard. For the first time the full isotopic analysis of CO<sub>2</sub> (<sup>13</sup>C, <sup>18</sup>O, <sup>14</sup>C) was combined with the analysis of O<sub>2</sub>/N<sub>2</sub> ratios. An air drying system for automatic event sampling is under construction.

Sampling in Siberia started in the summer, carried out by IPSL/LMCE (intensive campaign Fedoroskoye 7/98), MPG.GBC (Zotino, summer 98) and IPEE (general support and low-frequency sampling both sites).

In October a Gas Chromatographic measurement system was installed (third party financed), consisting of a commercially available Hewlett-Packard GC 6890, modified by Doug Worthy (Atmospheric Environmental Service Toronto, Canada). It is dedicated to measure the concentrations of CO<sub>2</sub>, CH<sub>4</sub> and CO in flask and tank air samples. The reproducibilities reached are better than ±0.08 ppm (CO<sub>2</sub>), ±1 ppb (CH<sub>4</sub>) and ±1.5 ppb (CO). All EUROSIB flask samples will be measured for the concentrations of these trace gases as well.

A new cryogenic extraction system for CO<sub>2</sub>-out-of-air samples was built up to trap CO<sub>2</sub> for eventual isotopic analysis (<sup>13</sup>C, <sup>18</sup>O, <sup>14</sup>C).

We started building up a European sampling network for O<sub>2</sub>/N<sub>2</sub> whole air flask samples. The first samples were taken in the autumn at Kasprowy Wierch, Tatra Mountains (Poland, responsible UMM), Mace Head (Ireland, cooperation project 3 IPSL/LMCE and University College of Galway) and we are about to start sampling at Zeppelinfjellet, Svalbard (Norway, station run by project 6 MISU).

## **Objectives**

For every quantity of CO<sub>2</sub> produced from fossil fuel burning a certain amount of oxygen is used. The same is true for biospheric CO<sub>2</sub> release and vice versa for CO<sub>2</sub> uptake. As no oxygen is released from the Ocean when CO<sub>2</sub> is taken up on a long-term basis (not regarding annual cycles) we will put experimental constraints on the partitioning of CO<sub>2</sub> taken up by the terrestrial biosphere and by the Oceans respectively, when concurrently measuring oxygen:nitrogen ratios and CO<sub>2</sub> concentrations.

With the combination of ground-based sampling at the northern and western boundary of Europe (Mace Head, Svalbard) and across the continent (Kollumerwaard, Kasprowy, EUROSIB-sites) we want to establish the ratio of Oxygen usage per CO<sub>2</sub> released, as a zonal continental mean value. With the aircraft sampling over Siberia we hope to resolve the more regional imprint of the terrestrial biosphere as compared to the zonally mean above the planetary boundary layer.

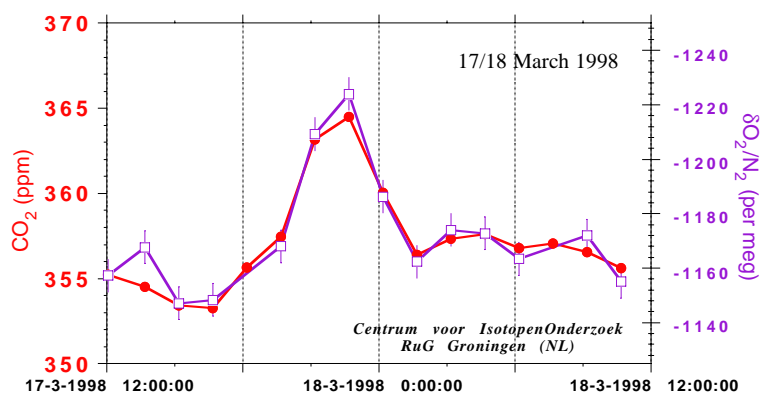
## **Methods**

The methods used include sampling of whole air samples at a few remote ground stations in Europe, and on aircrafts at three different sites of the EUROSIBERIAN CARBONFLUX campaigns, close to the ground and above the planetary boundary layer.

The samples are analyzed in the Groningen laboratory for their O<sub>2</sub>/N<sub>2</sub> ratio by isotope ratio mass spectrometry (IRMS), for their CO<sub>2</sub>, CH<sub>4</sub> and CO concentrations by gas chromatography (GC-FID), and finally from the remaining air sample CO<sub>2</sub> can be extracted quantitatively for stable isotope ratio analysis by IRMS and eventual <sup>14</sup>C-analysis by accelerator mass spectrometry (AMS). The latter, however, only if valuable additional information is expected that justifies the additional efforts and (third party funded) costs.

## **Results to date**

The overall analysis quality reached to date is demonstrated by the results of a diurnal cycle sampling carried out at our station Kollumerwaard. In fig. 1 the CO<sub>2</sub> concentration (filled circles) is shown, together with the O<sub>2</sub>/N<sub>2</sub> ratios (open squares). Note the different directions of the scales! The CO<sub>2</sub> excursion of about 12 ppm translates into a variation of the O<sub>2</sub>/N<sub>2</sub> ratio of about 80 permeg (= 0.08 permil). The variations are in the range of the expected annual amplitude and can be resolved very well. In fig. 2 the good correlation is shown between O<sub>2</sub>/N<sub>2</sub> ratios and CO<sub>2</sub> concentrations. We find for this particular diurnal cycle a slope of  $(-6.4 \pm 0.5)$  permeg per ppm, equaling an oxygen use of 1.34 mol per mol CO<sub>2</sub> produced. During other diurnal cycles we observed different slopes.



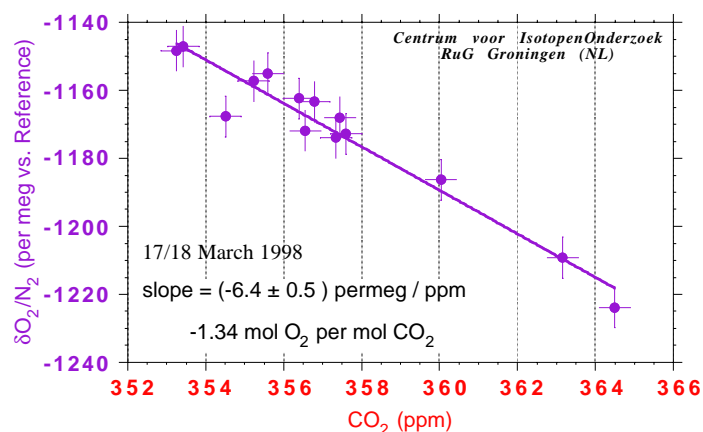
### Workplan for 1999

The measurements on the EUROSIB flasks of 1998 will be completed. The flask sampling suitcase for Syktyvkar will be brought there to start sampling at the third Siberian EUROSIB site.

