EUROSIBERIAN CARBONFLUX (ENV4-CT97-0491)

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4. IPSL/LMCE: Laboratoire des Sciences du Climat et de l'Environnement, Saclay, France 25

5. UPS: Université Paul Sabatier / Centre d'Études Spatiales de la Biosphère (CESBIO), Toulouse, France 31

6. RUG: Centrum voor Isotopen Onderzoek, Faculty of Mathematics and Natural Sciences, Rijksuniversiteit Groningen 39

7. MISU: Department of Meteorology, Arrhenius Laboratory, Stockholm University 43

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Project Summary

0.1. 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_2 concentration and other atmospheric tracers linked to the carbon cycle (carbon isotopes, SF_6, O_2/N_2 CH_4). A hierarchy of nested models of atmospheric transport is developed, which is used for forward and inverse simulations to infer and constrain surface sources and sinks over the target area based on the atmospheric observations.

0.2. 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_2 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_2 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_2 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.

CO_2 Monitoring Networks, Europe and Western Russia

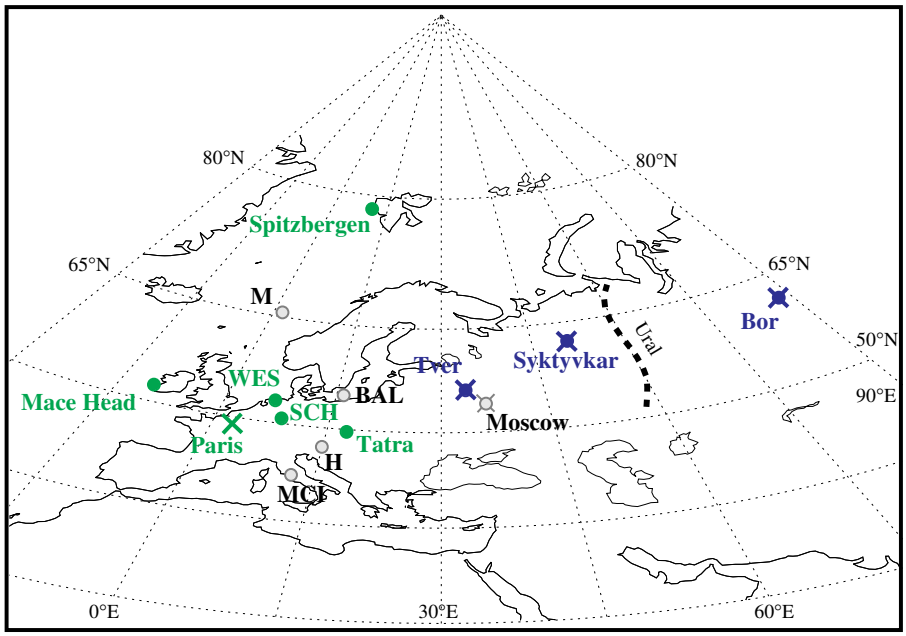

Figure 1. Map of monitoring stations in Europe and Western Russia

0.3. Methodological approach

EUROSIBERIAN CARBONFLUX includes three observational work tasks and an integrative modelling activity:

- Surface flux measurements with the eddy-covariance method together with additional ground measurements (canopy and soil profiles) of meteorlogical and carbon cycle relevant parameters (a.o. temperature, humidity, windspeed, CO_2 concentration, CO_2 fluxes, isotopic composition etc.) over selected representative ecosystems in two primary observational areas: in the Central Forest Reserve near Tver (Fedorovskoje, 56°N, 33°E) and in central Siberia near Bor (Zotino, 60°N, 90°E).
- Establishment of a trace gas (CO_2 and CH_4) climatology of the planetary boundary layer up to the free troposphere (approximately 4000m) at three selected sites by bi-weekly continuous and flask sampling from airplanes.
- The use of the Convective Boundary Layer (CBL) as integrator of surface fluxes in a series of intensive high-frequency intensive mesurement 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.
- 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_2 but, besides the standard meteorological parameters, a whole series of long lived atmospheric tracers such as the isotopic composition ($^{13}C/^{12}C$, $^{18}O/^{16}O$) of CO_2, CO, SF_6, O_2/N_2, ^{222}Rn and CH_4. The concurrent measurement of these tracers allows a separation of the measured signals into different source processes. E.g. CO and SF_6 allow an estimation of the contribution due to

anthropogenic CO_2 from the burning of fossil fuels. The observations of tracers with known sources and sinks, e.g. ^{222}Rn and SF_6 provide also a tool for the critical evaluation of the modelled atmospheric transport.

0.4. Project progress

The official start of EUROSIBERIAN CARBONFLUX 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 (see Annual Report of 1998). During 1999 both, the surface flux measurement and the aircraft measurement programme have been continued without major interruptions. In addition, several intensive field campaigns were held (see report of IPEE for details). During year 2 of the project, most of the logistical difficulties have been ironed out, e.g. severe winter weather conditions (temperatures in Zotino dropped below –55°C), Russian customs, shipments of hundreds of air flasks into and out of Russia, procurement of aircraft fuel etc. Complete annual observational records from the surface flux sites but also from the regular vertical profile observational program have been obtained. Most of these unique data sets are currently being analysed and will be available for the project synthesis during the final year of the project.

0.5. Project management

During 1999 two principal project meetings were held:

- The annual project meeting in Toulouse, April 12-15, 1999
- A project modeling meeting in Barcelona, November 2-4, 1999

In 1999 “CarboEurope”, a cluster of EU-funded projects to understand and quantify the carbon balance of Europe has been established. Because several of the approaches in EUROSIBERIAN CARBONFLUX are also employed in individual projects of CarboEurope, EUROSIBERIAN CARBONFLUX was merged to the CarboEurope project cluster. As a consequence a financial contribution of 1% of each group’s support (except for IPEE) for the year 2000 will be retained for the central functioning of CarboEurope. The project manager of the EU, Dr. Claus Brüning, has approved this change in funding schedule.

For electronic communication, the project maintains a mailing list (siberianlist@dkrz.de), with the email addresses of all project participants. In addition, a project webpage has been established: http://www.bgc-jena.mpg.de/~martin.heimann/eurosib.

Finally, during 1999 the project database has been set up. It includes a password protected web interface accessible from the project webpage.

0.6. Perspectives – EUROSIBERIAN CARBONFLUX and TCOS-Siberia

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 a hierarchy of mesoscale models. EUROSIBERIAN CARBONFLUX has been approved for funding nominally for 3 years (1998-2000). However, surface carbon exchange fluxes vary considerably from year to year because of climate fluctuations. The monitoring of these flux variations constitutes a key research topic in global carbon cycle research, as these variations document the climate-induced feedbacks on the carbon cycle. Because of this, carbon fluxes determined during a particular year (or a particular series of years) will only provide a “snap-shot” of the terrestrial carbon cycle over the Eurosiberian target region and will not be representative for an extended time period. In order to quantify the longer-term source-sink characteristics of the Eurosiberian region, a long term observing strategy is indispensable. For these considerations, it is indispensable that the measurement programs installed within EUROSIBERIAN CARBONFLUX be continued for an extended period beyond the formal termination of the project. Based on these considerations, a continuation project, TCOS-Siberia (Terrestrial Carbon Observing System – Siberia) has been developed and proposed for funding within the 5th framework programme of the EU. TCOS-Siberia includes the key components of EUROSIBERIAN CARBONFLUX (flux measurements, regular vertical profiling by small aircraft, multi-tracer approach, nested mesoscale modeling), but extends these over the entire boreal part of Eurasia by additional observation sites further east (Yakutsk) and north (Cherskii, Chatanga).

0.7. Principal investigators

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1.2. Objectives

1. Development of meteorological model hierarchy for forward and inverse simulations of CO_2 over the project target region (jointly with IPSL/LSCE, MISU and IPEE).
2. Development of inverse modelling strategy and tools for the determination of CO_2 surface exchange fluxes from atmospheric measurements.
3. Determination of optimal sampling strategy.
4. Development of project database (jointly with MPG.BGC).
5. Overall coordination of EUROSIBERIAN CARBONFLUX.

1.3. Summary

1. Implementation of REMO mesoscale model over Eurosiberian target region in coarse continental resolution (approx. 0.5x0.5 deg).
2. Implementation of TM3 global model needed for the simulations of boundary conditions for the nested REMO continental simulations. Preliminary investigation of seasonal cycle of CO_2 over Eurosiberian target region.
3. Study of dilution of seasonal O_2/N_2 signal over the northern hemisphere continents
4. Establishment of project database
5. Coordination of EUROSIBERIAN CARBONFLUX

1.4. Performed work and results

Model development at MPG.IMET during the reporting period included:

- Development, implementation and application of the REMO mesoscale model for the Eurosiberian target region.
- Implementation and simulation experiments with the global atmospheric transport model TM3 for the project target time periods to provide the boundary conditions for the continental scale mesoscale simulations with REMO.

For the mesoscale model simulations the project participants selected a target time period of July 1998. During this month, intensive observation campaigns took place in Fedorovskoje and in Zotino.

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1.4.1. REMO model development

The mesoscale model REMO (Jacob and Podzum, 1997, Karstens et al., 1996) has been implemented over the Eurosiberian target region. For this the needed auxillary datasets have been compiled, including the necessary surface parameters (a.o. maps of roughness length, albedo, vegetation and soil characteristics) and the meteorological boundary conditions from the ECMWF weather in order to provide atmospheric boundary conditions.

REMO model development encompassed:

1. Implementation and testing of passive tracer code
2. Implementation of tracer transport in convection code
3. Implementation of meteorological fields for the target period for the specification of the boundary conditions
4. Implementation of code for tracer transport within convective clouds.

These development steps have been successfully achieved and the model code has been implemented both in Hamburg and in Paris (for the IPSL/LSCE group). First simulation experiments with the inert tracer ^{222}Rn have been performed (Chevillard, in preparation).

1.4.2. TM3 transport model implementation

The mesoscale models employed in the project, REMO of MPG.IMET and MATCH of MISU need for the simulations the specification of the CO_2 concentration at the borders of the model domain. In order to provide this, the global model TM3 (Heimann, 1995) has to be run over the target time period.

The global transport model TM3 has been implemented by procuring from MISU the 6-hourly global analyses for the years 1998 and 1999. These fields have been preprocessed for the TM3 model (Heimann, 1995) and a series of test simulations have been performed. The model uses a horizontal resolution of approx. 4° latitude by 5° longitude and 19 layers in the vertical dimension, and a time step of 40'.

1.4.3. Preliminary simulations of the seasonal cycle over the Eurosiberian target region

Using the TM3 model a preliminary simulation of the seasonal cycle over the Eurosiberian target region has been performed. In this simulation, the monthly source fluxes of the Simple Diagnostic Biosphere Model (SDBM, Knorr and Heimann, 1995) were specified as lower boundary condition in the TM3 model. Figure 1.1 shows in the lower panel a map of the modelled seasonal amplitude of the atmospheric CO_2 concentration in the lower planetary boundary layer (in about 380m height above the surface). It is seen that the model predicts at Zotino at this height a seasonal amplitude of about 30 ppm, which roughly agrees with the observations (see contribution by MPG.GBC, chapter 2 of this report). The vertical dilution of the seasonal signal at Zotino is shown in Figure 1.2. Shown are smoothed curves fitted to the modelled annual time series of the model layers in the lower atmosphere (surface to approx. 4000m).

This model simulation, however, is preliminary in that it used the SDBM surface fluxes and atmospheric meteorology from the year 1987. This simulation will be repeated with the seasonal surface fluxes from the TURC model prepared by the UPS group (see chapter 5 of this report) and also the meteorological data for the target year 1998.

1.4.4. Model study of the seasonal cycle of O_2/N_2 over the Eurosiberian target region

A unique atmospheric tracer measured on the flasks collected by regular aircraft in EUROSIBERIAN CARBONFLUX is the O_2/N_2 ratio (see contribution by RUG group in this report). This tracer is of particular interest as it provides an independent check on the modelled transport over the continents in the northern hemisphere (Heimann, 2000). Thereby one monitors the dilution of the oceanic component of the atmospheric O_2/N_2 ratio, APO (which is defined as $\delta O_2 + f_{land}$ ([CO_2] + 2 [CH_4] + 0.5 [CO]), see Stephens et al., 1998) into the interior of the continent.

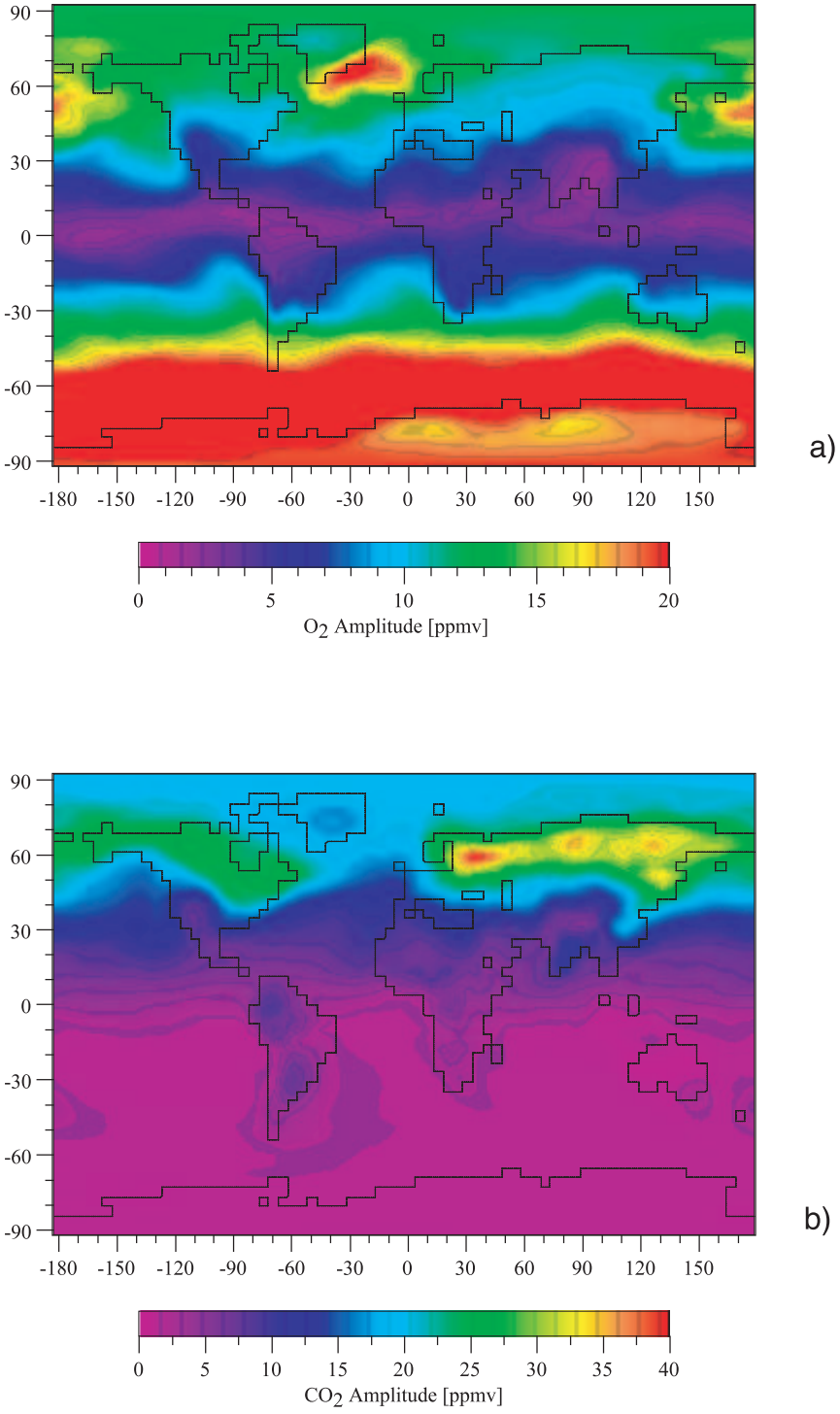

Figure 1.1. Amplitude of seasonal cycle of APO (a) and of the terrestrial biosphere (b) computed by the TM3 global transport model.

As an example, Figure 1.1 shows also the modelled amplitude of the seasonal signal of the oceanic O_2 (APO) in the lower planetary boundary layer (in about 380m height above the surface), simulated with the global TM3 transport model. The model predictions of the Hamburg Model of the Oceanic Carbon Cycle (HAMOCC3, Maier-Reimer, 1993) with the phytoplankton-zooplankton model of Six and Maier-Reimer (1996) has been used to prescribe the monthly oceanic O_2 exchanges (atmospheric simulation in the upper panel). The significant zonal structure of the oceanic O2 amplitude field and its dilution over the continents is a feature that remains to be verified by the atmospheric measurements of EUROSIBERIAN CARBONFLUX.

Detecting the dilution of the oceanic seasonal cycle signal in O_2 over the Northern Hemisphere continents is relatively straightforward and does not involve a detailed analysis and determination of the seasonal signal. All that has to be monitored is the O_2 versus CO_2 relationship over the course of one year. Since the seasonal signals in O_2 from the ocean and the terrestrial biosphere are closely in phase, this O_2-CO_2 relationship is expected to fall approximately on one line, with, however, a slope determined by the magnitude of the oceanic signal. The principle is shown in Figure 1.3.. If there were no oceanic contribution, the slope would merely reflect the biosphere stoichiometric factor (-1.1). A larger slope indicates a significant oceanic contribution. Figure 1.4 shows the spatial variation of the slope between O_2 and CO_2 in the lower troposphere resulting from the model simulations described above. The colour code has been chosen, such that only the variations in the Northern Hemisphere are highlighted; i.e. where the aforementioned relationship between the terrestrial and oceanic seasonal cycle is expected to hold. This is no longer the case in the Tropics and in the Southern Hemisphere, where a more complex relationship exists between O_2 and CO_2. It is seen that the slope of the relationship over the Atlantic and Pacific oceans reaches values above 2. Over the interior of the continent this ratio is progressively reduced to values of 1.3-1.4. It is expected that this pattern will vary considerably between different models, and should therefore provide a critical check on the realism of the modelled transport in the interior of the continents.

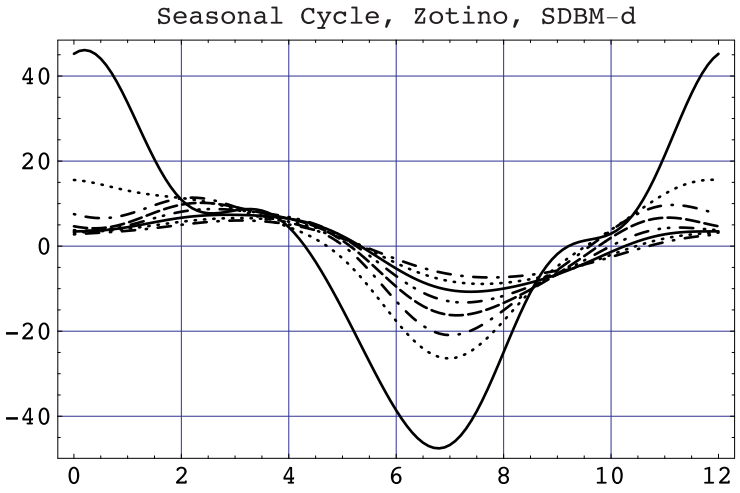

Figure 1.2. Seasonal cycle of atmospheric CO_2 in the lower part of the vertical column over Zotino (60°N, 90°E). Lower axis: time (months of the year), vertical axis: concentration (ppmv). The vertical layers are located approximately at 32m, 145m, 348m, 620m, 1150m, 1980m, 2940m, 4010m above the surface, respectively.