The aircraft flask sampling and measurement program will go on (sampling carried out by members of other groups) in low-frequency and intensive campaign sampling.

The intercalibration efforts will be continued, working with pure CO<sub>2</sub> stable isotope standards and natural air standards for CO<sub>2</sub>, CH<sub>4</sub> and CO concentrations and stable isotopes of CO<sub>2</sub>. Concurrent aircraft sampling in O<sub>2</sub>/N<sub>2</sub> and standard type flasks will generate an ongoing intercalibration dataset between CIO-RuG and the other analytical laboratories.

We will participate in the WMO-NOAA RoundRobin 98/99 exercise for CO<sub>2</sub> concentrations and stable isotope ratios.





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### ***Objectives***

The objectives of the MISU participation in EUROSIBERIAN CARBONFLUX are to:

- i) provide a continuous record of CO<sub>2</sub> on Zeppelinfjellet, Svalbard.
- ii) perform flask sampling for <sup>13</sup>C, <sup>18</sup>O in collaboration with the NOAA/CMDL.
- iii) perform flask sampling for <sup>14</sup>C in collaboration with the Groningen group on Zeppelinfjellet, Svalbard.
- iv) participate in the intercalibration of the CO<sub>2</sub> data sets with the other EUROSIBERIAN CARBONFLUX participants and the rest of the international CO<sub>2</sub> community.
- v) perform high-resolution regional transport modeling to identify and quantify regional sources and sinks of CO<sub>2</sub> in the Siberia region.

### ***Methods***

The continuous measurements of CO<sub>2</sub> on Zeppelinfjellet have been performed with a remotely controlled NDIR instrument. Preliminary data have been available in Stockholm during the entire year within 24 hours of the actual measurement via computer transfer. Instrument calibrations are performed automatically every three hours. The working standards on Svalbard are recalibrated when returned to Stockholm and have also been calibrated in the field once during the period reported here.

Flask samples have been collected on Zeppelinfjellet at least once a week during the entire year. The flasks are shipped via diplomatic pouch to NOAA/CMDL in Boulder, Colorado, USA where the analysis for <sup>13</sup>C, <sup>18</sup>O and CO<sub>2</sub> are performed. The analysis up to September 1997 is already available.

Flask sampling for <sup>14</sup>C was commenced in October 1998 in collaboration with Centrum voor Isotopen Onderzoek, Groningen.

The regional modeling component of the MISU effort has developed into utilizing an off-line transport model based on output meteorological data from ECMWF and high resolution regional meteorological models (the HIRLAM weather prediction model). The model is driven by observed meteorology, with a parameterized boundary layer, and utilizes a mass conserving advection scheme with only small phase and amplitude errors. The model has been successfully used over Europe to evaluate regional sources and sinks; it will be used over the Siberia region to evaluate data produced within this project. During intensive campaign periods prognostic trajectories provided by the Stockholm group will be used to guide field-sampling strategies.

### **Results to date**

The continuous CO<sub>2</sub> data are available in preliminary form up to and including January 1999. EUROSIBERIAN CARBONFLUX participants are given access to the entire data set on request for intercomparison studies and modeling. Data are available for more than 80% of the year. An evaluation of Siberian carbon uptake is ongoing with CNRS and the Heidelberg group.

The flask program on Zeppelinfjellet is working as planned and data are available up to August 1998. The new <sup>14</sup>C sampling program was commenced in October 1998.

The MATCH model is being transferred for calculations over Siberia. This work has been ongoing during 1998 and will be finished early in 1999.

### **Workplan for 1999 (year 2 of project)**

The CO<sub>2</sub> data will be further processed and delivered to the other participants upon request, as they become available also during 1999. The continuous measurements and flask sampling will continue as before.

The MATCH modeling tool will be utilized to study the periods of intensive campaign during 1998. The model will be intensively used to analyze the characteristics during the field campaign periods of 1998 as data become available within the project. Prognostic trajectories will be available to make day to day decisions regarding sampling during intensive campaign periods.

The utilization of the meso-scale model in conjunction with the global models will be further developed. The scaling problem from PBL budget calculations through the meso-scale models up to the global model will be pursued with a number of case studies based on the intensive campaign period data in collaboration with the other modeling groups.

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Principle Investigator: Prof. Dr. N.N.Vygodskaya

Coworkers:

Dr. Andrey Sogachev (IPEE) is responsible for flights in Syktyvkar, a joint research with Prof. Dr. G. Menzhulin on developing a computer mesoscale model of an unsteady turbulent air flow and hydro-thermal regime in an unhomogeneous forest and atmospheric boundary layer over it;

Dr. Igor Nepomniachii (IPEE) is responsible for flights in Tver, the customs and other organizing issues;

Andrey Varlagin (IPEE, a Ph.D. student of Prof. N.Vygodskaya) is responsible for studying water regimes in forest ecosystems by the sap flow method; for maintaining measurements of CO<sub>2</sub>, latent and sensible heat fluxes by the eddy correlation method in the Central Forest Reserve (CFR), the Tver region;

Maxim Panforyov (IPEE, a Ph.D. student of Prof. N.Vygodskaya) is responsible for maintaining eddy correlation measuring systems in both forest and bog ecosystems in the CFR, the Tver region, for data treatment with their analysis followed, for technical assistance in maintaining the eddy correlation systems the Krasnoyarsk territory);

Irina Milukova (IPEE, a Ph.D. student of Prof. N.Vygodskaya) is responsible for eddy correlation data treatment with their analysis followed, as well as for tree-ring data analysis in the CFR, the Tver region;

Prof.Dr. Gennady Menzhulin (INENCO Center of RAS, St.-Petersburg) responsible for development and analysis of a computer mesoscale model of an unsteady turbulent air flow and hydro-thermal regime in an unhomogeneous forest and atmospheric boundary layer over it and coupled model of water transport in "soil-roots-stems-leaves-air"(SRSLA) system;

Dr. Nadja Tchebakova (a head of the Krasnoyarsk group, V.N. Sukachev Institute of Forest, Siberian Branch, Russian Academy of Sciences, IF SB RAS) is responsible for all organization issues needed for successful running of the Project in Siberia, as well for flights in Zotino, Siberia, for eddy correlation data treatment and analysis on CO<sub>2</sub>, water and energy fluxes in a pine forest and a raised bog in middle taiga of Central Siberia to result in scientific papers;

Dr.Olga Chibistova (IF SB RAS) is responsible for measuring and collecting CO<sub>2</sub>-flux emission data in 4 bog sites; a carbon content of bog vegetation and peat;

Dmitry Salamakho (a diploma student of biology of the Krasnoyarsk State University, Krasnoyarsk) is responsible for maintaining the pine forest and bog eddy correlation systems near Zotino, Siberia, collecting and treating data on CO<sub>2</sub>-fluxes with their analysis followed;

Daniil Zolotoukhine (a diploma student of biophysics of the Krasnoyarsk State University, Krasnoyarsk) is responsible for maintaining the pine forest and bog eddy correlation systems near Zotino, Siberia, collecting and treating data

on water and energy fluxes in these ecosystems, as well as flask sampling along the CBL profiles;

Konstantin Sidorov (IPEE, a Ph.D. student of N. Vygodskaya) is responsible for treating and analyzing the long-term meteorological and hydrological record in the CFR and Tver region, participates in the flights, and assists in solving organization issues;

Alexander Cheliapin (IPEE, an electronic engineer) conducts a current control after all measuring systems and reparation when needed in the CFR, Tver;

Anatoly Buchkov (IPEE, a technician) guarding all the measuring systems in the CFR, Tver.

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### ***Overview of objectives for year 1***

- WP1: Regular monthly vertical aircraft profiling for flask sampling and gas-analyzer measurements (Tver, Syktyvkar, Zotino) and participating in campaign for high intensity data collection of air samples;
- WP2: participating in campaign observations, in organizing terrestrial measuring systems in the CFR in the Tver region and in Central Siberia (Zotino), in maintaining long-term eddy correlation measurements, in scientific analysis of data (see the attached report of MPI BGC);
- WP1 & WP2: solving all the customs and organization issues in Russia;
- WP3: developing a computer mesoscale model of an unsteady turbulent air flow and hydrothermal regime in the heterogeneous forest and atmospheric boundary layer over it (see the report of G. Menzhulin – Appendix 4).

### ***Overview of performed work 1998:***

- 46 flights (174 hours) are fulfilled during May-December in Tver, Syktyvkar, and Zotino, including intensive campaigns with IPSL/LMCE and MPI BGC;
- the study sites are selected and the eddy correlation systems are installed in May 1998 in the CFR, near the village of Fyodorovskoye, and Central Siberia, near the village of Zotino (see report of MPI BGC);
- long-term eddy correlation measurements in spruce forest and bog sites in the CFR and in pine forest and bog sites in Central Siberia are carried out; current daily checks and calibration of the measuring systems are fulfilled together with MPI BGC;
- the sap flow system is installed and xylem flows of 18 trees are measured in the forest site with the installed eddy correlation system in the CFR; collected xylem flow data are treated and analyzed;



- a computer model of the temporal dynamics of turbulence characteristics, wind speed, solar and thermal radiation fluxes, biomass temperature, and air humidity in the heterogeneous forest and atmospheric boundary layer is developed; adjustment numerical experiments for obtaining the sensitivity parameters of the output model characteristics are fulfilled;
- the main principles of the coupled model of the water transport in the SRS LA system are justified using the results of numerical experiments with the first version (parametric, non-isothermal) of the model;
- surface CO<sub>2</sub>-flux measurements in 4 bog sites near Zotino during the growing period are organized and conducted together with MPI BGC;
- data of stand structure and biomass of the target forest plot in the CFR are collected from literature and measured during previous years while we have been preparing the current Eurosiberian Carbonflux project; long-term weather station meteorological record is collected; synoptic situation data for the flight dates in Tver and Syktyvkar is collected;
- UNI-HD/IUP is assisted during the summer intensive measurement campaign in the CFR.
- All the currently customs issues are solved. Scientific research of all groups is organized in both the CFR and Siberia.

### **Objectives:**

According to the Eurosiberian Carbonflux proposal, the IPEE is responsible for:

- WP1; Regular monthly vertical aircraft profiling for flask sampling and gas-analyzer CO<sub>2</sub> measurements (Tver, Syktyvkar, Zotino) and participating in campaign of high intensity data collection of air samples;
- WP2; Participating in terrestrial campaign observations, in organizing measuring systems in the CFR (Tver) and in Central Siberia (near Zotino), maintaining long-term eddy correlation measurements and a scientific analysis of the data obtained (see report of MPI BGC);
- WP1, WP2; solving all the customs and organization problems in Russia;

In preparing the actual working plan for 1998, the Russian participants are also responsible for :

- WP3: to develop a computer mesoscale model of the unsteady turbulent air flow and hydrothermal regime in an heterogeneous forest and the atmospheric boundary layer over it (see report of G.Menzhulin, Appendix 4).
- WP2: to investigate a xylem flow in a spruce forest in the CFR;
- WP2 & WP3: to investigate net primary productivity in spruce forests in the CFR based on literature data and our measurements including that obtained together with Prof. E.-D. Schulze in 1996;
- to collect both archive meteorological information and measurements of 1998, synoptic situation information of 1998, ground water data for the CFR.