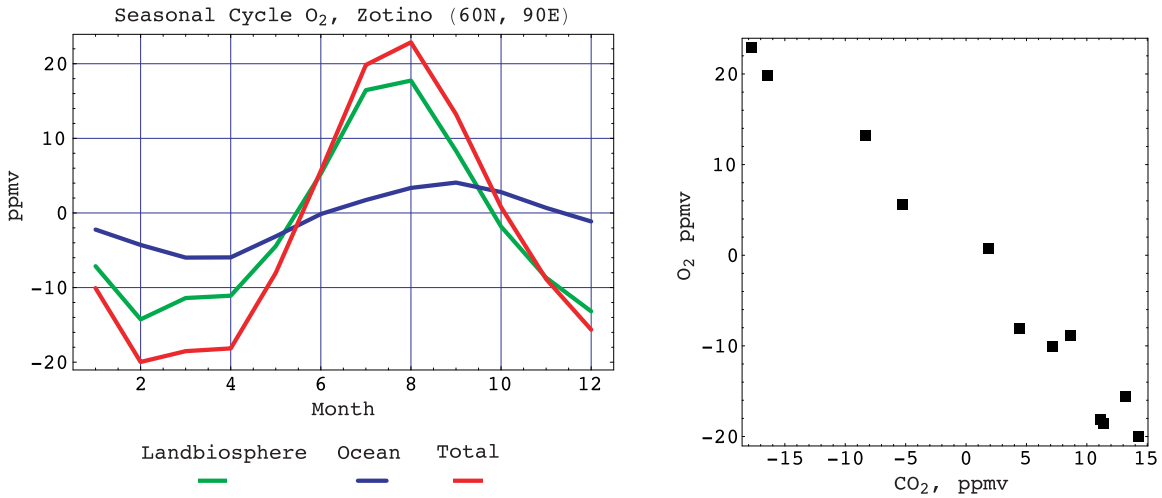

Figure 1.3. Principle of the O_2/N_2 vs CO_2 seasonal cycle method (from Heimann, 2000; see text for explanation)

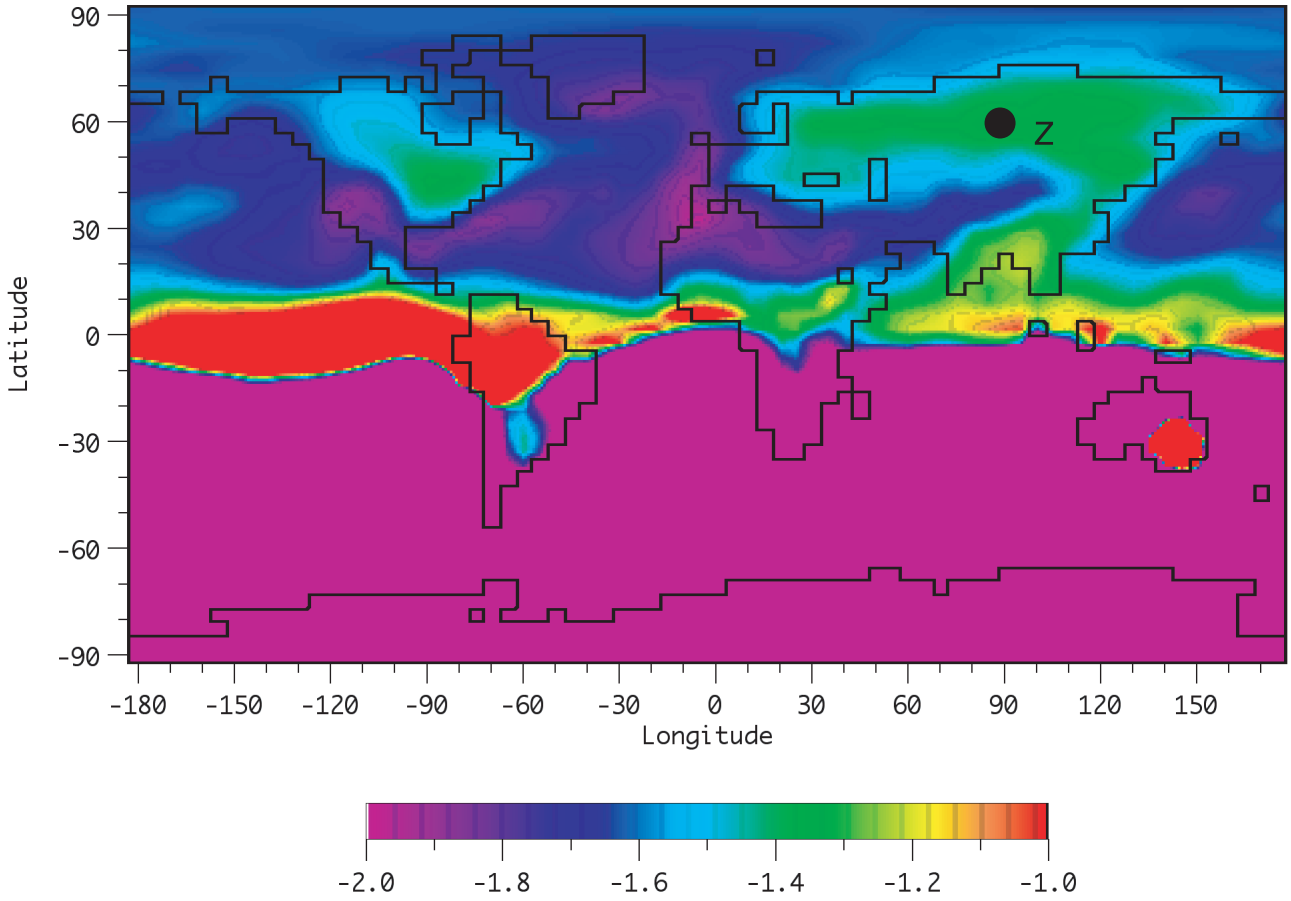

Figure 1.4. Slope of the O_2/N_2 versus CO_2 relationship in the lower planetary boundary layer over the northern hemisphere predicted by the TM3 model. The black dot labelled "Z" denotes the location of the Zotino station (from Heimann, 2000).

1.4.5 Project database

A simple project database has been established at MPG.GBC. It serves as a data archive which is accessible to all project participants by a password-protected web interface. The rules of data use and proper citations have been defined in a data charter.

1.5. Workplan 2000

- Completion of project data base
- Implementation of nested REMO model with 0.2° horizontal resolution around EUROSIBERIAN CARBONFLUX monitoring sites (see Figure 1.5)
- Modelling study of seasonal and diurnal variations of CO_2 over Eurosiberian target region
- Synthesis study on data and modelling needs to assess magnitude and interannual variation of Eurosiberian carbon balance.

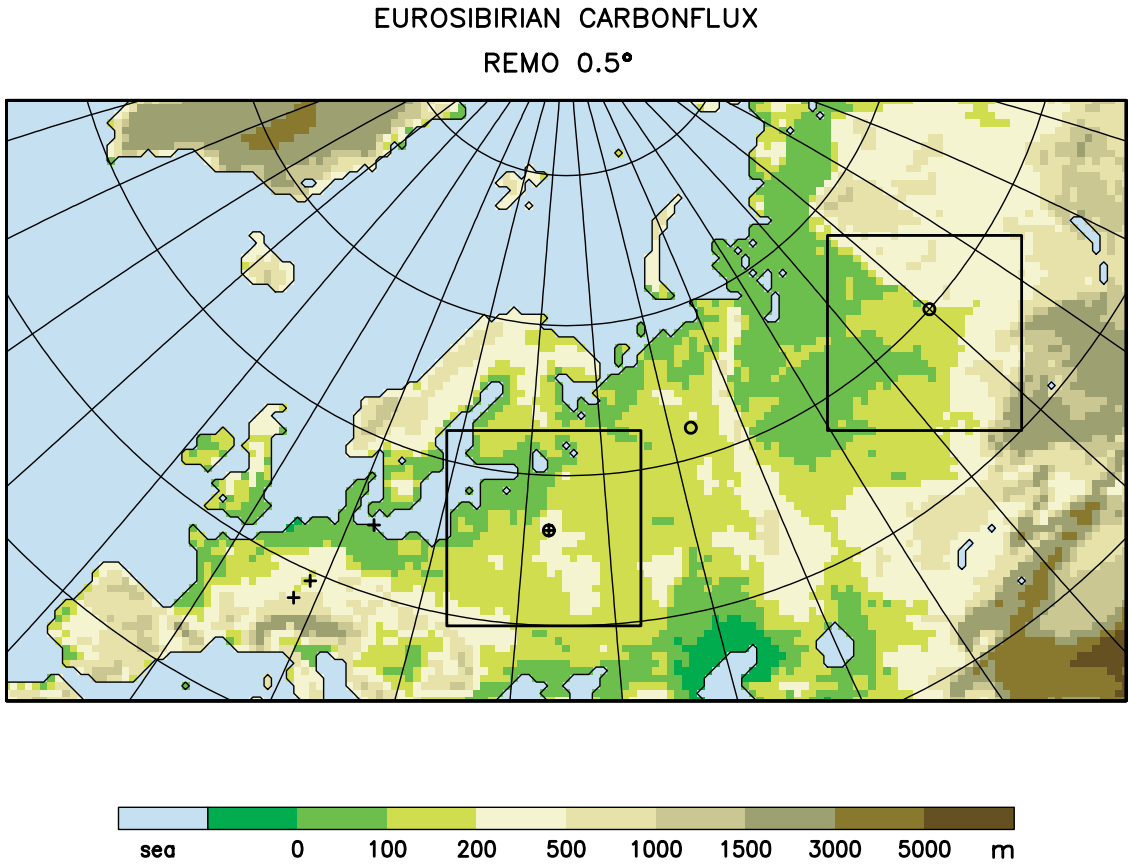

Figure 1.5. Topography of the REMO domain over the Eurosiberian target region with 0.5°x0.5° horizontal resolution. The two squares show the two regions around Zotino and Fedorovskoje, for which the REMO will be run in a nested fashion with approximately 0.2°x0.2° horizontal resolution.

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2.1. Participant information

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2.2. Summary

2.2.1. Objectives

- to study daily changes in the structure and composition of the convective boundary layer (CBL) in relation to surface fluxes
- to study intersctions between CBL and troposphere for continental climates

2.2.2. Methods

- eddy correlation measurementsfor surface fluxes in two habitats bog and forest at two locations (Tver and Zotino) in cooperation with the Russian partners
- bi-weekly to monthly flights through the CBL for taking flask samples and measuring continuous profiles of CO_2 and water vapor

2.2.3. Performed work 1999

- Measuring eddy fluxes at all sites throughout the winter
- Carrying out bi-weekly flights in cooperation with participant 3

2.2.4. Workplan 2000

- continuing flux measurements at the key sites Tever and Zotino
- continuing regular CBL flights
- Measuring eddy fluxes in the dark taiga on the east bank of the Yennessey
- Detailed analysis and assessment of CBL integration approach to estimate near local surface fluxes

2.2.5. References

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2.3. Results

2.3.1. Eddy Correlation measurements

The Eddy correlation measurements were managed in cooperation with the Russian partners. It was the plan, that the Russian partners take an increasing share in the day-to-day operation of the eddy towers. Thus, the Russian partners are to report on the details of the data processing. Here we report the annual C budget (Fig. 2.1)

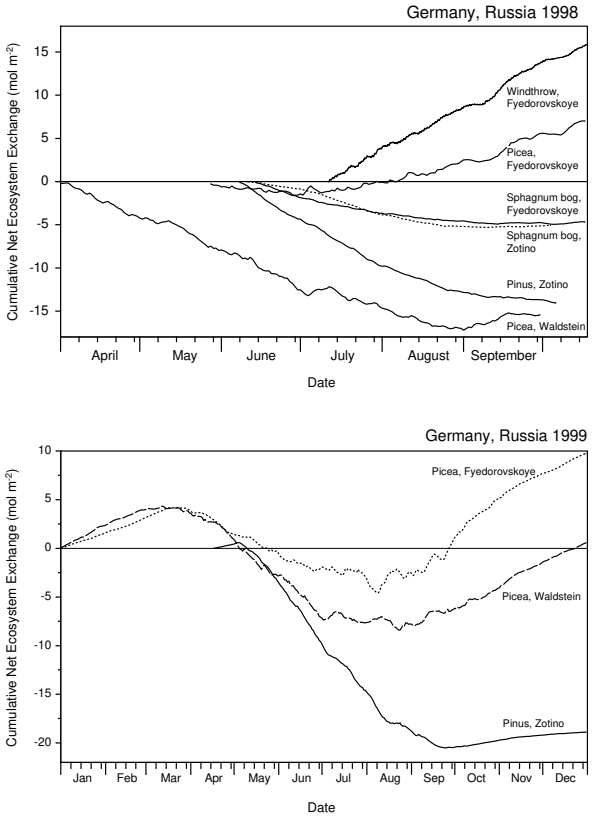

Fig 2.1: Cumulative Net Ecosystem Exchange of the main study sites

For 1998 we showed

- that the spruce forest at Waldstein had a similar C-budget as the Pine forest at Zotino despite large differences in NPP
- that the bog eached about half the C-uptake as the Waldstein and Zotino forest
- that Tver exhibits an annual C-loss

For 1999 we show

- that Pinus at Zotino was an even larger C-sink as in 1998. Including respiration until the end of the year, the pine forest had a cumulatice carbon uptake of 19 mol m^{-2}.
- that the spruce forest at Waldstein turned out to be carbon neutral. This became already apparent in mid summer, when the cumulative C-uptake by the vegetation was about half that in 1998.
- that the spruce forest at Tver remained a C-source of about similar size as in 1998.
- The data of the bog measuring site have not yet been fully analyzed.

The result is remarkable in that the two European forest sites remain C-sources or became C-neutral, but that the site at Zotino remained a strong sink. In order to confirm the observation, that ther Tver forest is a C-source, a second tower was built in 1999 at a forest site that represents a mixed boreal forest without organic soil. These data are not yet available.

2.3.2. Results of Regular Flights:

2.3.2.1. CBL Measurements

About 200 flasks from 30 regular (bi-weekly flights) filled above Zotino by the Krasnoyarsk team have now been analysed. This represents about 15 months of data and has allowed the seasonal cycle of carbon dioxide, and its carbon and oxygen isotopes above Central Siberia, and their variation with height, to be determined for the first time. This shows a marked variation in the amplitude of the seasonal cycle with height for all three entities. For CO2, the amplitude of the seasonal cycle is only about 30 ppmv at 100m and 15 ppm at 3000 m: much less than predicted above the EuroSiberian region by many carbon cycle model simulations. Consistent with the surface being a sink for CO_2 in spring/summer and a source in autumn/winter CO_2 concentrations close to the ground (100 m) are substantially lower that in the free troposphere (3000 m) during spring and summer; and likewise, higher near the ground during autumn and winter. Atmospheric CO_2 concentrations continue to increase during the winter months illustrating the continued sustained release of CO2 from snow-covered soils despite very-low air temperatures (Fig. 2.2 a).

As to be expected as a consequence of a depletion of 13C during photosynthesis, a marked seasonal cycle in the $\delta^{13}C$ of CO2 is also observed. It is of the same phase but of opposite sign than for CO2 concentration (Fig 2.2 b). Interestingly, although some seasonal cycle is discernable for the $\delta^{18}O$ of CO2 (Fig 2.2 c), values close to the ground are nearly always depleted compared to 3000m. This suggests that, irrespective of their relative magnitudes, the average net effect of respiration and photosynthesis is always a depletion of atmospheric $\delta^{18}O$ values in Siberia. This confirms some recent theoretical predictions.

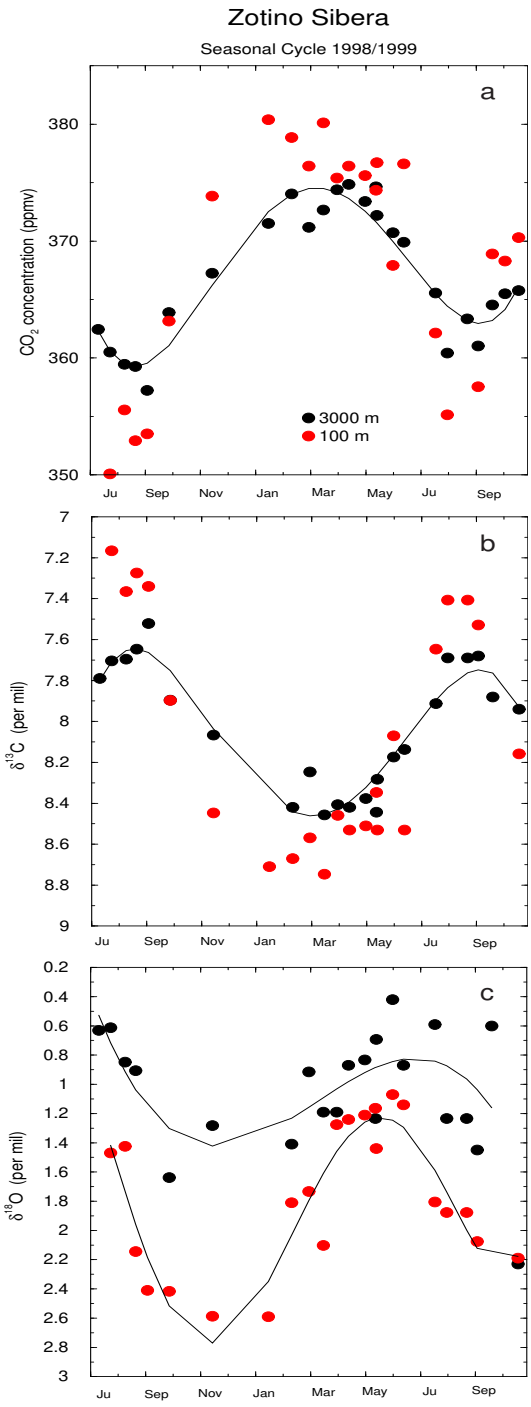

Fig 2.2: CO_2-concentration (a), $\delta^{13}C$ (b) and $\delta^{18}O$ (c) in the seasonal cycle of 1998/1999.

Analysis on the same flasks has also shown marked seasonal cycles for carbon monoxide, hydrogen and nitrous oxide and with marked altitudinal variations. Data for methane is more variable and without a distinct seasonal pattern. We believe the latter may be related to the origins of the air masses sampled; the area to the west of the Zotino sampling site being dominated by wetlands, but the area to the east being dominated by forest.

2.3.2.1. Intensive campaigns.

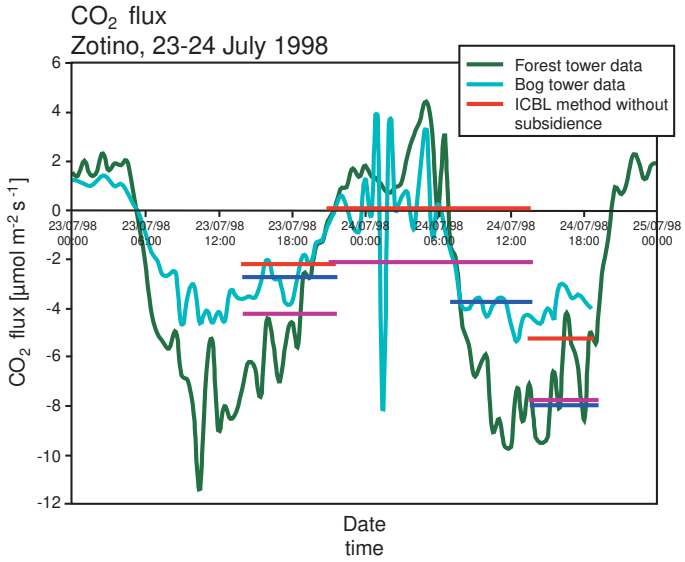

Figure 2.3. Comparison of surface flux measurements and CBL budgeting method from intensive flight campaigns during two days in July 1998.

Data from the 1998 summer intensive campaign has now been fully processed and analysed and was presented at the 1999 AGU Autumn meeting in San Francisco. This experiment showed a good congruence between regional and tower based CO2 flux measurements (Fig 2.3), with derived evaporation rates also showing regional agreement. Regional estimates of the fractionation against ^{13}C during photosynthesis ranged from 18 - 21 ‰ whereas the net effect of respiration and photosynthesis on o18 composition in the CBL tended to be a net depletion in the morning (i.e. a negative ecosystem discrimination) but a marked enrichment in the afternoons (associated with lower canopy relative humidities). A theoretical framework for the assignment of errors to fluxes and isotope fractionations inferred by the CBL budget method based on a „bootstrap analysis“ has also been developed. These theoretical aspects as well as the 1998 CBL work in currently in preparation for publication.

In collaboration with Krasnoyarsk, three further intensive campaigns were undertaken in early May, late June and mid-October 1999. Due to delays in flask transportation from Russia to Germany, flask analyses have only been undertaken for the May campaign. This data is currently being processed.

2.3.3. Soil and stem respiration measurements

In collaboration with Dr. Olga Shibistova at the Institute of Forest in Krasnoyarsk, seasonal patterns of soil respiration for the dominant ground cover types in both forest and bog at Zotino were determined from early April 1999 to late October 1999.

Diurnal patterns, especially in the forest, showed a strong dependence of ground cover type on observed rates, with the soil respiration rates in forest glades typically being lower than in shaded areas under trees (Fig 2.3). This was despite higher soil temperatures. These different rates are most likely a consequence of differences in soil carbon and/or nitrogen densities and soil cores where taken from sampled areas throughout the year for subsequent analysis of microbial and total carbon and nitrogen densities. These analyses are currently being undertaken by Dr. Shibistova.