**Methods:**

- For methods of canopy and soil CO<sub>2</sub>-flux measurements, eddy correlation and aircraft sampling see the report of MPI BGC. 5 scientists of IPEE (Moscow) and 4 scientist of FI SB RAS (Krasnoyarsk) have been trained at MPI BGC and IPSL/LMCE. Specialists of MPI BGC constantly consult and assist in solving current technical problems.
- Xylem flow was continually measured with a thermal method (Granier, 1985) in the target spruce forest in the CFR. The sensors were installed at breast height (1.3m) on the northern side of a tree in 10 cm distance from each other and protected from direct sun beams by a reflecting film. Readings were registered every minute and averaged for 30 minutes. The xylem flux sensors were installed into 18 trees, chosen according to the diameter distribution probability. From 18 trees, 14 are *Picea abies*, 2 are *Betula pubescens*, and 2 are *Pinus sylvestris*. To measure fluxes along the vertical profile and branches of the first order, 7 additional sensors were installed in 1 spruce.
- Carbon emission from the bog surface was measured during the growing period. The site under study was an oligotrophic bog surrounded by Scots pine forest. Daily bog surface CO<sub>2</sub>- flux was measured in August using a portable gas exchange system (model LI-6400, LICOR Inc., Lincoln, Nebraska), connected with the 6400-09 Soil CO<sub>2</sub>-flux chamber. The total surface area, which was covered by the chamber in our measurements, occupied 80 cm<sup>2</sup>. 4 sites were selected for the study, which differed by location. Three plots were established in each site. Peat layer depth was 1 m in the bog pools and 1,25 m on the ridge. Temperature was measured at depth of 10 cm with a thermocouple. Vegetation and peat were sampled to determine carbon and nitrogen contents. Also, moss samples were collected to estimate chlorophyll amount and biochemical composition. Samples were taken for assessing root and plant spices ratios in each site.
- For methods used to develop a mesoscale model and SRSLA-system models, see the report G.Menzhulin (Appendix 4).
- Net primary productivity of spruce forests in the CFR was estimated based on:
  - generalized published data on above- and below ground biomass in the study area;
  - measurements carried out earlier by the participants of the project along the transect of 390 plots of the size 20 m x 20 m comprising about 0.1% of the CFR area;
  - calculations of foliage biomass from vegetation indices resulted from aircraft scan survey of high spatial resolution (10 m) carried out with DLR in 1991;
  - measurements of all tree diameters and model trees of spruce, tree-ring analysis carried out jointly with Prof. E.-D. Schulze for the spruce forest - the principal study area of the project.

***Problems and Experiences in carrying out Eurosiberian Carbonflux research in Russia:***

- The major problem is related to importing the scientific equipment into Russia for the period of the project activity. The main reason is that the customs questions

between EEC and Russia within the Program Copernicus are not settled out. According to the Russian laws, the participants of the Project may import the scientific equipment for a period up to 1 year. In this case, the customs tax is 0.15% of the equipment cost. The same cost is to pay under exporting the equipment out of Russia. The tax is 3% of the equipment cost for each month when the term of equipment staying in Russia is extended. Favourable taxes (0.15%) for the entire period of joint scientific project activities concern only projects within Intergovernmental Agreements.

During 1998, Profs. Schulze and Vygodskaya have been trying to introduce our project within the framework of Intergovernmental Agreements.

We are supported by the chairman of the State Duma Committee on Natural Resources. So far, we cannot get a permission of the State Customs Committee of the Russian Federation because our project is not registered in any Intergovernmental Agreement. We still have time to get registered: before 12 May 1999 at the Moscow customs and before 21 July 1999 at the West Dvina Customs.

For solving the customs problems, we need support of other participants of the project: good ideas on including the project into current Intergovernmental Agreements, addressing EEC, Ministries of Germany or other countries for getting support.

Solving the customs problems at all levels was our major task with which 2-3 people of the Moscow group dealt throughout 1998.

- Problems of aircraft sampling are related firstly to a small fleet of aircrafts of the AN-2 type (most suitable for this work) in Tver and secondly to the lack of fuel for them in Siberia. Majority of these aircrafts cannot fly because of shortage of money for current reparation and necessary regular checks up.

So, there is only one aircraft in Syktyvkar. There is none in Tver, because one aircraft we used for flights till August exhausted its resource. Therefore, we had to rent another aircraft to fly to Tver from Moscow where only one aircraft appeared to be available. Because of a long flight its cost became correspondingly higher.

There are technical problems with the aircraft equipment. Some questions can be solved in situ after consulting with MPI BGC and IPSL/LMCE. Some problems arise because of low temperature especially in Siberia. E.g., rubber O-rings become fragile and crack under frosts. Glass around flask Torr-connectors may crack as well. Some gas-analyzer problems ( with its calibration ) may be apparently solved only in Germany. Because of long-term cloudy weather , aircraft sampling was not carried out in Zotino and Tver in October.

- Because of low temperatures, problems with solar batteries arose in both the CFR and Zotino. In the CFR, we did not manage to maintain power supply in the bog site because of prevailing cloudy weather. We temporarily installed automobile batteries in the bog site. Energy supply appeared to be sufficient after all eddy correlation systems were dismantled.
- Preliminary estimates of CO<sub>2</sub>-fluxes made us doubt if the forest site selected in the reserve is representative enough (see the MPI BGC report). A suggestion was put forward to select one more forest site. However, the windthrow caused by the 1996 hurricane makes it impossible to choose a proper site based on 1996 maps and aircraft images, for many areas of nemoral spruce forest (found in drier sites)

show apparent signs of disturbance. Therefore, to select a second site and get real estimates of windthrown areas that would help to better understand factors controlling local and regional formation of CO<sub>2</sub> fluxes, require to take aerial images of the reserve before spring 1999.

- More detailed information on vegetation of the Syktyvkar region (including experienced on-ground judgements about biomass) is also needed to identify what accounts for higher CO<sub>2</sub>-concentrations over this area.
- An increased work amount necessitates participation of four Krasnoyarsk specialists (two of them are students), who handle all organizational issues in Siberia, perform airborne measurements, and help with ground measurements. Dr. Nadja Tchebakova is the leader of the Siberian group. Protection of study sites and the foreign partners' property left in the reserve from unauthorized use by visitors collecting mushrooms and berries presents a special problem in CFR. Permanent project participants are unable to provide protection like that, for which reason we had to enlist support of two more people (A. Buchkov and A. Cheliapin) living in the reserve. In addition, A. Cheliapin performs current maintenance of the devices and electric supply systems. K. Sidorov has been working on the project since October 1998. He is responsible for collecting and analyzing weather and hydrological data, measuring snow cover depth, etc. Starting from March 1999, he is going to be on flights over Syktyvkar instead of Sogachev. On BGC and MPG IMET having approved it, Prof. Menzhulin, one of the best known modelling specialists, began to work on the project. All additional project participants, except for N. Tchebakova, are supported from sources other than the project salary fund.
- There also exist financial problems due to the current economic crisis and rapidly decreasing rouble exchange rate. So, IPEE had to spend the overhead for covering the Institute's expenses, because electricity, for example, was shut off many times in the Institute, etc. As a result, the Institute could not cover project-related mail costs (including e-mail) for March-Dec., 1998. For that same reason, we have not yet begun the installation of a project web-site on the internet.