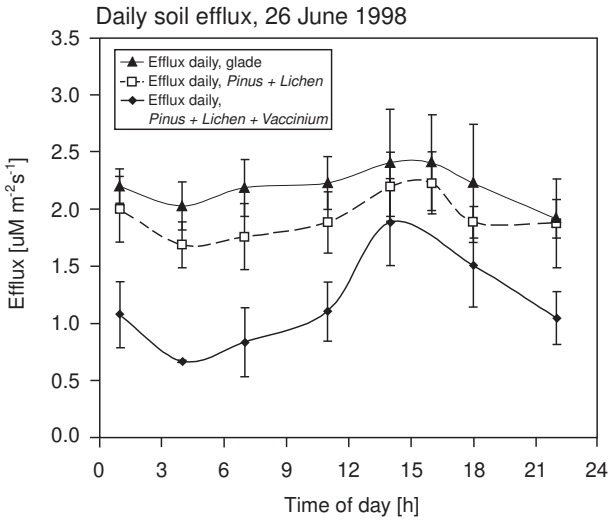

Fig 2.4: Daily soil efflux of different patches on the forest floor

A marked seasonal pattern in soil respiration rates was observed for both bog and forest (Fig 2.5).

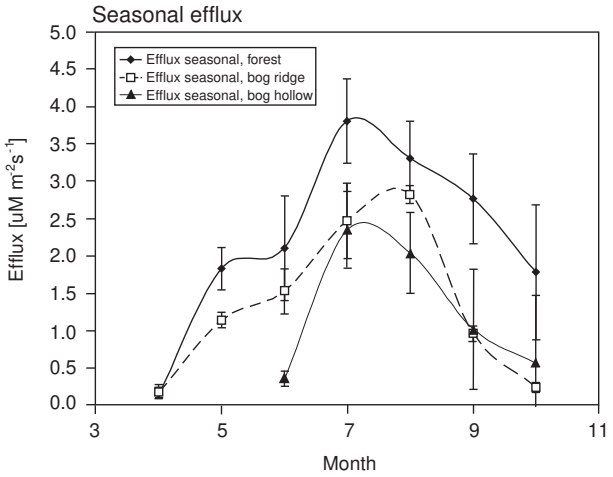

Fig 2.5: Seasonal efflux in bog and forest

Although mostly accountable for by variations in soil temperature, notable exceptions were observed, especially for the forest. Here, a substantial efflux of CO2 was consistently observed in May; despite soil temperatures being close to 0°C. Most likely this was a consequence of enhanced substrate availability and/or enhanced microbial and root activity associated with the freeze/thaw cycle. This phenomenon will be probed further in the 2000 spring campaign. Soil water deficit effects on microbial activity are most likely the reason for a decline in rates in August despite higher soil temperatures. It is hoped that the laboratory samples taken for microbial analysis throughout the year and currently being analysed will shed some light on both these phenomena.

Although of a similar seasonal pattern, soil respiration rates measured directly at the forest floor seem to be consistently higher than those implied by ground level or night-time top-of-tower eddy covariance measurements. This discrepancy has important implications for the carbon balance of this and other forests . It's basis is currently being investigated.

Soil respiration measurements where also undertaken along a logging chronosequence (Dr. Shibistova). This showed a complex relationship between soil respiration rates and time after logging. Soil respiration rates seem to show some stimulation after the initial land clearance, but after this a gradual decline with age is occurs. This decline is reversed around 25 years after harvest with soil respiration rates again increasing with stand age. Soil and root samples taken at time of measurement for all stands are currently being analysed in order to explain these observations in terms of the underlying root and soil carbon densities. The logging

chronosequence soil respiration data was used to calibrate a model of logging on Siberian forest Net Ecosystem Productivity also presented at the AGU meeting in San Francisco in December 1999.

Stem respiration measurements where also initiated in the forest stand in Zotino in 1999. These showed stem respiration to be a small but significant component of the total respiration of these stands (ca. 15%).

2.3.4. Modelling

Eddy-covariance data were used to calibrate a „big-leaf" model of canopy gas exchange for the Zotino pine stand. Using one full year's data from the meteorological station at the top of the Zotino forest tower, the model was then used to simulate the annual course of photosynthesis. The model was run both with and without an incorporation of an observed inhibition of photosynthesis by low soil temperatures in spring (Fig E). This simulation yielded the first data-based estimate of Siberian forest GPP of about 40 $molCm^{-2}yr^{-1}$. Scaled across the Siberian forest area, this would result in a GPP of only about 0.3 Pmol C yr^{-1} (*ca.* 4 $GtCyr^{-1}$). This is less than one-third of some model estimates. If correct, such a low GPP would virtually preclude the Siberian forest region as a substantial sink for anthropogenically released CO_2.

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3.2. Summary:

Within the second year of the project we improved our continuous measurement devices and sampling strategy for continuous CO_2 observations as well as the flask spot sampling system for the analysis of CO_2, CH_4 and N_2O concentrations and CO_2 stable isotopes at the Fyodorovskoye forest reserve: (1) Based on the experience from the 1998 summer campaign a cryo-cooling system prior to the chemical drying was implemented in the sampling lines. This allowed very efficient drying of the sample air combined with quantitative (99.8%) collection of water vapour for $\delta^{18}O(H_2O)$ analysis. (2) We reduced the 16 m sampling line to 1.8 m (for continuous CO_2 and ^{222}Radon observations, flasks spot sampling at 2 hour time resolution), and, in order to provide better canopy profile information, we added two more lines at 0.8 m and 0.1 m height for flask sampling at 4 hour (July '99) and 2 hour (October '99) time resolution.

High resolution flasks and continuous CO_2 concentration measurements at two different heights showed strong diurnal variations for both, CO_2 mixing ratios and CO_2 stable isotope ratios. The amplitude and variability of the diurnal signals increased from the top of the canopy (26 m) to the 1.8 m level. Correlation of continuous CO_2 and ^{222}Radon measurements yielded a mean CO_2 night-time flux of 14.09±4.93 mmol m^{-2} h^{-1}. The $\delta^{13}C(CO_2)$ source signature at 26 m height showed values of –24.73±0.4 ‰ during the day and –26.82±1.5 ‰ during the night, reflecting the discrimination of $^{13}C(CO_2)$ during photosynthetic uptake. $^{18}O(CO_2)$ shows considerably more depleted source signatures during the night than during the day. The respective processes need to be further investigated when $\delta^{18}O(H_2O)$ data of plant material and soil water become available.

As a logistical contribution to the project IUP co-ordinated the two intensive campaigns (July 1999 and October 1999, Fyodorovskoye forest reserve) in co-operation with IPEE, Moscow. IUP was also responsible for the preparation and conditioning of all new regular flight flasks (in total ca. 1300) and preparation of intercomparison flasks to be distributed regularly to all flask analysing groups.

3.3. Objectives:

1. Perform a number of intercomparison exercises for high precision atmospheric trace gas concentrations (CO_2, CH_4, SF_6, ^{222}Radon) and analysis of stable isotope ratios of CO_2 (WP1)
2. Trace gas and isotopic analysis of regular vertical aircraft samples collected over Eurosiberian Region, Syktyvkar (WP1)
3. Technical improvements of the instrumentation used during the intensive campaigns at Fyodorovskoye (WP2)
4. Completion of two intensive campaigns at the Tver site including sample analysis and preliminary data evaluation (WP2)

3.4. Methods and Sampling:

3.4.1. Continuous atmospheric ^{222}Radon daughter measurements

See annual report 1998

3.4.2. Continuous atmospheric CO_2 concentration measurements

See annual report 1998

3.4.3. Flask sampling of atmospheric air and analysis of CO_2 and stable isotope ratios, CH_4 and N_2O, water vapour sampling

The flask sampling set-up during the two intensive campaigns in 1999 (July/August and October) was installed in a newly built hut close to the forest tower. As in 1998 air was pumped through Decabon tubing from an upper level at 26 m. Additionally we built a small stage at 15 m distance to the tower, where three Decabon lines were installed to collect air from 1.8 m, 0.8 m and 0.1 m. Preconditioned glass flasks (1.2 liter volume each, for details of the preconditioning procedure, see "Paris Test Campaign Report") were flushed with atmospheric air for at least 50 minutes (air flow about 1.5 l/min) and finally pressurised to 2 bar. The 1.2 liter flushed flasks could only be used for sampling at 26 m and 1.8 m height. For the 0.8 m and 0.1 m levels 300 ml pre-evacuated glass flasks were used for sampling.

Condensation of water vapour within the flask can lead to isotopic exchange of ^{18}O between H_2O and CO_2, therefore samples had to be dried carefully. A cryo-cooling system prior to a chemical drying column (Magnesium Perchlorate) was implemented in the 26 m and 1.8 m sampling lines which reduced the vapour pressure of the air streams to a dewpoint of less than –40°C. The cryo-cooling system consisted of a commercial cryocooler (NESLAB CC-65, disposed by RUG Groningen) combined with specially designed cooling traps. Both, continuous Li-Cor CO_2 in situ analysis and the Heidelberg and Groningen flask sampling systems, were supplied by the same dried air streams.

As the ^{18}O signature of water vapour is an important component of the total ^{18}O balance at the tower site, we used the water vapour samples from cryogenic drying of the air for $^{18}O(H_2O)$ analysis (time resolution: 4 hours). For ambient dew points between 10 and 25°C the cooling traps yield an H_2O sampling efficiency of more than 99.8 %. To allow direct comparison of the flask CO_2 concentration results (by GC) with the in situ Li-Cor data the flask sampling intervals for the 26 m and 1.8 m line were synchronised with the integration intervals of the Licor system. During the whole intensive campaign periods, a time resolution of 2 hours for flask sampling was performed. Flask sampling of the Groningen group (time resolution: 4 hours) was shifted by one hour to further increase sample density.

Stable isotope ratios of CO_2 flask samples were analysed in the Heidelberg laboratory with a Finnigan MAT 252 mass spectrometer, combined with a multiport trapping box for CO_2 extraction [*Neubert,* 1998]. CO_2, CH_4 and N_2O concentrations were measured on the 1.2 liter flasks with an automated HP 5890 series II gas chromatograph equipped with a flame ionisation detector (FID) for detection of CO_2 and CH_4 and an electron capture detector (ECD) for N_2O [*Bräunlich,* 1996]. The reproducibility of these analyses (1σ) is ± 0.1 ppm for CO_2, ± 2.5 ppb for CH_4 and ± 0.3 ppb for N_2O concentration measurement.

3.4.4. Flask and bag sampling and analysis of soil emanation gas for CO_2, CH_4 and ^{222}Radon

During the intensive part of the summer campaign 500 ml aluminium bag samples have been collected regularly from soil respiration gas with the inverted cup method at one site 10 m away from the tower and at a time resolution of 6 hours. A stainless steel frame had been permanently installed in the top soil and covered with a water-sealed top for the actual soil flux measurement (duration: 10 – 15 minutes). In the Heidelberg laboratory, CO_2 and CH_4 mixing ratios were measured on these samples by gas chromatography (Siemens Sichromat 1) [*Born et al.,* 1990]. The same GC was used for analysis of the small flasks collected from the 0.8 m and 0.1 m tower levels. The reproducibility (1σ) for a bag sample analysis of CO_2 is typically ± 2.1 ppm, for CH_4 ± 23 ppb. For flasks sample analysis, the reproducibility is ± 1 ppm for CO_2 and ± 13 ppb for CH_4, respectively.

During the intensive part of the campaigns, samples along a hydrological transect were collected for ^{222}Rn emanation measurements. Samples were collected with the same stainless steel inverted cups as used for the CO_2 soil emanation samples. After transportation to Heidelberg they were measured as quickly as possible for their ^{222}Rn activity in a set of slow pulse ionisation chambers.

3.4.5. Bog study

During the 1999 intensive summer campaign we had the opportunity to perform a short sampling campaign at the bog site of the Fyodorovskoye forest reserve. In combination with chamber flux measurements in the vicinity of the eddy correlation tower air was collected at different heights between the bog surface and the top of the tower (5 m) during the build up of night time surface inversions. The time dependent integrals of the profiles were then used to estimate night time fluxes of CO_2 and CH_4. The results of this pilot study are reported by *Neumann* [1999].

3.4.6. Regular Flights

Flasks from regular vertical aircraft profiles at Syktyvkar have been collected every 3-4 weeks starting in July 1998. Flasks from a whole year of sampling have been analysed now for trace gases and isotope ratios in Heidelberg. In addition, if logistically possible, SF_6 analyses were made on flask samples from the other two sites, Tver and Zotino.

3.4.7. Intercomparisons

- A number of intercomparison exercises have been started already in the beginning of the project. Some will be continued during the whole period of the project, namely:
- Regular exchange of flasks with LSCE-Paris
- Regular exchange of flasks with CSIRO Australia (todate analysing the Jena flasks)
- Ongoing whole-air intercomparison for concentration and isotopic ratios: Heidelberg – Paris – Groningen – Stockholm (– Jena) by use of Round Robin tanks.
- In addition to this intercomparison exercises Heidelberg started a flask intercomparison, distributing regularly to all labs a set of identically flushed flasks with real air in the range of 340 to 450 ppm CO_2.

Finished Intercomparisons:

- Paris flight IC
- Pure-CO_2 intercomparison: Heidelberg – Paris – Groningen (– Jena)

For the results of the intercomparisons see detailed Intercomparison Report (part of EUROSIB 1999 report).

3.5. Results:

3.5.1. Preliminary results from canopy air and chamber measurements at the Tver forest site summer intensive campaign 1999 (July 27th to August 1st)

Diurnal variations of CO_2 concentration and stable isotope ratios at 2 heights (1.8 m and 26 m above ground) within the forest canopy measured on the flask samples are shown in Figure 3.1. Comparison of the flask CO_2 concentration values with continuous CO_2 measurement by NDIR (Li-Cor LI-6251) yields a mean difference (Li-Cor minus flasks) of –0,27 ± 0,38 ppm for the 26 m level and –0,65 ± 6,34 ppm for the 1.8 m level, respectively. The 1998 difference of -0,7 ± 2,3 ppm (at 16 m height) could be improved due to a better synchronisation of sampling and integration intervals of both systems and the supply of sample air by the same air stream. The standard deviation of the mean concentrations measured with the continuous Li-Cor system during a 5 minute interval increased with decreasing height (26 m mean $1\sigma = \pm 0{,}37$ ppm, 1.8 m mean $1\sigma = \pm 5{,}64$ ppm). This can be explained by a much larger variability of the CO_2 concentration near the soil CO_2 respiration source.

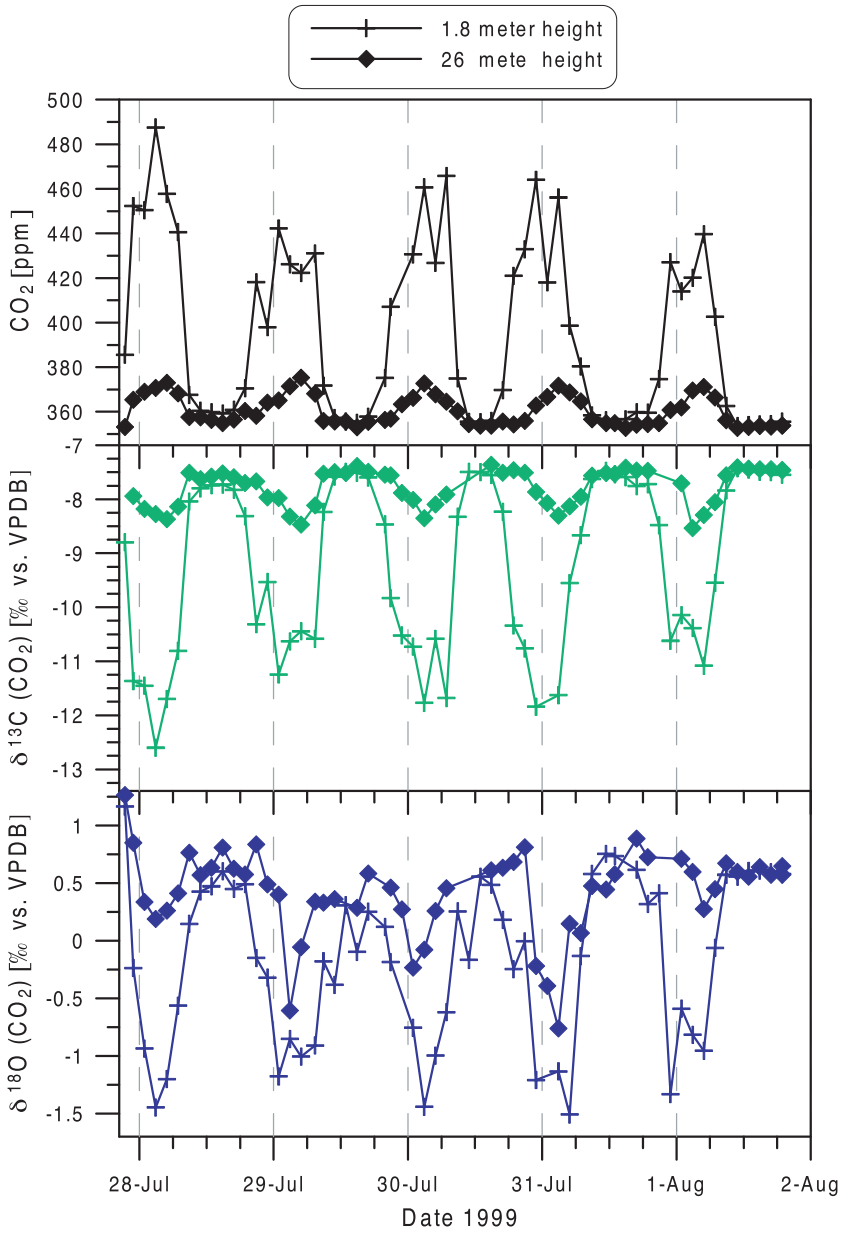

Figure 3.1: Diurnal cycles of CO_2, $\delta^{13}C(CO_2)$ and $\delta^{18}O(CO_2)$ at Fyodorovskoye forest during the intensive summer campaign in 1999.

Depending on the meteorological conditions within the canopy, CO_2 concentration shows a strong diurnal variability with maximum concentrations in the morning and minimum values during the afternoon. During the summer intensive campaign period the CO_2 amplitude of this diurnal cycle at 1.8 m of 70 to 120 ppm shows much more variability than the amplitude at 26 m, which is only about 20 ppm. The respirative source CO_2 signal at 26 m is considerably smoothed by the mixing of PBL air whereas the 1.8 m measurements detect the respirative soil flux to a much greater quota especially when vertical mixing is suppressed during the build up of night-time inversions.

The stable isotope diurnal cycles show an anticorrelated behaviour to the CO_2 concentration variations which is expected for both, $\delta^{13}C(CO_2)$ and $\delta^{18}O(CO_2)$. The mean source signatures derived from the correlation with CO_2 concentration for both heights - distinguished between day-time (concentration decrease) and night-time (concentration increase) - are given in Table 1.

Table 1: Source signatures of the stable isotope ratios, δ_s. (Accepted correlation coefficient r^2 used for the mean values: $\delta_s^{13}C(CO_2)$: $r^2 > 0.95$ and $\delta_s^{18}O(CO_2)$: $r^2 > 0.6$)

	$\delta_s^{13}C(CO_2)$ [‰ vs VPDB]		$\delta_s^{18}O(CO_2)$ [‰ vs VPDB]	
Period	*1.8 m height*	*26 m height*	*1.8 m height*	*26 m height*
Overall	-25.94 ± 0.1	-25.68 ± 0.4	-6.28 ± 0.5	-12.52 ± 2.1
Day-time mean	-24.79 ± 0.5	-24.73 ± 0.4	-6.12 ± 2.9	-11.92 ± 6.9
Night-time mean	-26.39 ± 0.4	-26.82 ± 1.5	-10.93±0.5	-21.95 ± 6.2

Day-time: 7:00 – 19:00

Night-time: 21:00 – 5:00

Continuous CO_2 measurements at 1.8 m and 26 m height allowed calculation of mean night-time CO_2 respiration fluxes via the correlation of ^{222}Radon activity and CO_2 concentration variabilities [Levin et al., 1999]. For this purpose the mean ^{222}Radon source strength had to be determined for the catchment area of the tower site (see 3.4). ^{222}Radon soil emanation fluxes showed a large variability along the hydrological transect which is due to the dramatically changing water table depth. The mean value of all 6 sampling sites was 1642±1752 dpm m^{-2} h^{-1}. Mean night-time CO_2 fluxes of 14.09±4.93 mmol m^{-2} h^{-1} (1.8 m height) and 14.89±3.1 mmol m^{-2} h^{-1} (26 m height) were calculated via the ^{222}Radon - CO_2 - correlation method for the 5 nights of the campaign. Comparison of this value with direct CO_2 soil emanation chamber measurements near the forest tower (time resolution 6 hours, mean flux for campaign period: 10.09±4.06 mmol m^{-2} h^{-1}) shows agreement within 1 σ standard deviation. Still there is a "footprint" problem for the determination of the mean ^{222}Radon source strength influencing the tower measurements, due to the difficulties to weight the spatial heterogeneity of the ^{222}Radon soil fluxes.

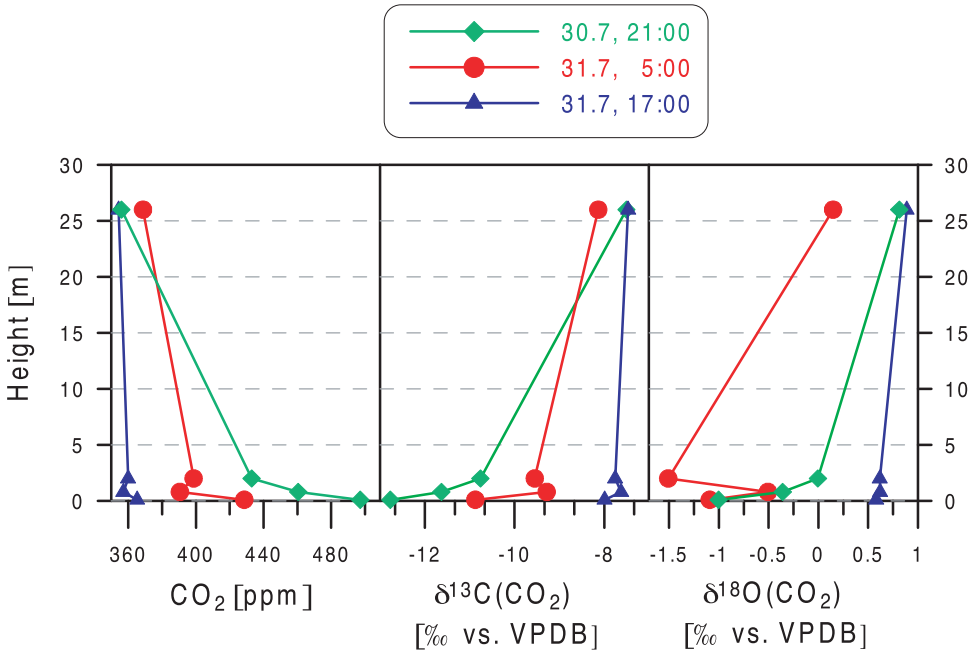

Figure 3.2: Vertical profiles of CO_2, $\delta^{13}C(CO_2)$ and $\delta^{18}O(CO_2)$ within the Fyodorovskoye forest canopy during 30./31. July 1999

Figure 3.2 shows vertical profiles of CO_2 concentration, $\delta^{13}C$ (CO_2) and $\delta^{18}O$ (CO_2) within the canopy at 4 heights (0.1, 0.8, 1.8 and 26 m). The build-up of the night-time inversion is clearly seen in the profile at 21:00, where CO_2 concentrations decrease from about 500 ppm near the soil surface to 360 ppm at 26 m height. At 5:00 in the morning CO_2 concentrations decrease to 430 ppm near the ground and the profile ends with 375

ppm at 26 m; indicating the beginning of vertical mixing at sunrise. The CO_2 concentration profile at 17:00 shows only a weak gradient from 0.1 to 0.8 m of about 10 ppm and stays nearly constant with height up to the top of the canopy with values of about 355 ppm. The temporal development of the stable isotope vertical profiles show a similar behaviour with strong gradients during the night-time inversion and well mixed profiles during day-time.

3.6. Work plan for 2000:

- Regular Flights:

  All flasks from regular flights at Syktyvkar will be analysed for trace gases in Heidelberg. In addition, if logistically possible, SF_6 analyses will be made on flask samples from the other two sites, Tver and Zotino.

- Intercomparisons:

  The following intercomparison exercises will be continued throughout the third year of the project, namely

  - Regular exchange of aircraft flasks with LSCE Paris
  - Regular exchange of flasks with CSIRO Australia
  - Preparation and distribution of intercomparison flasks to all labs

- Completion the 1999 October flask sample analysis
- Interpretation and modelling of the intensive campaign data
- Preparation of final project report

3.7. References: (*Thesis prepared within this project)

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4.2. Inversion of mean fluxes over Siberia from atmospheric CO_2 data.

4.2.1. Inversion of interannual changes in CO_2 fluxes

We have developed an inverse model to retrieve the net CO_2 fluxes every month from 1980 to 1998. We divide the land surface into 11 regions and the ocean surface into 8 regions with regional fluxes being assigned a priori monthly values, monthly uncertainties and spatial patterns. We next calculate the atmospheric CO_2 distribution caused by atmospheric transport acting on a "pulse" source of one GtC emitted at a constant rate by region *i* during month *j*. We do this for all regions in a 3D global transport model, and archive the resulting CO_2 concentration field for the following two years. This concentration pattern, initially with a maximum over the source region, progressively becomes uniform in the atmosphere, as CO_2 emitted over the source region gets diluted globally by the atmospheric transport. Let $B_{ij}(\mathbf{x})$, $O_{ij}(\mathbf{x})$ and $F_{ij}(\mathbf{x})$ denote respectively the land and oceanic, and the fossil CO_2 concentration patterns induced by region i at month j, the modeled spatial CO_2 pattern P caused by all sources (Nregions and Nmonths) is

$$P = \sum_{i=1}^{Nregions} \sum_{j=1}^{Nmonths} (\beta_{ij} B_{ij} + \omega_{ij} O_{ij} + \phi_{ij} F_{ij})$$

The coefficients ϕ_{ij}, corresponding to the regional magnitude of fossil emissions are set to fixed monthly values, based on fossil fuel emissions statistics. We solve for thecoefficients β_{ij} and ω_{ij} in order to minimize a cost function based on the distance between the modeled and the observed CO_2 concentrations at the location of monitoring sites (*12*). Note that the value of β_{ij}, reflects the sum of land use and of other biospheric carbon sources and sinks. The atmospheric data used for the inversion are monthly atmospheric CO_2 measurements at 67 monitoring sites, over the 1980-1998 period, that have been smoothed in the time domain to remove synoptic variability. An increasing number of stations are progressively being assimilated in the inversion, from 20 sites in 1980 up to 67 sites in 1997, with a marked increase in the number of stations during the late 1980s. Data uncertainties are estimated each month at each station from raw flask measurements and from instrumental errors.

In addition to the control inversion described above, we carried out a sensitivity study consisting of 7 inversions where key parameters are varied individually, which provides *a range of uncertainty* on the inferred fluxes. The sensitivity study is performed to better account for uncertainties not represented in the inverse procedure which only returns *a residual uncertainty* . The inferred flux anomalies are substantially similar among our sensitivity tests, suggesting that flux anomalies are more robustly retrieved than long term

mean fluxes. The latter are inferred from mean spatial concentration differences among stations, which are rather small within a given latitude band. For instance the apportionment of sources and sinks between North America and Eurasia relies on spatial mean differences on the order of 0.5 ppm at mid northern latitudes. In contrast, flux anomalies for these regions are inferred from temporal changes of concentration differences between stations, which are larger than the spatial mean differences in longitude.

4.2.2. Changes in carbon balance of Siberia and North America

During the early and mid 1990s, Northern Hemisphere lands dominantly influence the carbon flux anomalies. A strong drop in growth rate occurred in 1992/93 at mid-northern latitudes. We invert this signal into an enhanced terrestrial uptake over the Northern Hemisphere continents. Terrestrial carbon storage increased there by 1.4 GtC between 1989/90 and 1992/93 (Figure 4.1), in accordance with previous analysis of atmospheric carbon isotopes and oxygen data. Our regional inversions locate the 1992/93 enhanced terrestrial sink predominantly over North America (Figure 4.1) . This striking result is also directly visible in the CO_2 observations of the annual mean difference in CO_2 concentration between Atlantic and Pacific stations, which relates to the North American carbon balance. The Atlantic stations were 0.4 ppm higher than the Pacific ones in 1990, but became 0.6 ppm lower in 1993. The enhanced North American uptake in 1992/93 is robustly inferred by the 7 sensitivity inversions. Between 1989 and 1993, North American and Eurasian carbon fluxes are anti-correlated (r = -0.65) but the enhanced uptake over North America remains on average three time larger than the reduced uptake over Eurasia. Furthermore, the error correlation estimated by the inversion between those two regions is not significant (r = -0.35), which indicates that the present atmospheric network is able to correctly separate anomalous changes in Eurasia vs. in North America.

In contrast to North America, the inverted carbon balance of Siberia was more stable over the 1990's (Figure 4.2). Whether this is real or due to less stations there is still unclear, and will be clarified by new atmospheric data collected within EUROSIBERIAN CARBONFLUX. When looking at the net fluxes inverted from the atmospheric observations, it is apparent that there are some interannual variations of the summer time uptake of carbon by Siberian ecosystems, but little changes from one year to the next in the wintertime respired fluxes. It is also evident that the seasonal cycle of the flux inverted from atmospheric CO_2 measurements is much larger north of 50°N than south of 50°N. This feature is not reproduced correctly by the biogeochemical model CASA-SLAVE shown as an example on Figure 4.2. Again, new data being collected over Siberia will help to resolve the flux seasonal cycle in atmospheric inversions.

4.2.3. Regular biweekly profiles in Fedorovskoye, July 1998 - October 1999

We have analyzed flasks taken during regular vertical profiles at Fedorovskoye. The flask data for CO2 were compared to the continuous profiles obtained with the LI-COR built by MPG-Jena. Unfortunately, because of problems in the air intake system and of bad weather conditions during the winter 1998/99, no flasks were available between August 1998 and May 1999. The data collected so far indicate that the CO_2 seasonal cycle at Fedorovskoye in the free troposphere (ca 3000 m) does not differs from the one measured over Orleans in Western Europe (Figure 4.3). New data into 1999 will allow better comparison of the seasonal cycle and mean CO_2 value between Western and Eastern Europe.

4.2.4. Intensive campaigns at Fedorovskoye, 25 May-28 May, 28 July- 02 August 1999 and 22-25 October 1999

LSCE carried out two intensive campaigns at the forest site of Fedorovskoye. Both campaigns were organized jointly with Uni-Heidelberg. During each campaign, LSCE sampled vertical profiles in the atmosphere from above the canopy (50m) up to 3 km in the atmosphere using an Antonov-2 aircraft. Flasks and continuous LI-COR data were collected (Figure 4.4). In July 1999, we have also operated ^{222}Rn monitor in the aircraft. Verctical profiles were taken at three distinct time of the day (morning, midday, late afternoon) to budget CO_2 in the atmospheric boundary layer. Aircraft sampling was synchronous with ground sampling of leaves, needles and litter every 4 hours, soil cores (< 1m), soil water and litter once a day, and with canopy CO_2 measurements by Uni-Heidelberg. The prime objective of the isotope sampling programme is to characterize diurnal variations of leaf water isotopes. We have found that :

1. the observed diurnal variation of δ18O in leaf water is incorrectly predicted by the steady state approximation equation commonly used in global models. A non steady state model of the $d^{18}O$ in leaf water is however suitable to reproduce correctly $d^{18}O$ diurnal changes in leaves and needles.
2. Unlike during the first 1st intensive campaign in August 1998 (described in the previous report), in August 1999, the presence of an unsaturated layer in the top soil enabled us to sample $\delta^{18}O$ in the soil depth. A persistent difference of 2 ‰ between the top soil and 1 m depth was observed.
3. In October 1999, needles showed no changes in $\delta^{18}O$ over the course of one day, indicating reduced activity (Figure 4.5). They were however still 10‰ enriched compared to ground water $\delta^{18}O$, indicating a residual transpiration flux, as confirmed by eddy-correlation measurements on top of the flux tower.

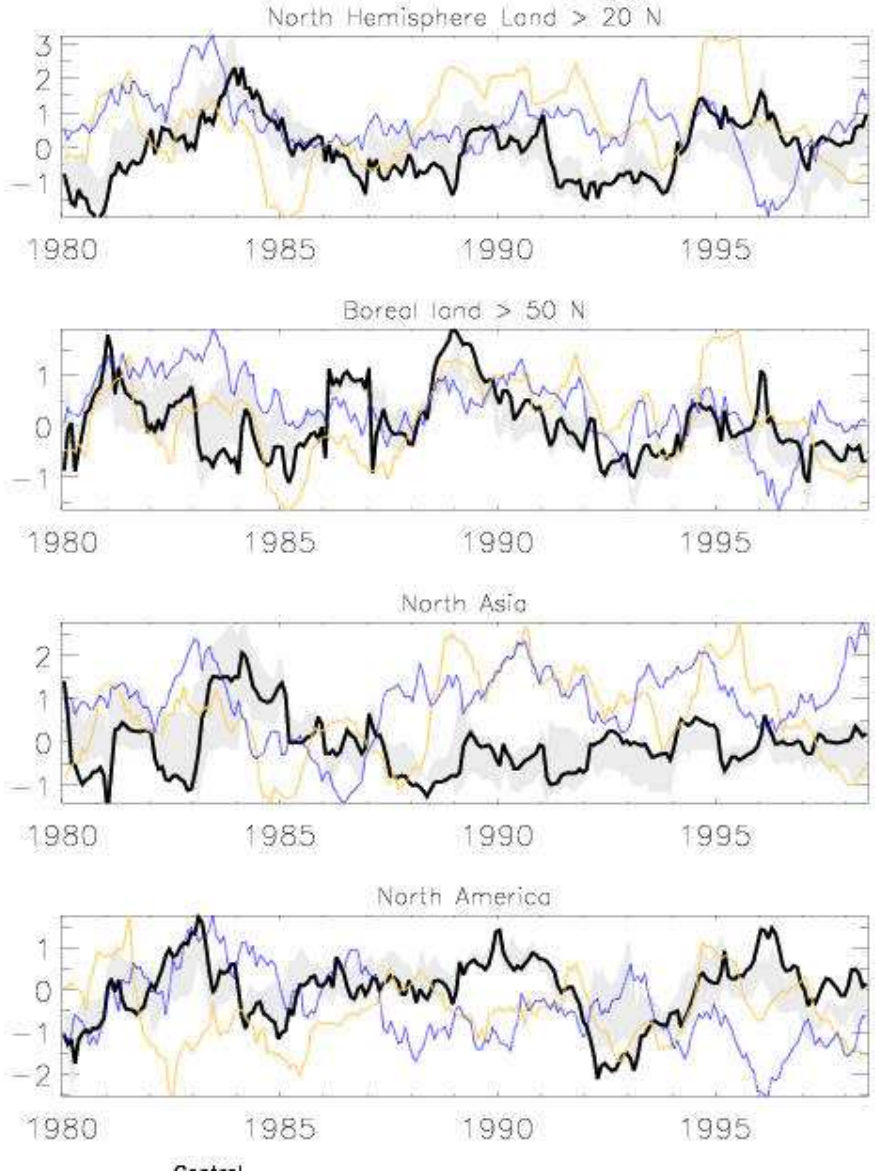

Figure 4.1. Carbon balance anomalies of Northern Hemisphere continents after 1980. All results are anomalous fluxes with a 12-point running mean to remove the seasonal cycle. Black line is the average of the 8 inversions. Shaded area is the envelope of the results from 8 sensitivity inversions. Yellow = temperature anomalies, Blue = precipitation anomalies

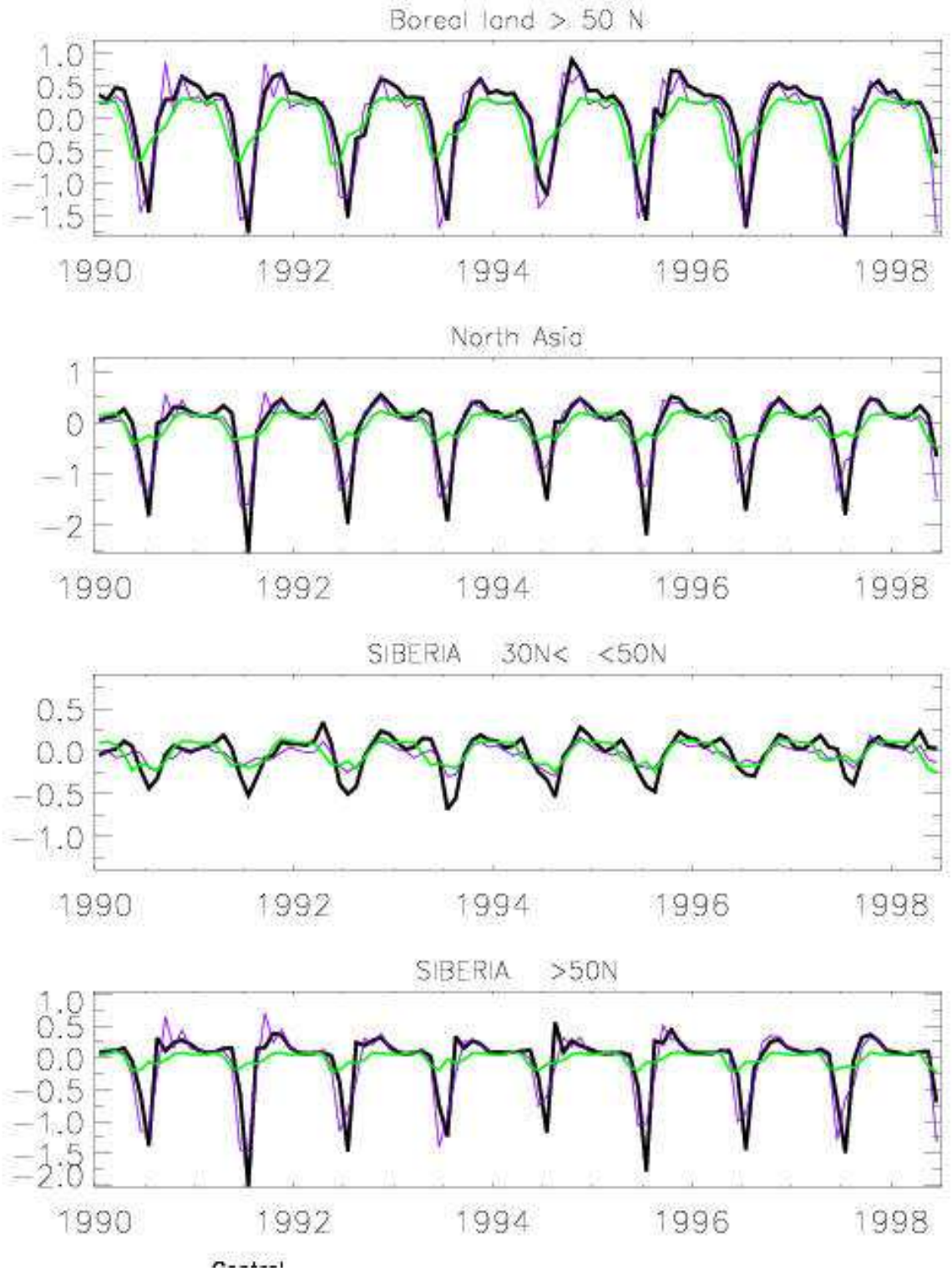

Figure 4.2. From top to bottom. Interannual anomalous variations in the carbon balance of boreal forests, Siberia, bemperate Siberia and boreal Siberia. Inversion results using TM2 = black line. Inversion results using TM3 = purple line. Biogeochemical model (CASA-SLAVE) prediction = green line.