### **Results:**

1. From mid-May to June, 3 test sites in the CFR and test sites in Zotino were selected and measuring equipment was installed jointly with the colleague from MPI BGC. Regular eddy correlation measurements in Siberia were carried out from 11 June to 4 October. Two students of the Krasnoyarsk State University maintained the measurements in Siberia. In the bog and windthrow sites in the CFR, measurements were maintained until 20 October. In the forest site in the CFR, the measurements are not interrupted and are maintained throughout the year. At present, eddy correlation data is being processed. 5 Russians (4 from Krasnoyarsk and 1 from Moscow) get trained to analyze eddy correlation data during a two- week course in MPI BGC, Jena, in December 1998. From MPI BGC preliminary evaluation of Net Ecosystem Exchange (see the MPI BGC report), the spruce forest in the CFR is a C- source compared to a pine forest in Siberia and bogs in both the CFR and Siberia.
2. This estimation puts questions on how representative the selected forest type (*P. sphagnosa-myrrilloso*) is for the southern taiga zone in general and for the CFR in particular (*see Appendix 1*) and should additional measurements be conducted in

another forest site in the CFR? One of a most probable reason of the forest site in the CFR being a C-source is that the summer weather conditions of 1998 were abnormal (*see also Appendix 2*). Precipitation for the period with temperature greater than 10 °C was 186% of the long-term norm for the weather station Fyodorovskoye, and about 235 % of precipitation of the most moist month July. From data (kindly given by V. Abrajko), the mean depth of temporary perched ground water for May-September of 1998 was 12 cm compared to 21.7 cm, averaged for 30 years. During separate days in July, it was even 15 cm higher than the ground surface. Under these conditions, water storage in the upper soil layer of 0- 20cm is close or greater than full field capacity (*see Appendix 2, Figure 1*). Under soil moisture like this, fine root (< 0.6mm) dying off was earlier registered resulting in biomass decline as great as 0.0585 kg/sq.m/yr under annual increment 0.0118 kg/sq.m (M.Abrajko 1983) (*Appendix 1, Tables 1.1-1.4*).

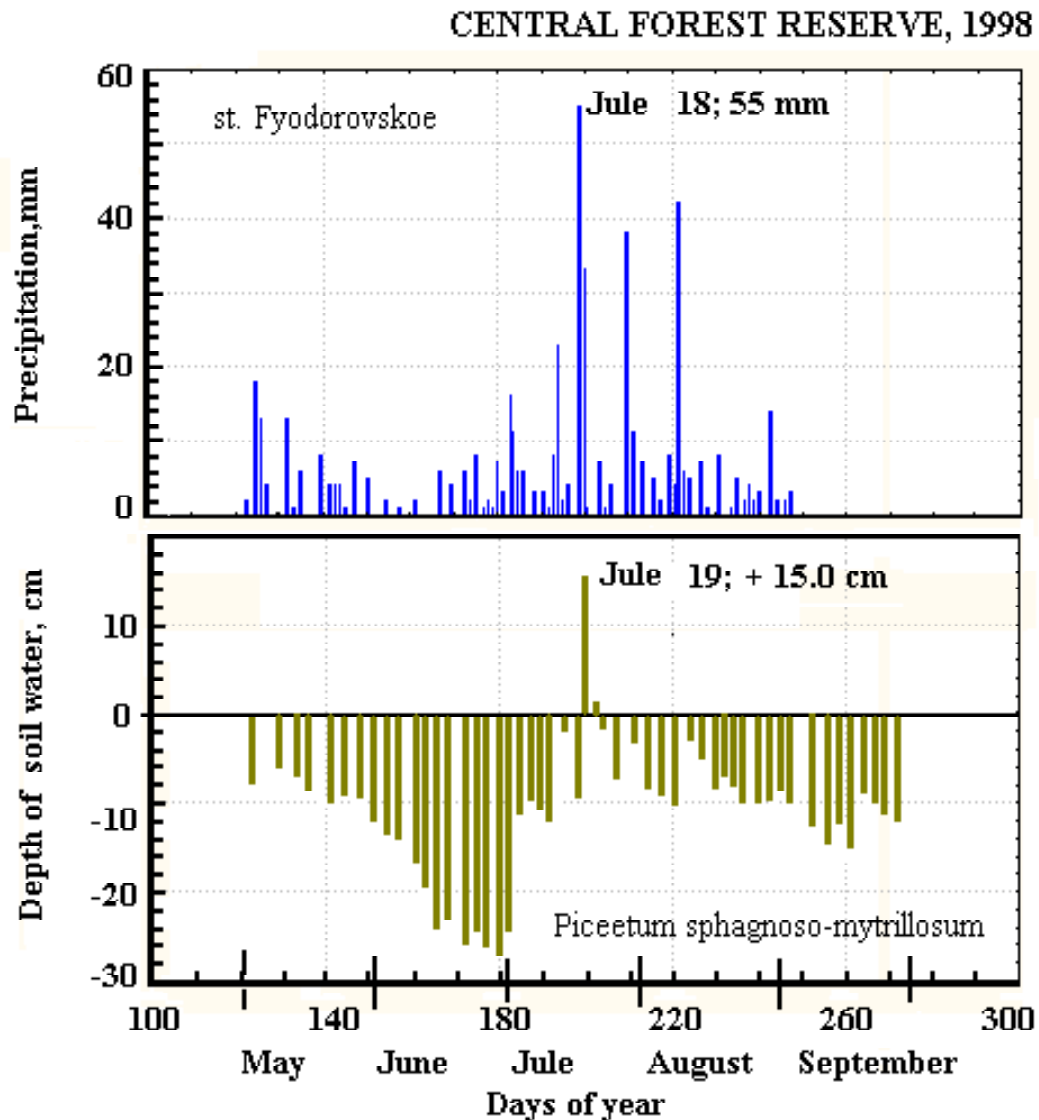


Figure 1: Daily precipitation and average depth of soil water in the forest during May-September 1998 (Average depth calculated from 28 points, V. Abrajko, unpublished).