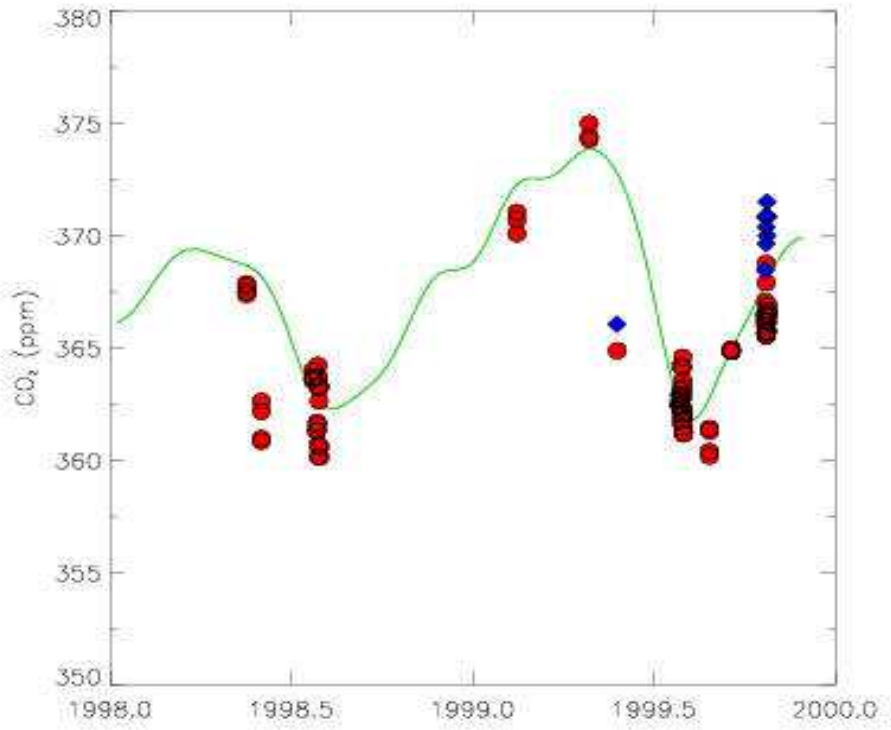

Figure 4.3. Seasonal cycle of CO2 over Fedorovskoye, Russia from flask (red) and in situ LI-COR data coincident with the flasks (blue). The green line is a fit to the seasonal cycle of CO_2 over Orleans, France

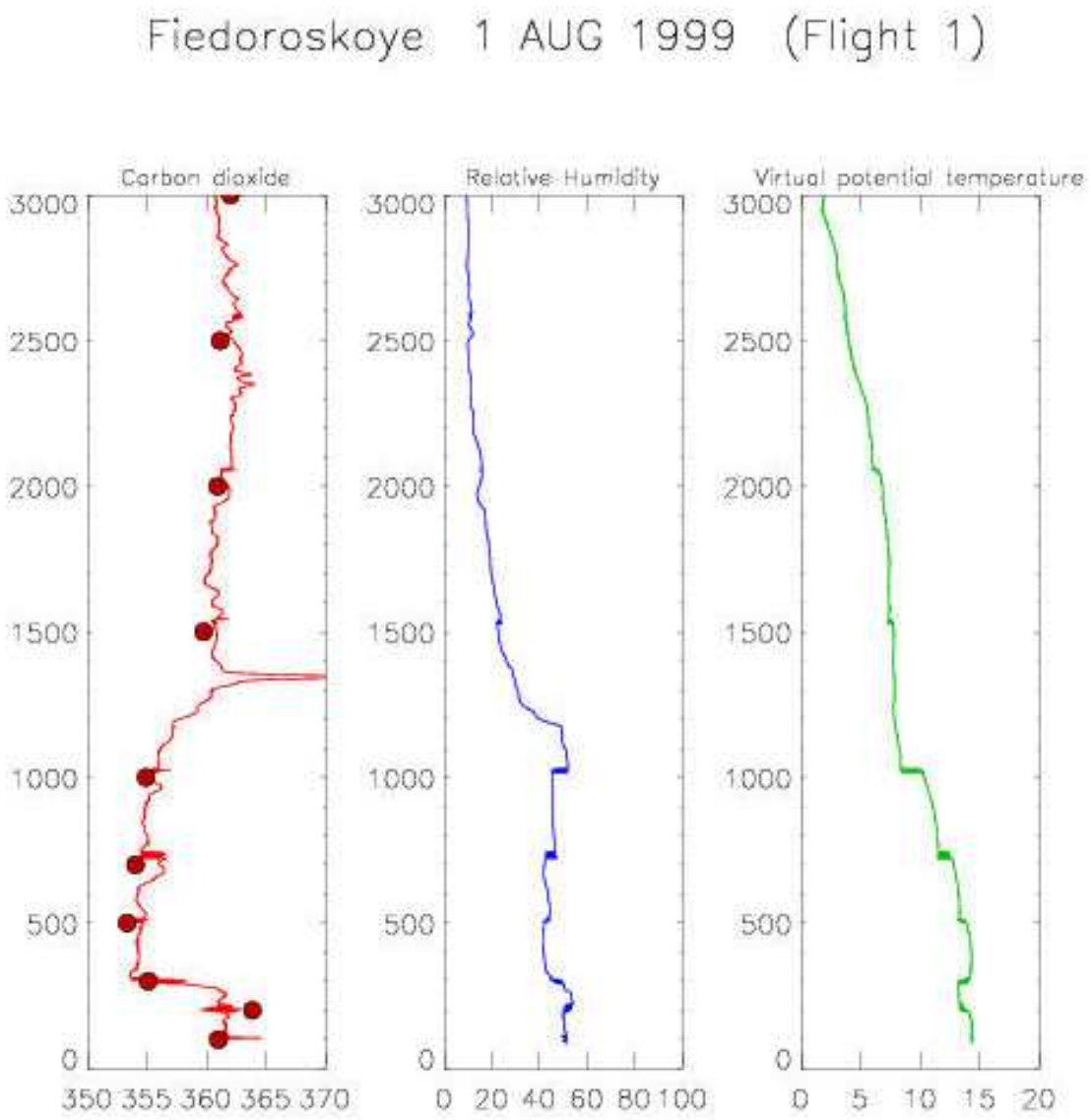

Figure 4.4. Example of CO_2, water vapor and virtual potential temperature vertical profiles over Fedorovskoye, local time 9:00 AM. Flask data in red dots (LSCE) are shown together with CO_2 measured in-situ by an IR instrument (MPG-Jena).

5. UPS Université Paul Sabatier / Centre d'Études Spatiales de la Biosphère (CESBIO), Toulouse

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5.2. Objectives

CESBIO is in charge of the development of high resolution surface CO_2 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 Ecosytem Productivity (NEP) at a daily time step. This task is performed in close collaboration with LET (L. Kergoat) 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 (see previous intermediate report).

5.3. Methods

5.3.1. Models

Net Primary Productivity is inferred using the TURC[2] model developed by Ruimy et al. (1996) in the framework of ESCOBA-Biosphere. TURC is a diagnostic model, driven by low resolution (≥ 1km), high repetitivity satellite data acquired in the shortwave domain.

TURC computes NPP as the difference between photosynthesis (i.e. 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. Biomass is derived from the Olson's global map of vegetation biomass.

Time varying inputs of the model are the incoming solar radiation (300-4000 nm), air and soil temperature and satellite vegetation index (NDVI). NDVI is used to estimate the fraction of incoming photosynthetically active radiation (fPAR) that is absorbed by vegetation and leaf biomass. Solar radiation and air temperature are derived from general circulation models of the atmosphere, respectively ECMWF for global scale and REMO for runs over Eurasia.

Heterotrophic respiration (R_h) is estimated by using a Q_{10} parameterization that relates carbon release to temperature. This parameterization is calibrated by assuming that over one or several years R_h balances *NPP* (zero net ecosystem productivity) for each grid cell of the model. In the following, we will call TURC the set of NPP (i.e. original TURC) plus Rh models. Since the REMO driven TURC simulations are available from April to October only, we first used ECMWF driven simulations to compute the ratio of April-October NPP to annual NPP. Then, we assumed that this ratio is similar for REMO calculations of NPP. The ratio of April-October R_h to annual R_h from the ECMWF driven TURC is used for the REMO driven TURC likewise.

5.3.2. Data

In the previous stage of the projet (see 1999's intermediate report), the TURC model was run at a weekly time step for the years 1989 and 1990, using GEWEX-SRB global dataset for solar radiation, NOAA/AVHRR datasets for fPAR and Leemans and Cramer (1991) climatology corrected by Spangler and Jenne data (1990) for temperature.

TURC is now run daily for the period April 1998 - September 98 with different datasets. Solar radiation and air temperature are now derived from two atmospheric models, respectively REMO for the Eurasia area and ECMWF for the whole of the Earth. As a first step, the radiation fields have been corrected to match the SRB measurements. REMO resolutions are 0.5x0.5° for space and 6h for time. ECMWF temporal resolution is also 6h, but grid-cells are 1x1°**.** These data are accumulated or averaged to produce daily inputs for TURC.

fPAR is now retrieved from SPOT4-VEGETATION data instead of NOAA/AVHRR. SPOT4 was launched on March 24st 1998 and the first image was taken on friday 27 March, 1998. The Vegetation system was funded by the European Commission, Belgium, Sweden, Italy and France. The VEGETATION cameras cover a wide field of view of 101° producing a swath width of 2 250 km. The nominal resolution is 1.165 x 1.165 km. Measurements are performed in four spectral bands, namely blue (0.50 to 0.59 µm), red (0.61 to 0.68 µm), near infrared (0.78 to 0.89 µm) and shortwave infrared (SWIR) (1.58 to 1.75 µm). Nearly every point on the earth is observed at least once a day. In the framework of the VEGETATION preparatory programme, the CTIV[3] supplied us with global ten days synthesis (S10) at both 1 and 4 km resolution, plus the so-called P-product over approximately 500x500 km areas centered on Fyodorovskoye (56°N, 33°E, Fig. 5.1) and Zotino (60°N, 90°E) sites. Both S10 and P-product are geometrically corrected, while only S10 products are corrected for atmospheric effects. The results presented here were obtained from S10 products at 4 km resolution that we further averaged at 0.5° resolution.

[2] *Terrestrial Uptake and Release of Carbon*

[3] *Centre deTraitement des Images VEGETATION (Vegetation imagery processing centre), Mol, Belgium*

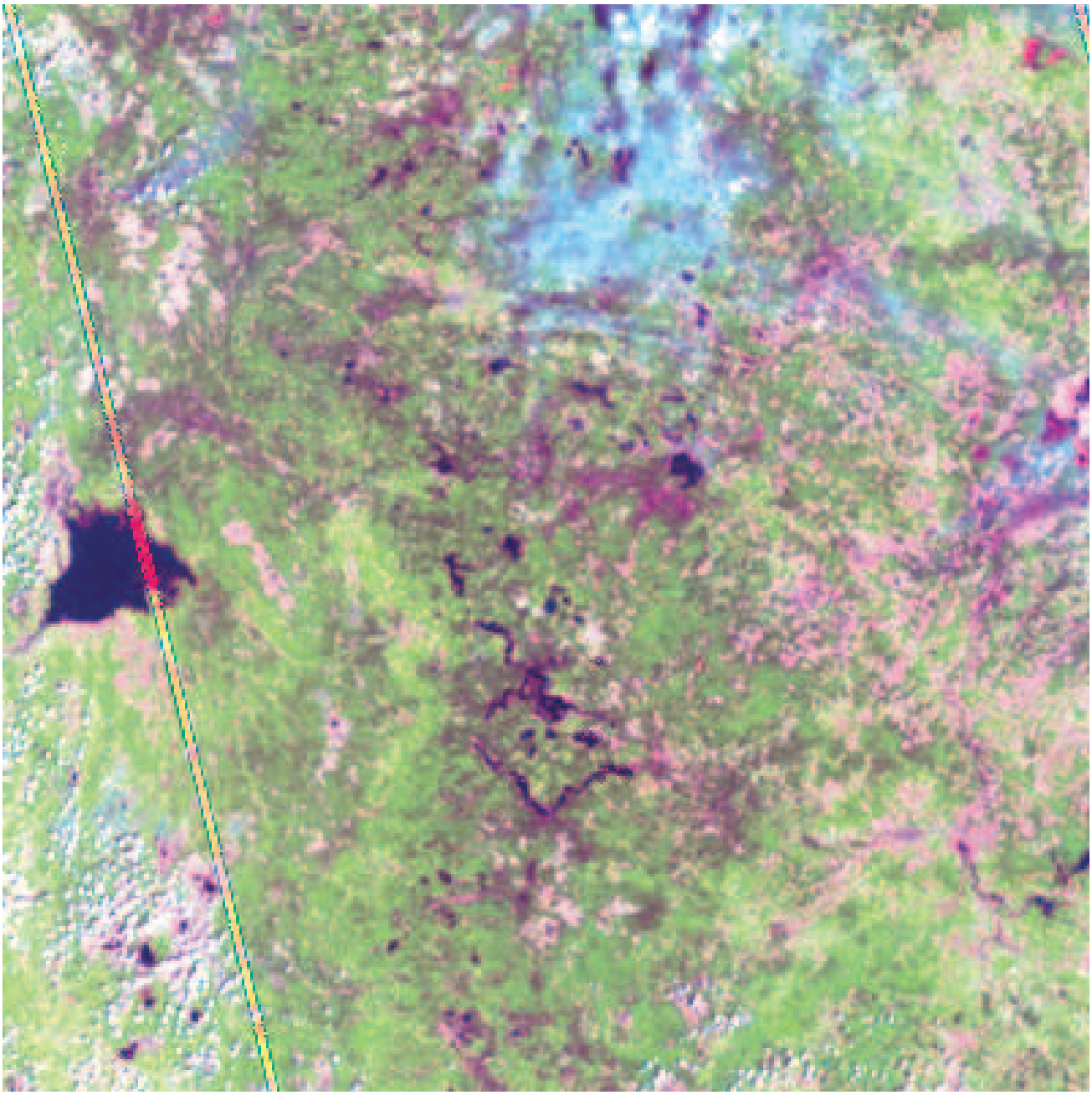

Figure 5.1: *Composite image of Fyodorovskoye on July 13th 1998. The image covers 429 by 570 km. (red color is used for shortwave infrared channel, green color for near infrared channel, and blue for red channel). Forests appear in dark green, bogs appear in light pink, lakes and rivers appear in black.*

5.4. Performed work : 1999

We produced daily estimates of Gross and Net Primary Productivities, autotrophic and heterotrophic respirations, and net carbon flux at both regional, i.e. the eurasian continent, and global scale.

Indeed, carbon flux estimates are needed at both global and continental scales. First, estimates over the Eurasian continent are intended to run the regional, fine resolution, atmospheric circulation model (REMO). The CO_2 transported by REMO will be compared to in-situ measurements of CO_2 atmospheric mixing ratio. Global estimates of carbon fluxes are also required for runs of the global atmospheric transport model (TM3) used to prescribe inputs and outputs of CO_2 at the border of the regional model. Lastly, finer scale study zoom over the two project sites of Fyodorovskoye and Zotino are intended to test and improve carbon models and up-scaling techniques.

In addition to the work described hereafter, CESBIO hosted the annual meeting of the project (12-15 april 1999). Also, S. Lafont contributed to ground experiments in Fyodorovskoye.

5.4.1. Eurasian continent

Net CO_2 fluxes from the REMO driven TURC simulations are shown in figure 5.2 and 5.3. Daily flux is very sensitive to solar radiation. For example, carbon release to the atmosphere is usually associated with cloudy conditions.

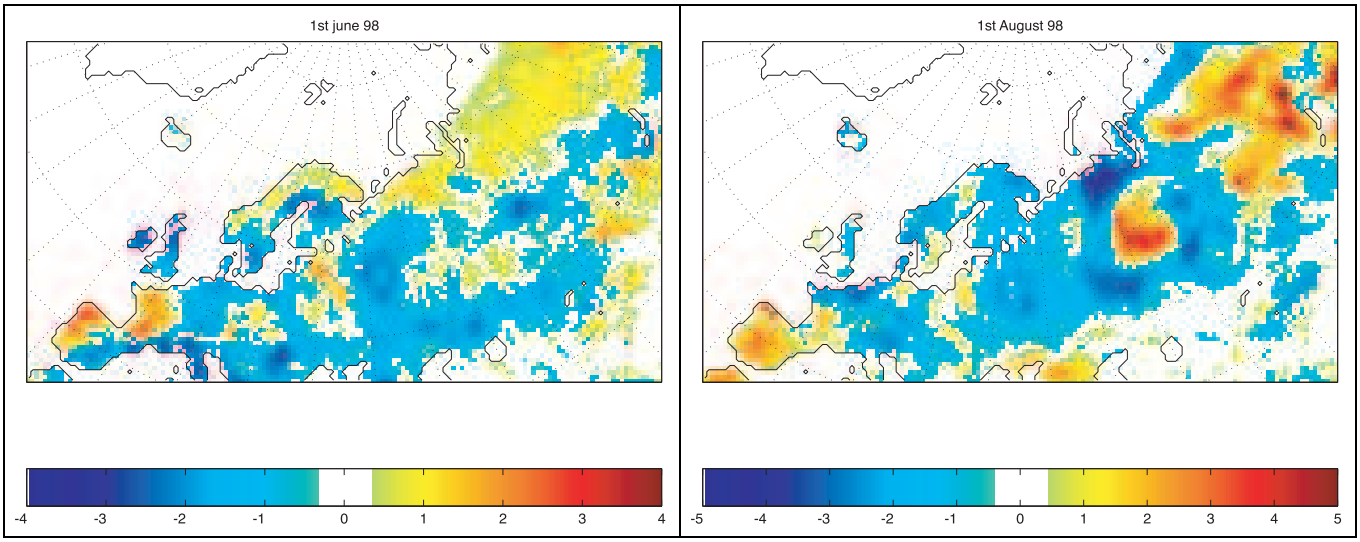

Figure 5.2: *Daily net biospheric carbon exchange for June 1st (left) and July 1st (right), 1998 (Net primary productivity minus heterotrophic respiration). Unit is g[C].m^{-2}. Negative (resp. positive) values correspond to uptake (resp. release) of carbon by the land. The geographic projection is the one used by the REMO atmospheric model, the resolution is 0.5x0.5°*

The monthly net flux, displayed in Fig 5.3 for June, is much more homogeneous, because clear and cloudy conditions are averaged.

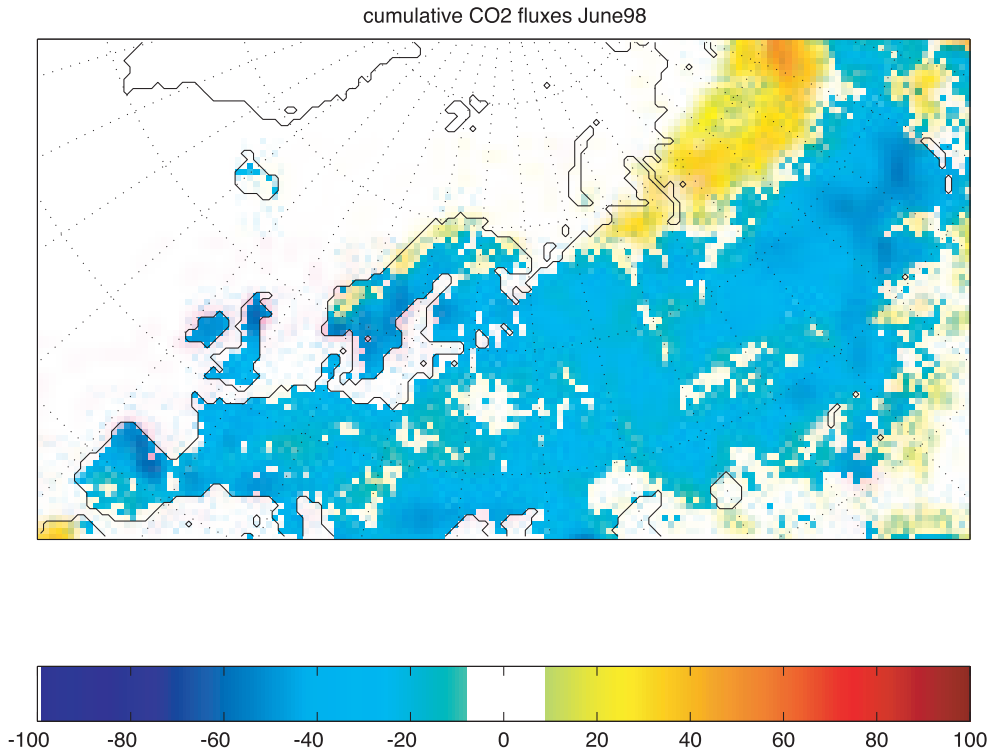

Figure 5.3: *Monthly net biospheric carbon exchange for June 1998 (Net primary productivity minus heterotrophic respiration). Unit is g[C].m^{-2}. Negative (resp. positive) values correspond to uptake (resp. release) of carbon by the land. The geographic projection is the one used by the REMO atmospheric model, the resolution is 0.5x0.5°.*

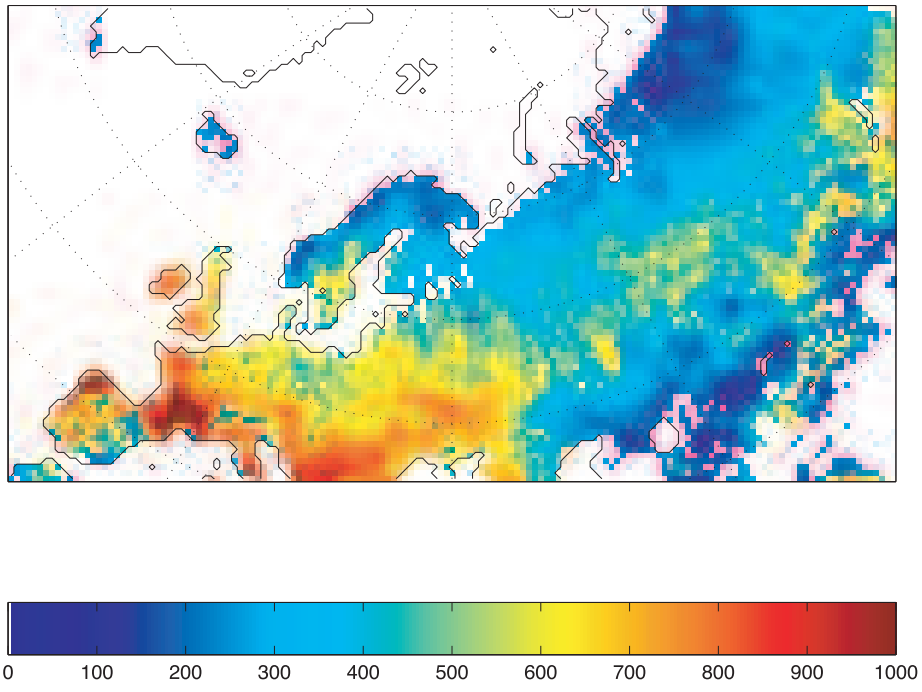

Figure 5.4 *: Cumulative NPP of REMO driven simulation between april and october 1998. Unit is g[C].m^{-2}.*

5.4.2. Global

In order to prescribe carbon dioxyde concentration at the boundary limits of the REMO model, TURC was run with global ECMWF meteorological fields. The global NPP, shown on figure 5.5, is similar to the published results of Ruimy et al. (1996).