3. Elevated soil moisture as well as occasional droughts typical for the region are main factors determining spruce forest structure and productivity dynamics in the southern taiga zone. For *P. sphagnosa-myrtillosa*, the number of living mature spruce trees declines with a rate of 1.7% with respect to the initial number of trees averaged over 1972-1996. For 4 years comprising the extremely wet 1990 and dry 1992, dead trees counted 3.5% of one-year old trees. During years characterised by normal and excessive soil moisture, the proportion of dry standing trees is 11-12% of all living trees. Two years later the drought of 1992 with precipitation 49% less than the norm, the number of dry standing trees reached 26% of all living trees. Trees fall at a rate 1% of all living trees per year on average regardless of soil moisture. In years with strong winds, this number may increase up to 8-10% per year. From data of 1996 for the target spruce forest, dry standing trees included 12%, fallen trees 87.6% of all living (0.0596 trees/sq.m) spruce trees. Tree-ring response to drought is 30-45% decreased annual growth compared to average one (0.53 mm per year) during 3-4 years after the dry year. In years with elevated precipitation, a 10-15% decrease in the annual increment is observed.

As a whole the annual growth of stemwood biomass and aboveground biomass for stands after the wet year 1990 and dry year 1992 was negative ( accordingly : - 0.358 kg m<sup>-2</sup> a<sup>-1</sup>. and ANPP - 0.445 kg m<sup>-2</sup> a<sup>-1</sup>) by the 1994. As a result this period formed total tendency of annual growth for 1988-1996: the growth of stemwood biomass was 0.138 kg m<sup>-2</sup> a<sup>-1</sup>, ANPP was 0.173 kg m<sup>-2</sup> a<sup>-1</sup> (by comparison with 1972-1988: 0.13 kg m<sup>-2</sup> a<sup>-1</sup> and 0.05 kg m<sup>-2</sup> a<sup>-1</sup> accordingly and 1994 -1996: 0.14 kg m<sup>-2</sup> a<sup>-1</sup> and 0.17 kg m<sup>-2</sup> a<sup>-1</sup> accordingly ) (*Appendix 1, Table 1.5*). This result is highly probable explanation of the observed CO<sub>2</sub>-flux tendency for spruce forest in the wet year 1998.

4. Results from data collected earlier on an area of 18.52 ha (0.1% of the CFR area) from 390 plots of 20m by 20 m along a 2.6 km long transect, aboveground biomass is 18.16 kg/sq.m, from which wood with bark is 74.9%, branches are 16.5 %, foliage is 8.6 %. Biomass of dry standing trees is 4.9% of stand living aboveground phytomass. Discrepancies between direct foliage estimation and that found for the same plots from vegetation index VI (a combination between spectral brightness in bands 520-600, 760-900, and 910-1050 nm of the DLR scanner) are 14.7-30%, which is of the same order of magnitude as the error of phytomass estimation found with traditional surface phytometric methods. However, the largest discrepancies are found in spruce forests which can be explained with additional influence of dense shades under heterogeneous surface of the upper boundary of a stand.
5. Based on a preliminary data analysis of water regime of separate trees we find:
  - The xylem flux course is similar for different trees. However, its absolute value is greatly dispersed even within one dbh class (*Fig. 2*).
  - Along with the xylem flux dynamics for 24 hours, oscillations of lower frequency with intervals from 10 to 30 days (16 July-6 August; 7 August-1 September; 2 September-16 September) are found that are related to weather situation variability (*Figs 2 and 3*).
  - In the seasonal course, averaged daily xylem flux values steadily become close to 0 by 31st October 1998 under daily temperature 0°C, VPD = 3mb, and PAR

intensity about  $50 \text{ mol m}^{-2} \text{ s}^{-1}$ . Snow cover becomes continuous by this date (Fig. 2 and 3).

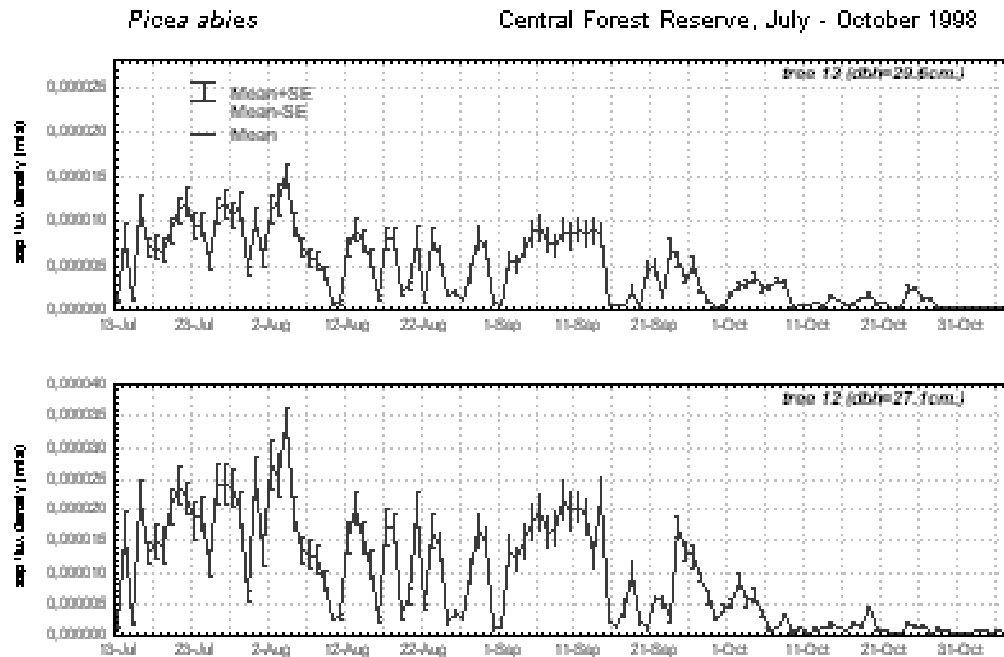


Figure 2: Seasonal course of daily mean and standard deviation of sap flux density for two trees *Picea abies*.

- On the background of excessive soil moisture, a strong influence on the xylem flux is not found (Fig. 4 and 5). Intra-daily variability of xylem fluxes under humid and chilly weather ( $t = 15^\circ\text{C}$ ,  $\text{VPD} < 8 \text{ mb}$ ) follows the PAR regime to great extent (Fig. 5). In hot days with abundant precipitation and high ground water, greater influence of high temperature is found ( $T$  is around  $25^\circ\text{C}$ , Fig. 4,

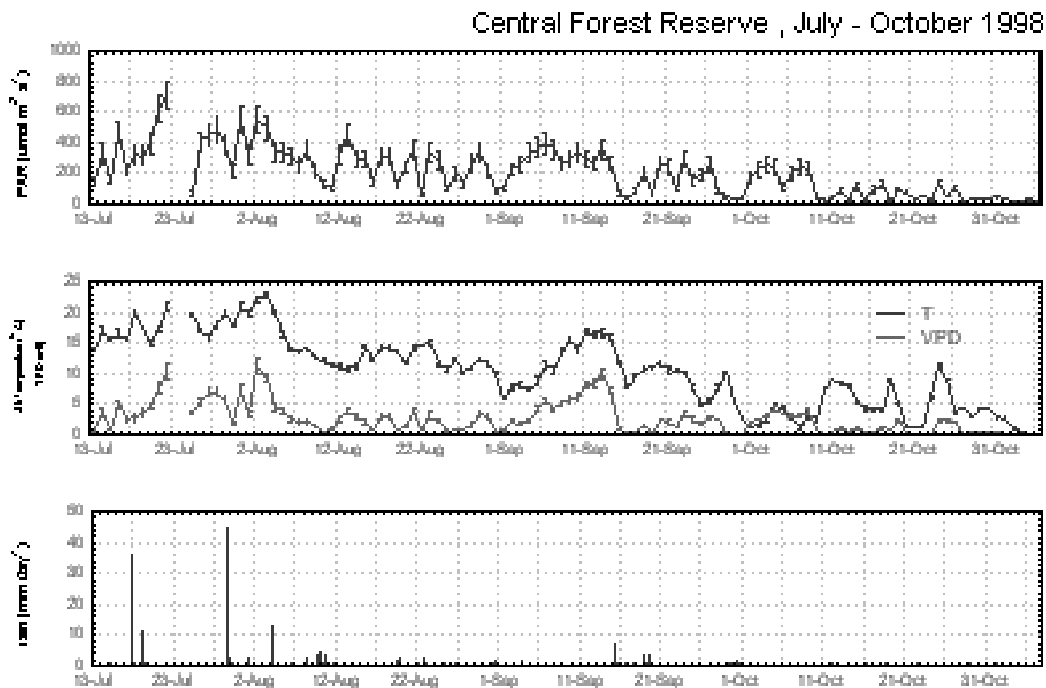


Figure 3: Seasonal course of daily mean and standard deviation of meteorological parameters: PAR (top panel), temperature and VPD (middle panel), rainfall (lower panel).

18-19 July).

- In the daily course, a common thing for all cases considered is time lag of the xylem flux starting point after night rains (Fig. 5, 12 August, and Fig. 4, 18 July).

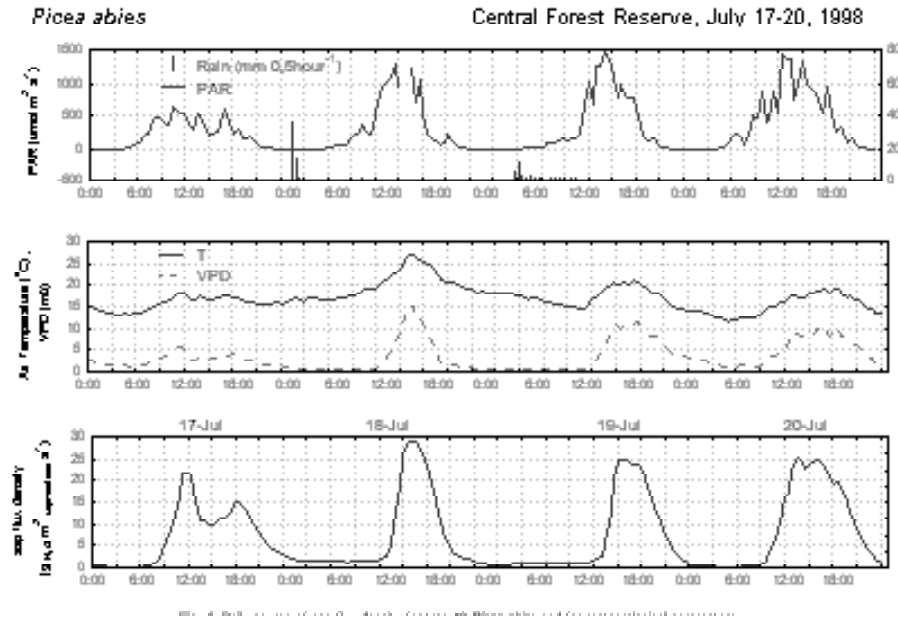


Figure 4: Daily course of sap flux density (bottom panel) for *Picea Abies* and for meteorological parameters: PAR (top panel), temperature and VPD (middle panel), July 17-20, 1998.