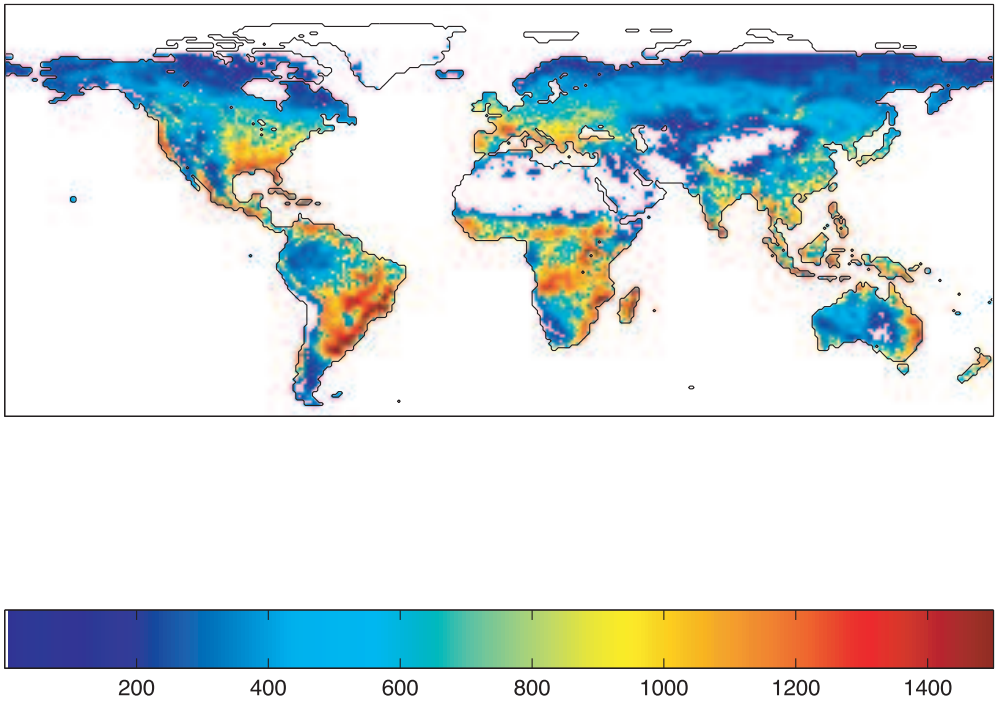

Figure 5.5: *Annual NPP from the ECMWF driven TURC model. Unit is g[C].m-2.*

The estimated global *NPP* is 66.2 Gt C/yr for 1998. As in Ruimy et al. 1996, there is a sharp contrast between tropical grasslands and forests. Over the REMO area, the ECMWF driven TURC and REMO driven TURC produce very similar NPP (Fig. 5.6a). The net CO_2 fluxes over the April-October period are correlated, the slope is very close to 1 (Fig. 5.6b). Discrepancies of the two estimates are due to differences of REMO and ECMWF air temperatures.

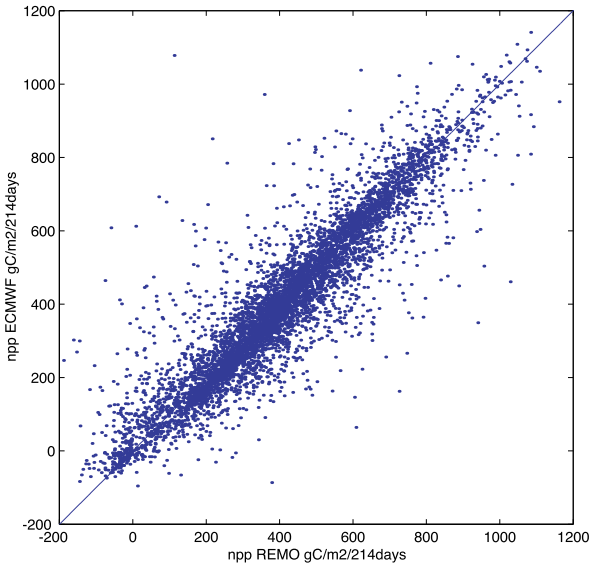

Figure 5.6a: *comparison of NPP estimates produced with ECMWF and REMO meteorological fields.*

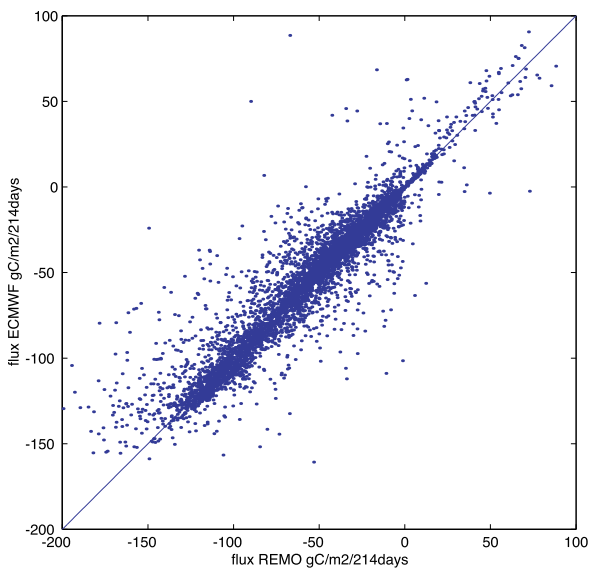

Figure 5.6b: *comparison of net biospheric CO_2 fluxes produced with ECMWF and REMO meteorological fields.*

5.4.3. Local

The comparison of TURC results with local tower CO_2 flux measurements from Fyodorovskoye and Zotino aims at checking/calibrating and improving the model, especially for regional simulations. Figure 5.7a and 5.7b show the REMO driven TURC outputs for a 0.5x0.5° grid-cell over every site. The net CO_2 flux is much lower than the other components of the carbon budget. Days with a positive carbon balance (= C source) are frequent in summer and fall.

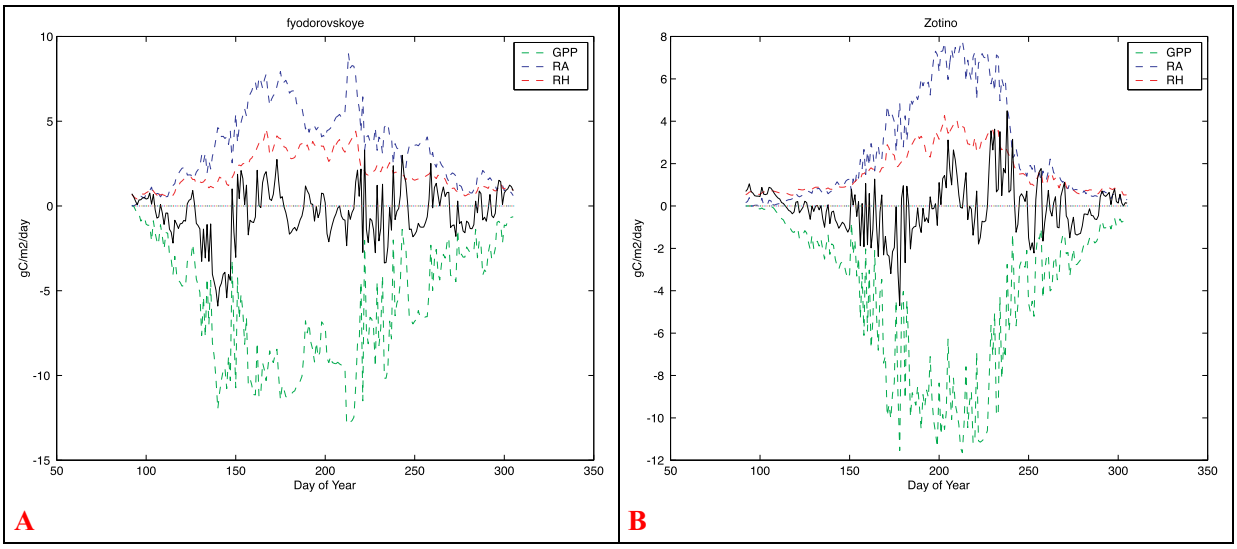

***Figure 5.7**: Daily REMO driven TURC outputs for a) Fyodorovskoye site and b) Zotino site. Black solid line is net carbon flux.*

Figure 5.8a and 5.8b show cumulative net CO_2 flux for 1998 over the two sites. The modeled flux for a 0.5° degree grid-cell is compared to the fluxes measured for the bog and forest subsites. The measured fluxes are derived form Shultze et al. 1999. It is difficult to conclude on the validity of TURC results from this comparison since the in-situ measurements do not integrate over a 0.5x0.5 degree cell. A specific work with high resolution data is planned to further analyse model results.

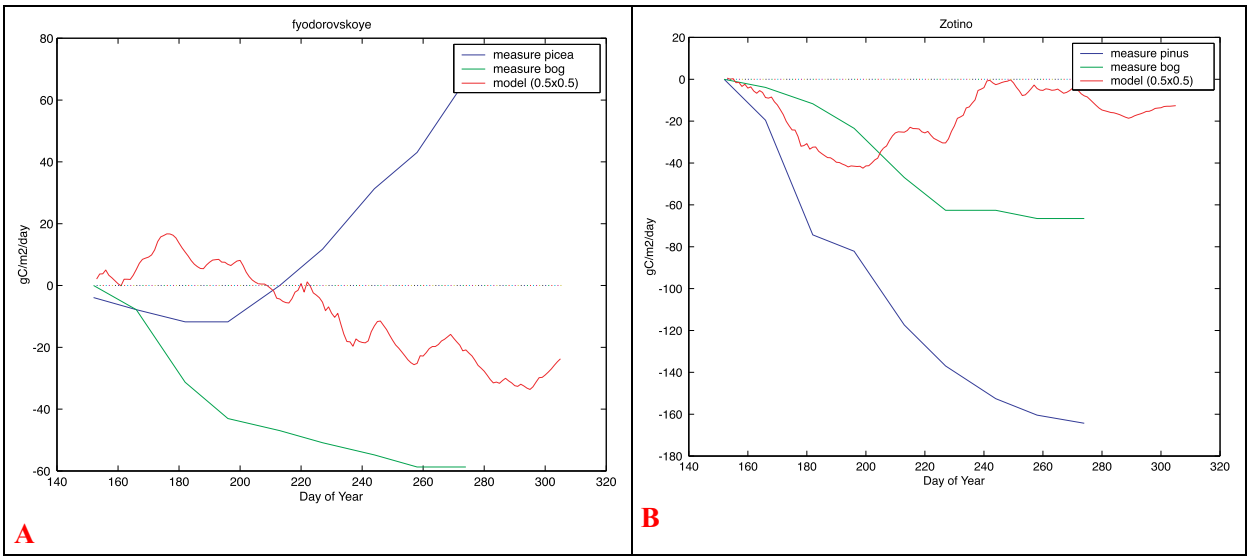

***Figure 5.8:** Measured and modeled (red) cumulative net CO_2 fluxes for a) Fyodorovskoye site and b) Zotino site. For both sites, measures for bog (green) and picea (blue) are presented.*

5.5. Work plan 2000

We plan three main activities for the year 2000.

First, our estimates of carbon exchange at the surface will be used as *a-priori* fluxes by atmospheric transport models operated by project partners. We also plan to improve the heterotrophic respiration parameterization by slowing respiration rate when soil moisture decreases as well as photosynthetic assimilation by taking into account the short term history of freezing days.

Second, ECMWF and REMO solar radiation estimates will be further analysed and compared to Gewex-SRB and in-situ datasets, in order to establish if they can be used without correction. This is an important point for the coupling of atmosphere and biosphere models.

Third, the TURC model will be run with 1km resolution VEGETATION data over Fyodorovskoye and Zotino sites in order to make more significant the comparison of model results to ground measurements. Land cover around (50x50 km) these sites will be determined from the analysis of high resolution satellite images (SPOT).

5.6. References

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6.2. Objectives

For every quantity of CO_2 produced from fossil fuel burning a certain amount of oxygen is used, depending on the kind of fuel. The same is true for biospheric CO_2 release and vice versa for CO_2 uptake. As no oxygen is released from the Ocean when CO_2 is taken up on a long-term basis (not regarding annual cycles), we will put experimental constraints on the partitioning of CO_2 taken up by the terrestrial biosphere and by the Oceans respectively, when concurrently measuring oxygen/nitrogen ratios and CO_2 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_2 released and vice versa, including its seasonal variations. With the aircraft sampling over Siberia we are working to resolve the imprint and the global role of the siberian terrestrial biosphere, in addition to the measurements of the stable carbon isotopes of CO_2.

6.3. Methods

The methods used are based on whole air sampling into 2.5 l glass flasks at 1 bar absolute at (i) a few remote ground stations in Europe, (ii) on aircrafts at the three different sites of the EUROSIBERIAN CARBONFLUX project, sporadicly close to the ground-related source/sink at 100 m height and regularly above the planetary boundary layer at 3000 m height, mostly in pairs, and (iii) at two different heights, very close to the ground (2 m) and in the top of the canopy (26 m) during the summer and autumn intensive campaign at the Fedorovskoye site.

The samples are analyzed in the Groningen laboratory for their O_2/N_2 ratio by a dedicated isotope ratio mass spectrometer (IRMS), for their CO_2, CH_4 and CO concentrations by gas chromatography (GC-FID), and finally from the remaining air sample CO_2 can be extracted quantitatively for stable isotope ratio analysis by IRMS ($\delta^{13}C$ and $\delta^{18}O$ of CO_2) and eventual $^{14}CO_2$-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.

The data will form part of the project's database and will be used by the CIO and the partners for simulations using the partners' models.

6.4. Performed work 1999

In 1999 the air plane whole air flask sampling, done by the Russian partners into Groningen flasks, went on at the stations Fedorovskoye and Zotino and was started in march 1999 at the station Syktyvkar. In July as well as in October a participant from Groningen joined the Fedorovskoye intensive sampling campaigns for near-

ground sampling. The measurements of the 1998 samples were finalised and the dataset was extended with the 1999 samples, as far as they already arrived from Russia. With some data gaps, due to different logistical problems, sampling went on at the stations Mace Head, Spitzbergen and Kasprowy Wierch.

We took part in the isotope- and concentration intercomparison exercises organised by IUP-HD.

6.5. Some results of 1999

Figure 6.1 gives an overview of the Oxygen concentration measurements on airplane samples from the three different Siberian stations, all results given as ratios O_2/N_2 versus the local Groningen reference gas. As an example for the sensitivity of the flask analysis for water vapour, the results from the very wet 1998 summer intensive campaign are included. Unfortunately, only after the summer campaign the sample quality appears to be sufficiently high. In both the datasets from Tver and Zotino we observe a distinct annual cycle with a minimum oxygen concentration in February/March 1999, inverse to the general behaviour of the northern hemispheric CO_2 concentration. More detailed analysis even showed a phase-shift in the Zotino-signal as compared to Tver in the order of six to eight weeks. This is indeed what is expected from simulation runs, due to the very different oceanic influences at both stations. The Oxygen concentration at Zotino is lower than at Tver by about 50 per meg. Both phase and concentration shift have to be confirmed in the later 1999 and the 2000 samples, however.

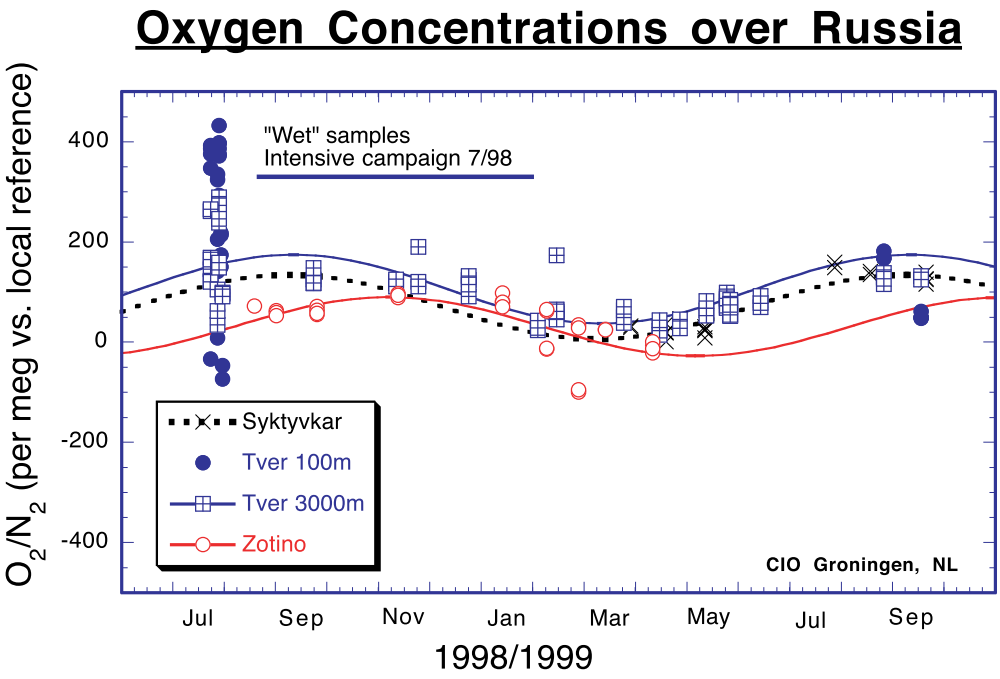

Fig.6.1: Oxygen concentrations in Tver and Zotino air, measured by mass spectrometry as Oxygen : Nitrogen ratios, given in per meg (1000 permeg = 1 ‰) deviation from the ratio of the laboratory reference, with first order harmonic fits.

A different behaviour at the two stations can also be seen from figure 6.2. Now the oxygen concentration is plotted versus the respective CO_2 concentration of the same sample.

At Tver and Syktyvkar we see quite similar ratios of oxygen vs CO_2 concentration change of about -1.77 mol O_2 per mol CO_2, over the whole annual cycle. The details will be evaluated together with the whole available dataset. The air at Zotino clearly shows a different regime: While at high concentrations (in winter) the data are lying on the same curve as the Tver/Syktyvkar data, at low summer CO_2 concentrations there is only very little variation in oxygen concentration.

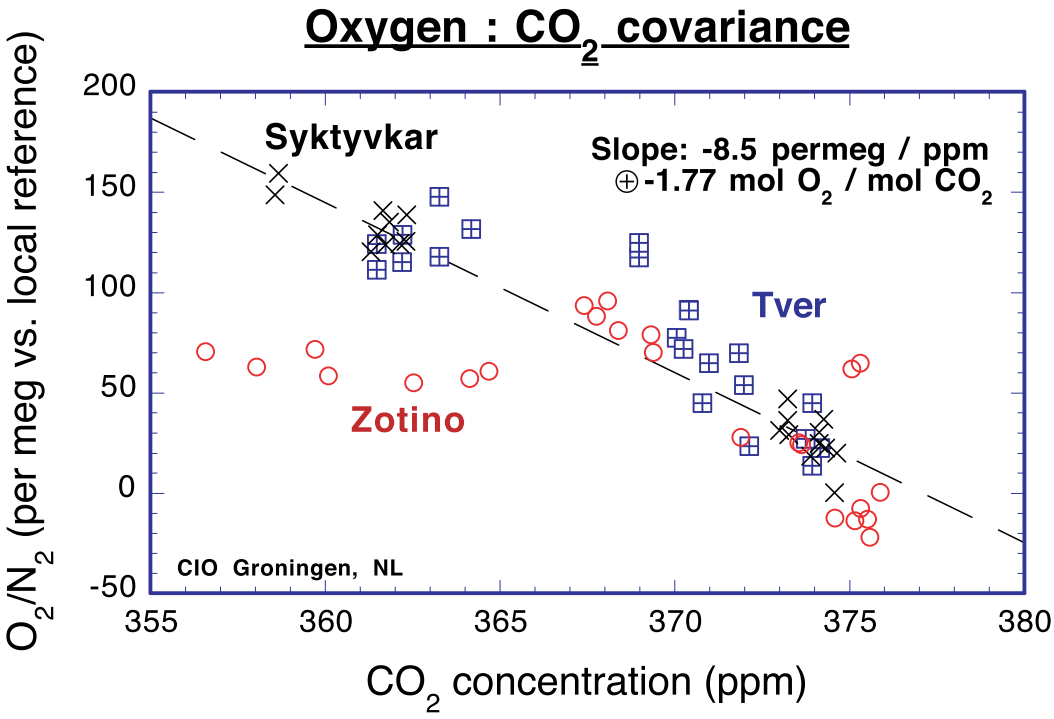

Fig.6.2: The annual cycle in Oxygen- and CO_2 concentrations at all three stations in 1998/1999, the more continental station Zotino clearly behaving different from Tver and Syktyvkar

6.6. Workplan for 2000

The measurements of the EUROSIB flask samples of 1999 will be completed and the results be evaluated and interpreted, the latter including own simulation work to be done with the Hamburg/Jena transport model.