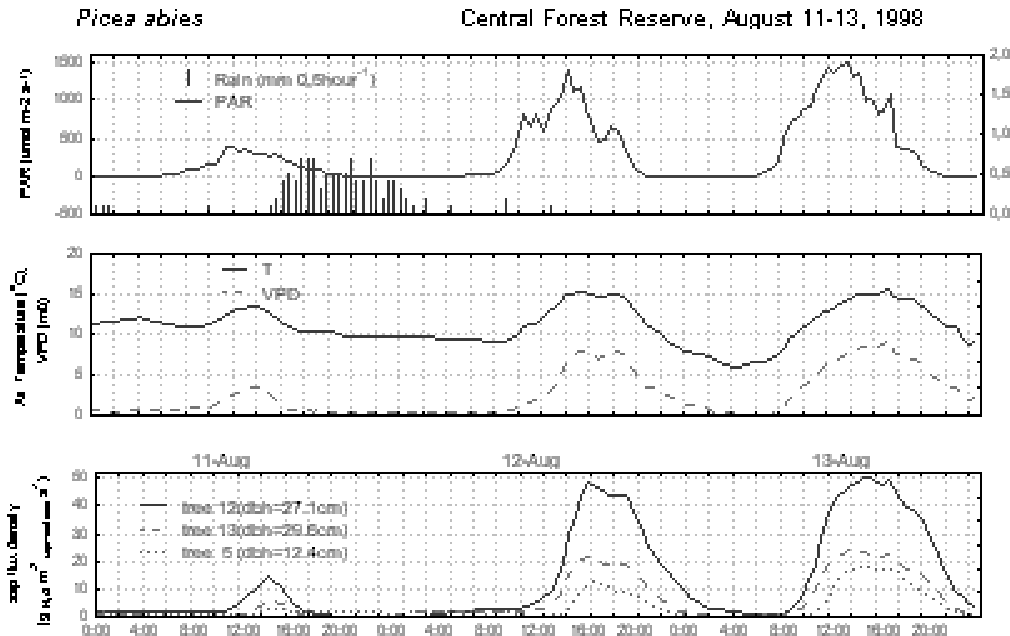


Figure 5: Same as Figure 4 but for August 11-13, 1998.

6. Boreal wetlands occupy a large territory of Central Siberia, for example, in the region under investigations, bog area covers 40- 90% of terrestrial surface (Glebov,1965). It is known that the stock of the total terrestrial carbon pool can



amount to 20-30% (Gorham,1991). Significant temperature variations were found for hummocks during the day (15.2 °C at 6.00 a.m. to 19 °C at midday), while it was stable in all other places. During daytime, CO<sub>2</sub>-concentration varied on the bog surface from 570 ppm (6.00 a.m.) to 350 ppm (9.00 a.m.). It remained at the level of 350 ppm until 10.00 p.m. and then it increased up to 730 ppm at midnight. CO<sub>2</sub>-flux was measured the highest at the bog edge (ca 6.6 ppm/sq.m/s) at 2.00 p.m., decreasing to 3.5 ppm/sq.m/s by midnight. CO<sub>2</sub>-fluxes were more stable at site 2 and 4 (3.8 to 3.6 ppm/sq.m/s, and 3.8 to 3.0, respectively). Wetter places (bog pools) were remarkable for lower respiration intensity, CO<sub>2</sub>- fluxes were fairly stable, ca 1.5-1.8 ppm m<sup>-2</sup> s<sup>-1</sup>). Relationship between CO<sub>2</sub>- flux and temperature was not established, but a reverse correlation between a respiration activity and water availability was found. To sum up, bog respiration activity is most likely dependent on its hydrochemical regime.

7. Aircraft measurements are not fully analyzed so far. 46 flights (176 flight hours) were performed during May-December 1998, including the intensive campaign. In some months, there were no flights because of rainy weather. A part of collected data appeared to be wrong since gas analyzers and other associated systems were out of order from time to time. Most of the flasks obtained were sent to Jena. Preliminary data from a gas-analyzer mounted at the height of 100 m above the underlying surface, CO<sub>2</sub>-concentration in middle taiga (Komy, Syktyvkar) is generally higher than that in southern taiga (CFR); at the height of 3000 m difference in CO<sub>2</sub>-concentration between the two regions varies, but the variability shows no clear trend. CO<sub>2</sub>-concentration consistently increases at all elevations during autumn-winter in both regions (*Appendix 3*). In July, when CO<sub>2</sub>-concentration was persistently higher in Tver than in Syktyvkar, a strong anticyclone centered over Karsk Sea reigned over Komi, while eastern and southeastern (mass) transfers, with a number of frontal zones, were observed around Tver and Moscow. No relationship of CO<sub>2</sub>-concentrations with synoptic situations and air mass transfers was, however, identified, when analyzing daily weather maps for the period of measurement. In Syktyvkar, the area under measurements is located 80 km south-east of the town. 20-25yr-old pure pine stands and oligotrophic bogs make up 40% of the area . But young pine stands are not typical for the Europe-Ural region. In 1999, therefore, along with handling the issue of probable impacts of the town and distant air mass transfers, it would be reasonable to conduct airborne measurements both to the west and to the east of Syktyvkar, where typical undisturbed vegetation can be found.
8. A mesoscale model based on the second order closure hypothesis with some additional semi-empirical equations is developed to adequately examine the principal features of the turbulent regime (see report of G. Menzhulin, *Appendix 4*).

### **Work plan 1999:**

1. To continue: a) eddy correlation measurements in the forest and bog in both the CFR and Zotino; b) measurements of xylem fluxes, water potential and stomatal conductance in the spruce forest in the CFR (jointly with MPI BGC);
2. To treat and analyze data obtained in 1998 and prepare publications (jointly with MPI BGC);

3. To select and organize eddy correlation and flow flux measurements in the second forest site in the CFR (jointly with MPI BGC);
4. To measure snow cover depth in the CFR in January-March in order to determine water content storage;
5. To take areal images of the test sites aiming at selecting windthrow sites and determining their areas;
6. To continue regular aircraft profiling for air sampling in Tver, Syktyvkar, and Zotino;
7. To develop available versions of a mesoscale model and carbon dioxide exchange and thermal regime of "soil-vegetation-atmosphere" submodels; to prepare publications;
8. To solve the customs issues and facilitate organizing research of all groups in the CFR and Siberia.

### ***Publications***

In preparation which include both unpublished data and data partly published in Russian :

- Vygodskaya, N., Abrazko, V., Tchebakova, N., Milukova, I., Abrajko, M., Panforyov, M., Sidorov, K., Sapochnikov, E., Solnzeva-Elbe, O., Tatarinov, F., Sogachev, A., Varlagin, A., Minaeva, T., Jeltuchin, A. and E.-D.Schulze (1999). Aboveground biomass and annual growth in spruce stands of European south taiga (a preliminary title, in preparation)
- Vygodskaya, N., Kuznetzova, V., Tatarinov, F., Panforyov, M., Milukova, I., Sogachev, A., Varlagin, A., Neponmiachii, G., Wirth, C., Schulze, W., Ziegler, W. and E.-D.Schulze.(1999). Branch structure in a Siberian Scots pine forest (in preparation, to be submitted to "Tree").
- Sogachev, A.F. and G.V.Menzhulin (1999). A model of an unsteady turbulent flow, energy and matter transport in a horizontally heterogeneous forest stand and the air layer over it: Theory and methodological experiments. (to be submitted to Transactions of the RAS Section for the Atmospheric and Oceanic Physics).