The aircraft flask sampling and measurement program will go on, the sampling being carried out by members of the Russian partner groups, at two flights per month per site.

Flask sampling will start again at Mace Head, go on after reconstruction of the station at Svalbard, and go on at Kasprowy Wierch.

The continuous flask intercalibration dataset of measurement results from aircraft samples taken in parallel with other groups' "standard" flask samples will be extended continuously, regularly up-dated and evaluated.

The common intercalibration efforts will be continued (organized by IUP-HD) and, as we are considerably expanding on our laboratory infrastructure, on our side be improved by shorter response-times.

The WMO-NOAA Round-Robin 98-00 samples arrived in December 1999 and will finally be measured for CO_2 and CH_4 concentrations and stable isotope ratios of CO_2.

7. MISU Department of Meteorology, Arrhenius Laboratory, Stockholm University

7.1. Participant information

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7.2. Objectives

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

i) provide a continuous record of CO_2 on Zeppelinfjellet, Svalbard.

ii) perform flask sampling for ^{13}C, ^{18}O in collaboration with the NOAA/CMDL.

iii) perform flask sampling for ^{14}C in collaboration with the Groningen group on Zeppelinfjellet, Svalbard.

iv) participate in the intercalibration of the CO_2 data-sets with the other EUROSIBERIAN CARBONFLUX participants and the rest of the international CO_2 community.

v) perform high resolution regional transport modeling to identify and quantify regional sources and sinks of CO_2 in the Siberia region.

7.3. Methods

The continuous measurements of CO_2 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. The research station was rebuilt during the period July 15, 1999 to March 15, 2000. During this period the continuous measurements were discontinued.

Flask samples have been collected on Zeppelinfjellet at least once a week during the entire year. During the period when the continuous sampling was discontinued double sets of flask samples have been collected. The flasks are shipped via diplomatic pouch to NOAA/CMDL in Boulder, Colorado, USA where the analysis for ^{13}C, ^{18}O and CO_2 are performed. The analysis up to February 2000 are already available.

Flask sampling for ^{14}C was commenced in October 1998 in collaboration with Centrum voor Isotopen Onderzoek, Groningen. These data will contribute to the climatology of the carbon cycle.

The regional modeling component of the MISU effort has developed into utilizing an off-line transport model based on output meteorological data from ECMWF or high resolution regional meteorological models (e.g. 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 will be utilized for high resolution studies over Siberia.

7.4. Results to date

The continuous CO_2 data are available in preliminary form up to and including July 1999. EUROSIBERIAN CARBONFLUX participants are given access to the entire data-set on request for intercomparison studies and modeling.

The flask program on Zeppelinfjellet is working as planned and data are available up to February 2000. The ^{14}C sampling program was commenced in October 1998; the results are still pending from the Groningen laboratory.

Meteorological data for the first two years of the project have been prepared by the Stockholm group and made available for the other project participants.

The regional model is now prepared for boundary conditions provided by the other groups global circulation models and land surface flux calculations. During 1999-2000 a study of the influence of the meteorological data resolution (1 degree vs. 0.5 degree resolution) on modeled transport has been performed. The differences are small but not insignificant for horizontal transport calculations. The vertical resolution in the model has also been considered in comparisons with the first continuous vertical profiles available from the field studies. The vertical studies reveal significant problems since the vertical profiles contain structures that the current models are unable to resolve. When quantifying the vertical transport of CO_2 it will be necessary evaluate the errors that this model weakness can create.

7.5. Workplan for 2000 (year 3 of project)

The CO_2 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 and 1999 in close collaboration with the other EUROSIB partners. This year will provide exciting opportunities to compare the performance of the models with the accruing data-sets. In particular the Stockholm group will quantify regional fluxes of carbon dioxide and the role of the vertical and horizontal resolution of the model for the flux quantification process.

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8. IPEE Severtzov Institute of Evolution and Ecology Problems, Sukatschev's Laboratory of Biogeocenology

8.1. Participant information

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Coworkers: *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_2, 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_2-flux emission data (stem and soil respiration) in pine forest and bog sites;

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

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 inhomogeneous forest and atmospheric boundary layer over it (period of work in the project is from January to February, 1999);

*Daniel Kozlov** (IPEE, student of Moscow State Univ.) is responsible for ground measurements stand structure, litterfall in the CFR;

*Yulia Kurbatova** (IPEE, a Ph.D. student of N.Vygodskaya, was beginning to work in the project in August, 1999) is responsible for eddy correlation data treatment and analysis on CO_2, water and energy fluxes in bog of the CFR;

*Irina Milukova** (IPEE, a Ph.D. student of Prof. N.Vygodskaya) is responsible for eddy correlation data treatment with their analysis followed in the Central Forest Reserve (the CFR), the Tver region;

Maxim Panfyorov (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);

*Michael Puzachenko** (IPEE, student of Moscow State Univ.) is responsible for analysis of spatial structure within footprint area for eddy measurements in the CFR;

Konstantin Sidorov (IPEE, a Ph.D. student of N.Vygodskaya) is responsible for flights in Syktyvkar (with March, 1999), analyzing the long-term meteorological and hydrological record in the CFR and Tver region, organization of the 2nd forest station in the CFR, measurements of snow cover in the CFR and assists in solving organization issues;

Andrey Varlagin (IPEE, a Ph.D. student of Prof. N.Vygodskaya) is responsible for studying water fluxes in spruce forests by the sap flow method and eddy covariance technique; for maintaining measurements in the Central Forest Reserve (the CFR), the Tver region;

Daniel Zolotoukhine (Ph.D. student of IF SB RAS) is responsible for regular flights and intensive flight campaigns in Zotino, eddy correlation measurements in Zotino and treatment data;

*Prof. Dr. Gennady Menzhulin** (INENCO Center of RAS, St.-Petersburg) is responsible for development and analysis of a computer mesoscale model of an unsteady turbulent air flow and hydro-thermal regime in an inhomogeneous forest and atmospheric boundary layer over it and coupled model of water transport in "soil-roots-stems-leaves-air"(SRSLA) system; (period of work in the project is from January to March, 1999);

*Anatoly Bychkov** (IPEE, a technician) is guarding all the measuring systems in the CFR, Tver;

(Note: * - payment is beyond the project)

8.2. Objectives for year 2 (according to the working program):

- WP1: Regular monthly vertical aircraft profiling for flask sampling and gas-analyzer CO_2-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-99 of G. Menzhulin).

8.3. Performed work

- 107 flights (380.4 hours) are fulfilled during January – December in Tver (155 h.), in Syktyvkar (61.4 h), and in Zotino (164 h), including 54 flights in 6 intensive campaigns with IPSL/LMCE and MPI BGC;
- In the CFR (with MPI BGC) the all-round-year eddy flux measurements were continued on the 1st *Sphagnum* spruce plot (*P. sphagnoso-myrtillosum*); eddy fluxes measurements in the bog were provided from March 26 to November 26, 1999, micrometeorological measurements – round the year; the calibration is fulfilled once in 7-10 days; all the half-hourly data from June, 1998 to August, 1999 are checked for energy balance closure; all these data are analyzed and a part of them is ready for publication;
- In Zotino (with MPI BGC) the long-term eddy measurements were started in the beginning of April in both a pine forest and bog; the measurements are continued now in the forest and stopped in the bog in November; the calibration was fulfilled once in two weeks; the energy balance closure of half-hourly data was checked for the period from June to August, 1999 for pine forest; all the energy and vapor fluxes data are analyzed and prepared for the publication;
- In the CFR the 2nd tower (48 m) is erected in the other spruce stand. This spruce stand is a nemoral-complicated stand with drained soils. Equipment was installed and continuous measurements began from October 7, 1999;
- In the CFR the all-round-year measurements of sap flow of 19 trees were continued in 1st spruce stand; collected xylem flow data are treated and analyzed; data of 1998-1999 are prepared for publication;
- In Zotino soil CO_2-efflux measurements (with MPI BGC) in bog, pine forest and 4 transformed ecosystem (cuttings of different age and burnings) near Zotino were made from May to October, 1999 (several days per month); *Pinus sylvestris* stem respiration measurements were made in same periods;
- In the CFR 20 litter screens ($1m^2$) were installed on October 22, 1999 in two spruce stands;
- In the CFR in winter-spring, 1999 measurements of snow cover were fulfilled to characterize moisture supply in snow in the bog and forest sites; the data were used in analysis of winter eddy measurements;
- In the CFR the annual increment, project area crowns and stem wood area are measured in the both forest sites; the decomposition of wood rate was estimated; in the 2nd spruce stand the diameter at breast height (1.3 m) and height of trees are measured in the area of 0.1 ha; 5 pipes are installed in the soil holes to measure the water table height; 5 soil profiles are described;

- In the CFR in the beginning of 1999 the air-photo survey of the test site of the CFR territory was provided; the spatial structure of the site was fulfilled by these data; these data were used for the selection of new forest site for the 2nd tower and for footprint analysis;
- UNI-HD/IUP is assisted during the summer and autumn intensive measurement campaigns in the CFR;
- All the currently customs issues are solved. Scientific research of all groups is organized in both the CFR and Siberia.

MAIN REPORT

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_2 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 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 1999, the Russian participants are also responsible for:

- WP3: to develop a computer mesoscale model of the unsteady turbulent air flow and hydrothermal regime in a heterogeneous forest and the atmospheric boundary layer over it (see report of G.Menzhulin).
- WP2: to investigate a xylem flow and supporting measurements in the *Sphagnum* spruce forests in the CFR;
- WP2 & WP3:
- to organize the 2nd forest site in the drained spruce stand, to install the 2nd tower (48 m) and the eddy measurements system, to begin observations by October, 1999, to install pipe in the soil holes to measure the water table height, to install the 10 litter screens ($1m^2$), measure the diameter at breast height (1.3 m) and height of trees on this plot;
- to investigate the thinning and net primary productivity in 8 spruce forests in the CFR based on literature data and our measurements;
- to collect both archive meteorological information and measurements of 1999, ground water data (water table level and soil water content) for the CFR, measured of snow cover depth in winter 1998-99 and installed 10 litter screens ($1m^2$) that were placed in random location in spruce stand with 1st tower in the CFR. Litter screens were deployed in the end of October 1999;
- to analyze the spatial structure on the base of air-photo survey provided in the beginning of winter 1999 for the test site in the CFR.

8.4. Methods:

- For methods of canopy and soil CO_2-flux measurements, eddy covariance technique and aircraft sampling see the report of MPI BGC.
- The treatment of eddy data was fulfilled on the base of methods and recommendations from MPI BGC. In 1999 3 specialists of FI SB RAS (Krasnoyarsk) have been trained at MPI BGC. Specialists of MPI BGC constantly consult and assist in solving the current technical problems.
- Xylem flow was continually measured with a thermal method (Granier, 1987) in the target *Sphagnum* spruce forests in the CFR (see Report-1998).
- For methods used to direct chamber measurements of soil CO_2-efflux and stem respiration in Zotino, see Report-1998.
- For methods used to develop a mesoscale model and SRSLA-system models, see the report of G.Menzhulin.

- Thinning of spruce forests and average mortality rate in the CFR was estimated by: 1) generalized published data in the 8 spruce forests in the CFR study area; 2) the measurements of living, dead standing, living and dry fallen spruces for two spruce stand with different drainage conditions for 1972-1996 on the base of archive reserve data and our own measurements. One of these spruce stands is *Sphagnum* stand (the 1st tower plot), the second one is close to the 2nd site by soil-ground moistening; 3) the decomposition rate of wood k_d (Olson, 1963) was defined with account of time after death and falling of trees; 4) the above-ground biomass of individual living spruces was calculated by allometric correlation equations for stem wood, bark, branches and needles dry weight biomass and $(dbh^2) H_{tr}$; 5) the average annual growth was estimated from biomass difference between the beginning and the end of the period divided by longevity of the period (14 years – *Oxalis* spruce stand and 8 years – *Sphagnum* stand); 6) total below-ground biomass was estimated from the ratio of total roots biomass to total above-ground biomass (M.Abrazko, 1973) equals 36.1% (*Oxalis* stand) and 44.5% (*Sphagnum* stand).
- For analysis of spatial structure on the base of the _ir-film the spectral and fractal analyses are used.

8.4.1. Problems and Experiences in Carrying out Eurosiberian Carbonflux:

Organization problems:

1. CUSTOMS.

In 1999 the customs problems were solved by the support of Ministry of science and technology. There were 4 import and 4 reexport procedures in 1999. Two procedures of changes in customs regimes allowed prolonging duration of imported equipment for the unlimited period without changes in exempted customs dues (0.15%). The maximum difficulties were connected with prolonging the exempted customs regime for the equipment imported in 1998 through Zapadnaya Dvina. This problem was solving from May to December 1999 in spite of positive opinion of the State Customs Committee of the Russian Federation in April 1999.

It took 200 days (in total) for Moscow group to solve of the customs problems though the period from equipment imports to its letting out from the customs was just 10 days. The most time is needed to concordance invoices with requirements of Russian customs and to check invoices.

To the present time the main unsolved problem is the reexport for import-98 through Brest. We are looking for the optimal solution of this problem and suppose that the reexport will be fulfilled up to November 2000. The prolonging of the dates of imported equipment by the other imports will be provided in February 2000 by the changes of customs regimes.

However, this way is seemed to be ineffective in the future because the State Customs Committee of the Russian Federation intends to complicate the import-export regimes and to reduce a list of variants with exempted (0.15%) customs dues (such proposals are given to the Government).

Therefore Ministry of science and technology of RF again supposes to use a possibility of including of our current and possible future project to the working plan into current Intergovernmental Agreements, Ministries of Germany and RF for getting support.

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. In other case, the tax is 3% of the equipment cost for each month when the term of equipment staying in Russia is extended.

2. AIRCRAFT SAMPLING.

The main problems were associated with the following:

1. limitations in fuel (Zotino);
2. troubles of equipment for automatic collection of CO_2 data;
3. troubles of dataloggers;
4. replacement of aircraft used for measurements in Tver;
5. stable cloudy conditions in Autumn-Winter over the center and the northern-western part of the European part of Russia.

There were 2 replacements of gas-analyzer in Tver and 1 replacement in Zotino. Due to problems of gas-analyzers, dataloggers and power supplies a part of regular flights were provided just with flasks program. Because of long-term cloudy weather, aircraft sampling was not carried out in Tver (January, November), there were only 1 flight in September in Tver and 1 flight in Syktyvkar in November.

All the flasks collected in the period from January to October 1999 are sent in Germany and France.

Scientific questions:

The weather conditions of vegetation periods of 1998-99 period in the CFR are sharply different from the long-term climate normal. Therefore we are not sure that estimates of CO_2 flux and the other fluxes, Bowen ratio, and maximum conductance values as well as different results of parameterization for the investigated seasons with soil moisture anomalies are representative for the spruce forest and bog of the southern European taiga.

Compared to NEE over 1-y period and NNPt, NEP (Whittaker, 1975) over 14-8-y periods for two uneven-aged natural unmanaged spruce forest (that has not been managed in historic times) showed that NEE (summer, 1998) and average NPPt, NEP have the different sign for *Sphagnum* spruce stand. By preliminary estimates, the sign for NEE over summer 1999 and average NPPt, NEP is similar and *Sphagnum* stands may be a weak C-sink to the atmosphere. Clearly, the difference between NEE measured by eddy covariance and NPPt, NEP result from different time constant for carbon turnover. Also obviously, in our case NEE measurements were carried out in the with soil moisture anomalies that may essentially affect in sign and absolute values of NEE. Therefore, we suppose that long-term measurements are needed in Tver region before further conclusion can be drawn.

The main methodical problem for the procession and analysis of eddy measurements for both Tver and Zotino data is the poor energy balance closure.

In general, one of the main reasons of the well-known problem is limitation of Monin-Obukhov similarity theory (Zvang et al., 1962) by the turbulence conditions. Another reason lies in different fetch areas for different periods of measurements. Effect of different fetch area increases under the conditions of spatially inhomogeneous surface. The third reason is a local advection but to estimate its effect it is necessary to measure fluxes by several towers placed over fetch area. Besides, there may be other systematical and stochastic technical sources of errors associated with accuracy of sensors, calibration errors, precipitation effect and breaks of electric power supply.

The introduction of different tests and limited conditions didn't result in good balance closure for half-hourly intervals. The other methods for improvement of balance closure are not clear yet.

The best energy balance closure is 9 % for spruce forest in 1998;13 % for pine forest in 1998 and 22 % for Tver bog in 1999.

Because of poor energy balance closure, a number of CO_2 efflux measurements used for parameterization is limited (especially for nighttime fluxes).

Lack of Granier method for sap flow measurements don't permit us to rely on data on tree transpiration during winter thaws, late spring and early autumn frosts. Therefore in spite of the all-year-round sap flow measurements we mainly analyzed only data for growing season 1998-1999.

As it is prohibited to cut trees on the territory of the CFR, we have data of stem wood area in 1999 only for the 1.3-m height. It restricts possibilities of calculation of tree sap flow. In 2000 we plan to core trees through the whole height to collect necessary data for recalculations of the tree total wood area.

Analysis of transpiration and evapotranspiration showed a necessity of soil, roots and needles water potentials that may improve parameterization under water stress conditions during droughts or over-moistening periods. IPEE has a pressure chamber and collected incident measurements of water potential of little needle twigs. However these data are not complete and we plan detailed observations in 2000.

To understand behaviors of nighttime CO_2 effluxes and to estimate daily respiration flux as well as to improve parameterization of nighttime CO_2 fluxes, it is reasonable to carry out chamber measurements foliage, branch, stem and roots respiration in the CFR forest site. Besides, it is reasonable to provide also parallel measurements of effluxes with measurements of growth of aboveground biomass in the CFR bog site. It is also unclear yet a question of chamber measurements of CO_2 emission from soil under snow in forest and bog in the CFR. Due to low winter CO_2 effluxes it is difficult to estimate accurately dynamics of CO_2 effluxes of

the ecosystems in winter and snowmelt period. However IPEE doesn't have necessary equipment to provide such measurements.

8.5. Results:

8.5.1.Accuracy of flux measurements: Closure of the surface energy budget.

The estimates of energy balance closure for half-hourly periods were carried out for the following data (see Appendix B):

1) In Zotino:
   - the pine forest: 8 June – October 2, 1998;
2) In the CFR:
   - the *Picea-Sphagnum-Vaccinium myrtillus* community (1st tower): May 27 – September 30, 1998; November 1, 1998 – February 22, 1999; March 3 – August 31, 1999;
   - the bog: June 13 –October 12, 1998; March 26 –August 31, 1999.

The examination of the other periods of eddy measurements is not completed yet. Calculations of fluxes for 1-hour period didn't result in improvement of energy balance closure. An examination of closure balance for larger periods is also continued (2h and 24h). According to the preliminary estimates the flux averaging for 2 hours didn't give a distinct improvement in balance closure in comparison with half-hourly data.

1.1. The following criteria were applied to assure the quality of the flux measurements above the canopy in any half-hour period:

1) unreliable flux values or very large values of air temperature and humidity variations by eddy system;
- the stationarity test (Foken, 1996);
- high-frequency component ("inductivity" term) of the flux was <1% for spruce forest and bog (the CFR);
- data after errors in calibration of H_2O were rejected (in the CFR);
- the time of calibration and 1-1.5 hour after calibration were excluded from the analysis (bog, the CFR);
- criteria PAR>0 and Rn>0 was used for selection of daytime;
- the half-hour periods with precipitation were excluded.

2) Also we examined our measurement in detail using the following wind speed and turbulence criteria:
- the horizontal wind speed V > 1.5 – 2.0 m s^{-1};
- the friction velocity criteria u*>0.4 m s^{-1} or > 0.25 m s^{-1} (unstable atmospheric conditions);
- the Monin-Obukhov length (or upwind distance) L <0 m (unstable atmospheric conditions).

3) Daily average Bowen ratio for spruce forest criteria was less than 3-5.

4) After applying any criteria the half-hourly fluxes within three standard deviations of their respective means were retained.

1.2. Our inspection of the closure of the surface energy balance on a 30-min basis data showed that:

1) Example of spruce stand, May 27- September 30, 1998:

1. To calculate energy balance closure H+LE (Y) = Rn-G (X) without accounting for sensible and latent heat storage (S_H+S_{LE}) and without stationarity test:

Y=0.73 X – 8.8 (n=5969, R^2=0.84); without intercept: Y = 0.71 X (n=5969, R^2=0.83);

2. Introduction of stationarity test (Foken, 1996):

Y=0.76 X – 5.3 (n=4024, R^2=0.87); without intercept: Y = 0.75 X (n=4024, R^2=0.87);

3. Introduction of S_H:

Y=0.82 X – 7.7 (n=3871, R^2=0.90); without intercept: Y = 0.80 X (n=3871, R^2=0.90);

4. Introduction of S_{LE}:

Y=0.81 X – 7.2 (n=3869, R^2=0.95); without intercept: Y = 0.80 X (n=3869, R^2=0.95);

Thus introduction of sensible heat storage improves forests data by 5-6% in comparison with initial database; introduction of S_{LE} improves balance closure by more 1-2 %. The total storage was 6-8 %.

2) Example of bog, June 13 – September 30, 1998:

1. Without accounting for sensible and latent heat storage (S_H+S_{LE}) and without stationarity test:

Y=0.579 X + 10.0 (n=3864, R^2=0.89); without intercept: Y = 0.610 X (n=3864, R^2=0.89);

2. Introduction of stationarity test (Foken, 1996):

Y=0.587 X + 8.9 (n=3113, R^2=0.87); without intercept: Y = 0.615 X (n=3113, R^2=0.89);

3. Introduction of S_H:

Y=0.591 X + 8.6 (n=3104, R^2=0.90); without intercept: Y = 0.618 X (n=3104, R^2=0.90);

4. Introduction of S_{LE}:

Y=0.590 X + 7.8 (n=1733, R^2=0.89); without intercept: Y = 0.617 X (n=1733, R^2=0.89);

5. Introduction of additional storage of water S_w:

Y=0.602 X + 6.8 (n=1732, R^2=0.90); without intercept: Y = 0.623 X (n=1732, R^2=0.90);

S_w was calculated for 5-cm layer of open water covering bog surface during summer 1998 as following:

$$S_w = h_w c_w \rho_w dT_w/dt$$

where h_w – water height over bog surface; c_w – specific heat capacity of water; ρ_w – water density; dT_w/dt – a rate of water temperature changes.

This 5-cm layer of open water is an additional physical layer with its own heat capacity, its heating isn't accounted in the other storage terms.

Totally, accounting of S_H adds 2-3 % to energy balance in the bog; that of S_{LE} – 0.5-1% and Sw – nearly 1%. Decrease of total storage by 3.5-4.5% in the bog in comparison with the forest is connected with the less air column under reference height and the less volume of air with canopy.

In 1999 the impact of storage terms through growing season was twice less both in the forest and in the bog in comparison with 1998.

As a hypothesis for less impact of storage terms during dry growing season 1999 we suppose that in 1999 the intermass convection was stronger expressed, there were less fronts with sharp changes of meteorological parameters. It resulted in the less air temperature and humidity fluctuations on the reference height above canopy.

3) Overall, for all data base the least underestimates of available heat were following (see Appendix B):

Pine forest in Zotino:

- **13%** (September, 1998) and 23 % (June, 1998) for daytime (PAR>0, Rn>0) and no rain and unstable conditions (u* > 0.4 m s^{-1});
- 26% for whole period (117 days) for 24 h and u*>0.4 m s^{-1}.

Conditions of PAR>0 and no rain don't improve closure balance for whole periods.

Spruce forest in Tver (the CFR)

- **12-13%** (May 27 – September 30, 1998) for 24 h and unstable conditions (u*>0.4 m s^{-1}**;** V>2 m s^{-1}**),** including additional criteria “no rain” not change underestimate value (14%);
- 16% (May 27 – September 30, 1998) for daytime (PAR>0), no rain and unstable conditions (u*>0.4 ms^{-1});

- 19% (May 27 – September 30, 1998) for nighttime (PAR=0), no rain and unstable conditions (u^*>0.4 ms^{-1}), but R^2 was very small (0.09);
- 29% **(**November 1, 1998 – February 22, 1999), half-hourly data and unstable conditions (u^* >0.4 m s^{-1});
- 30% (March 20 – August 31, 1999) all half-hourly data for 24h, no limit conditions;
- 27% (April 19 – August 31, 1999) for 24 h and unstable conditions (u^* >0.4 m s^{-1}, V > 2 m s^{-1});
- 28% (April 19 – August 31, 1999) for daytime (PAR>0).

The bog, Tver (the CFR)

- **22-23 %** (July, 1999) for 24h, no rain, unstable conditions (L<0 m and u^* > 0.25 m s^{-1});
- 38% for whole period (June 13 – October 12, 1998);
- 41% for whole period (March 26 – August 31, 1999).

4) The calculated flux of sensible (S_H) and latent (S_{LE}) heat storage did not compensate the loss of eddy flux. In the most cases including of storage term S_H improve balance closure by 2-4%, and S_{LE} value equals to 1% of (S_H + S_{LE}).
5) Excluding of stable and near-neutral atmospheric conditions don't always improve estimates of balance closure. For examples, energy closure slightly improves with increasing of L and u^*.
6) According to Tver spruce forest and bog data, the worst energy closure is observed for nocturnal period. The limitations by friction velocity (or by horizontal wind speed) showed a good closure of energy balance (<10%) for unstable conditions but R^2 was very small.
7) The worst energy closure occurred for the pre-dawn hours and for the evening period especially if there was condensation of dew.
8) The essential difference in closure as function of wind direction observed only for north-north-east winds (0-45°) in 1998 and for south winds (90-225°) in 1999 in both forest and bog sites.
9) Balance closure of summer 1998 data in spruce forest was better than summer 1999 data.
10) Intercept a_2 in equation (_+LE) = a_1(Rn – G- S) + a_2 may increase up to 30 W m^{-2}. As we observed large a_2 value in midsummer both in pine and spruce forests and bog for unstable conditions, we can proposed that local laminar advection may occur.

8.5.2. Weather in 1999, the CFR:

Overall, the period from June to August 1999 may be characterized as anomaly dry and warm and the same period of 1998 is anomaly moist and warm in comparison with long-term climate normals. In spring of 1999 anomaly late atmosphere and soil frosts occurred and in winter 1998-1999 there were a lot of thaws.

Growing season precipitation (ΣP) of 1999 was 387 mm and close to long-term climate normal for the nearest weather station Fyodorovskoye. These ΣP was 66 % of ΣP of the wet growing season 1998. However, the ΣP for May-September doesn't adequately characterize the conditions of atmosphere moistening because in 1999 several long precipitation-free spells occurred within this period. For examples, in 1999 precipitation summed in the 32-day period (July 15 - August 15) was only 42.8 mm and 252.2 mm in the same period in 1998.

The average air temperature T for the warmest month (July) was 20.3°C in 1999 and 19.0°C in 1998. These July T is greater by 4 _ 3 °_ than the long-term July averages (1889-1995 and 1970-1995) from the nearest weather stations, Vychnii Volochek (meso-net station) and Fyodorovskoe, respectively.

In 1999 the driest period was from June 3 to June 30 and from July 26 to August 15. In these periods maximum air T was 26-32°C.

The long-term normal (June-August 1968-1999) the average ± SD water table depth (WT) in *Sphagnum* spruce stand (*P. shagnoso-myrtillosum,* 1st tower plot) was –24 ± 15 cm, and the May-September soil water content (SWC) in 0-20 layer was 116 ± 18 mm.

In this stand in 1999 these values were –31 ± 18 cm (June-August) and 108.5 ± 27.7 mm (May-September); in 1998 - 11 ± 9 and 136 ± 18 mm respectively.

During the driest growing periods 1999, the WT decreases to –63 cm (June end and 1st decade of August) and SWC decreases to 60-50 mm in 0-20 cm soil layer. The last values didn't reach a wilting point (it equals for 0-20-cm layer to 14.7 mm) and the WT was higher in comparison with the known droughts in 1972 and 1992 when the WT decreased to -90 cm in the end of August 1972 and -102 cm in 1st decade of August 1992. However, the WT in 1999 was lower than the average spruce rooting depth (20 cm) during 60 days. In contrast 1999, in wet 1998 the WT was stable higher than soil surface during one week in July, the water logging was even 15 cm higher than ground surface. After July 4, 1998 and to the end of September 1998 all spruce roots were in soil water.

In *Oxalis* spruce stand with the better-drained soil (as example for the 2nd tower plot) the average spruce rooting depth is 30 cm. The long-term WT at the 30-years normal was -72 ± 17 cm (June-August) and the SWC in 0-20 cm soil layer was 67 ± 10 mm (May-September). In wet 1998 average WT was -38 ± 30 cm and SWC in 0-20 soil layer was 84 ± 13 mm; during dry 1972 and 1999 WT and SWC were -96 ± 44 cm and 56 ± 16 mm and - 178 ± 33 cm and 52 ± 22 mm, respectively.

Based on weather conditions, we may suppose to have the different __2 fluxes, transpiration and evapotranspiration in two spruce stands and bog during two years because of relation of soil CO_2 emissions to water table (Funk et al., 1994; Shurpali et al., 1995) and snowmelt influence to heat storage (Lafleur et al., 1997), etc.

8.5.3. Xylem sap flow and evaporation in Sphagnum spruce forest in the CFR.

Overall, the low transpiration and evapotranspiration rates were observed at the *Sphagnum* spruce stand in the CFR through the growing seasons 1998-1999. Same results show good correspondence to the data reported in the conifer evaporation literature (Jarvis et al., 1976; 1997; Kelliher et al., 1993; J. Geophysical Research, v.102, D24, 1997). One of the main reasons of the low evapotranspiration rate at the *Sphagnum* spruce stand is nitrogen-poor environment. Other reasons observed in 1998-1999 were water soil stress connected with the drought (1999) and the excessively moist soils (1998), low concentration of O_2 in soil water and decreasing of surface area of physiologically active thin roots during period with soil moisture anomalies.

The effect of moistening conditions to two growing seasons caused the differences in transpiration E_T of spruce stand through two growing seasons, though it didn't affect to evapotranspiration E.

For example, on the base of xylem sap flow measurements in the dry May-September, 1999 the total E_T of spruce stand equals to 154.4 mm that is nearly 40% of ΣP of this period. For the same period (July 13 – September 30) E_T in wet 1998 was higher by 30 % in comparison with dry 1999 (86.9 and 67.8 mm, respectively). In the peak of growing season (July 15 – August 15) average daily E_T rate equals to 1.30 mm day^{-1} in wet 1998 and 0.96 mm day^{-1} in dry 1999. Transpiration of spruces of dbh>20 cm has the main impact (75-79%) to total stand transpiration.

During the same 32-days period the E_T were 59% in wet 1998 and 45% in dry 1999 of total forest E and 41 and 55% were understory evapotranspiration, respectively. On rainy days and after nighttime the E from understory decreased to 10% of total forest E in wet year and to 12% in dry year.

Thus the transpiration of moss and *Vaccinium* layers equals to 10% of spruce transpiration in moist years and to 4-3 % of dry years (unpublished data of V.Abrazko). It is reasonable to suppose that the other part of evaporation from understory is formed mainly by physical evaporation (soil, intercepted precipitation by tree stand), but not due to transpiration of lower layers.

Daily total forest E rate averaged over the 32-days were 2.19 and 2.11 mm day^{-1} in 1998 and 1999, respectively. These values was good agreement with data on daily E in boreal forests (Lafleur et al., 1992; Pattey et al., 1997; Jarvis et al., 1997) and average daily E in Siberian forests with *Larix gmelinii (*Kelliher et al., 1997).

In the middle of the growing season, the total ratio of E to potential evaporation Eo was determined to be 0.52 in dry year and 1.02 in moist years. During July 13 –September 30 the average ratio of Eo to ΣP were 1.10 and 0.37 in dry and wet seasons. Through these periods only 31 % and 22% precipitation transpired from trees in dry and wet seasons, respectively.

For two years with soil moisture anomalies in the CFR we collected data characterized interconnections between transpiration and CO_2-exchange under water stress conditions of southern taiga uneven-aged spruce

forest. For example, during the period of July 15 – August 15, the total CO_2 flux was directed upward to the atmosphere (0.46 μmol m^{-2} s^{-1}) in excessively moist and warm 1998 and downward (-0.64 μmol m^{-2} s^{-1}) in extremely dry and warm 1999.

We may suppose that impact of the consecutive growing seasons with anomaly hydrological and meteorological conditions may cause distant responses of weak spruce stands in the further years.

8.5.4. Stomatal, tree, stand and bulk surface conductance.

Obtained values of conductance for two extremely moistening seasons 1998 and 1999 evidence that the regime of soil-ground moistening in the spruce forests of the European southern taiga has a large impact to both conductance parameterization and maximum conductance values in dependence of PAR, air temperature and VPD.

Availability of the daytime hysteresis of tree (g_t), stand (G_s) and bulk surface (G_c) conductance observed for *Sphagnum* spruce forest induces certain problems in parameterization of conductance as function of air temperature, VPD and photon flux density.

Values of both Q_{50} and Q_{85} in parameterization for PAR (used to select the maximum conductance) are independent to soil-ground moistening. However, slope *a* and intercept *b* in conductance parameterization of VPD are different in 1998 and 1999.

The obtained values of *Picea abies* maximum stomatal conductance ($g_{s\,max}$ = 2.6 mm s^{-1}) and bulk surface (canopy) conductance ($G_{c\,max}$ = 27 mm s^{-1}) are similar in moist 1998 to those for coniferous forests (5.7 ± 2.4 and 21.2 ± 7.1 mm s^{-1}, correspondingly (Kelliher et al., 1995)).

Maximum values of conductance in dry 1999 are much lower than average maximum of $g_{s\,max}$ and $G_{c\,max}$ for conifer forests (0.8 and 12 mm s^{-1}, respectively). The values of $g_{t\,max}$ and $G_{t\,max}$ were 14 and 9.5-mm s^{-1} in wet season and 9 and 5.2 mm s^{-1} in dry season.

Therefore, values of $g_{t\,max}$, $G_{t\,max}$ and $G_{c\,max}$ obtained during 1998 and 1999 cannot be considered as representative for spruce forest in southern taiga. Overall, it is reason to continue the measurements to obtain data corresponding to long-term regional of hydro-and meteorological normal.

8.5.5. The decomposition rate of wood and carbon losses in southern taiga spruce stands

The decomposition rate (k_d, yr^{-1}) of wood (Olson, 1963) was variable, depending on the way the tree died and on the time while the tree was standing dead biomass. For dead standing trees (DST) the average k_d was 0.0318 ± 0.004 (n = 37), for fallen living trees was 0.040 ± 0.03 (n = 6). It takes between 3 and 15 years after the DST fall to the ground, k_d decreased on average to (0.020 ± 0.006, n =12) for fallen dry trees. The smallest k_d value (0.011) was recorded for a tree that was standing dead biomass for 16 years and decomposition for 11 years on the ground.

The differences between average k_d for *Sphagnum* and *Oxalis* spruce stands were within the accuracy of mean value ± SE. Therefore, the main differences in decomposition of wood in these stands were caused by the composition of coarse litterfall (proportions of DST, fallen living and fallen dry trees) and by decomposition time.

The time while a dead tree remains standing varies with forest type. On average, this period ranges 5 to 14 years for different spruce stands, and we found the oldest dry standing trees (22-24 years old) in the *Oxalis* spruce stand. This is much higher than the average value (5-6 years old) given in literature as the limit of dry standing trees duration (Molchanov, 1971).

The rate decomposition constants for uneven-aged spruce forests in target region of European southern taiga (mean annual temperature 3.9 ± 1.0 °C) was very close to the estimates of average decomposition rate constants (0.030 yr^{-1}) for temperate conifers in New Hampshire (mean annual temperature 3.4 °C) (Lambert et al., 1980; Foster and Lang, 1980). But our data are lower than average decomposition rate constant and equal to 0.04 yr^{-1} for southern taiga (mean annual temperature is 3.7 °C) by Krankina and Harmon (1995).

If we assume this average decomposition rate constants to be 0.04 yr^{-1} for southern taiga wood biomass (Krankina, Horman, 1995), then the time needed for complete wood decomposition would be 25 years.

The value of k_d of 0.0318 yr^{-1} for stem wood biomass obtained in our study suggests that a dry tree will decompose completely during 30 years, and if we account for average 5-yr period (in the *Sphagnum* spruce stand) and 14-yr period (in the *Oxalis* spruce stand) of its being a drying, as well as k_d=0.02 yr^{-1} for a fallen dry tree, the average time needed for complete decomposition of organic matter will be 47 years and 47 years in the former and the latter stands, respectively. Maximum recorded DST period (12 year in the *Sphagnum* stand and 22-24 in the *Oxalis* stand) and the average rate of decomposition of a fallen dry trees (0.011 yr^{-1}) after 11 years since it fell down allow to conclude that the period needed for complete stem wood decomposition can be as log as 68 years in the *Sphagnum* stand and 46-49 years in the *Oxalis* stand. Fallen living tress are decomposed more rapidly (k_d =0.040 yr^{-1}). Consequently, decomposition of these trees will be completed in 25 years. However the proportion of these trees in the total number of fallen trees is 16% in the *Sphagnum* stand and 27% in the *Oxalis* stand. So, with account of k_d and coarse litter structure, the period of decomposition of wood fallen trees can be 61 years in the *Sphagnum* stand and 42 years in the *Oxalis* stand.

These estimates agrees with the complete humification of decomposition products takes 60-70 measured in the southern taiga spruce stands (including those in the CFR) (Storozhenko 1990, Storozhenko et al., 1992) more better than those which do not consider the time factor and categories of dead trees.

When calculating carbon losses of aboveground stand biomass only based on downed wood biomass of living trees, it can be concluded that 263 gC m^{-2} yr^{-1} of carbon is on average released to the atmosphere and soil during 14-yr period (1972-1990) in the *Oxalis* stand (with a decrease in number by 12 ind ha^{-1} yr^{-1}) and 195 gC m^{-2} yr^{-1} during the 8-yr period (1988-1996) in the *Sphagnum* stand (with a decrease in number by 16.6 ind ha^{-2} yr^{-1}). The same carbon losses, with account of the actual rate of decomposition of coarse litter biomass, are 77 and 42.5 gC m^{-2} yr^{-1} for the two stands, respectively (i.e. 29 % and 22 % of the total carbon in all fallen trees).

8.5.6. ANNP and NPP for two natural unmanaged uneven-aged spruce stand in the CFR

The estimates of productivity parameters (ANNP and NPP) vary essentially in relation of accounting the carbon losses from decomposition of dead biomass and roots growth. As different authors account the components of above- and below-ground biomass in different ways we have compared the different schemes of ANNP and NPP to obtain data compared with published ones. Calculations were carried out for the averaging periods with known tree quantity and life status.

Our study showed that above-ground net primary production of spruce stand (tree $ANPP_s$), decreased from 1976 to 1990 with the rate equal to 169 gC m^{-2} yr^{-1} in *Oxalis* spruce stand and from 1988 to 1996 with rate 68.8 gC m^{-2} yr^{-1} in *Sphagnum* stand. Tree $ANPP_s$ was estimated only through changes of biomass (stem with bark, foliage, branch) of remaining living spruce. This decrease is primarily related to mortality of spruces that is not compensated with annual growth of the rest living trees.

In contrast, tree ANNPs calculated from above-ground biomass of living trees and coarse litter (standing dead biomass and fallen dead biomass) were increased up to 16.4 gC m^{-2} yr^{-1} in *Oxalis* stand and 83.8 gC m^{-2} yr^{-1} in *Sphagnum* stand through same periods.

The total above-ground net primary production (canopy plus understory biomass plus coarse litter plus aboveground litter measured using litter screens) in spruce communities ($ANPP_t$) for the same periods were 11.4 gC m^{-2} yr^{-1} in *Oxalis* community and 113.8 gC m^{-2} yr^{-1} in *Sphagnum* community.

Accounting for the total annual growth and dead of all roots averaged for 6-years (M.Abrazko,1973-1983) NPPt averages to 68.9 and 161.3 gC m^{-2} yr^{-1}. If NNPt is calculated only from annual growth of fine (<0.6 mm) roots of spruces trees, these values are 64.8 and 139.5 g C m^{-2} yr^{-1}, respectively.

On average for two stands, 52-58% NPPt occurs as coarse litter.

ANNPt for two uneven-age spruce communities in southern European taiga is more less that ANNPt (110 ÷166 g C m^{-2} yr-^{1}) for two 115-155-yr old black spruce (*Picea Mariana*) communities in Canada (BOREAS, Gower et al., 1997). However, the number of trees per ha in black spruce stands were about 14-8-fold greater than density of *Picea abies* stands. Also, in the Canadian spruce stands the ratio of standing dead biomass to stem biomass to living trees was only 16-8 % versus 34-16% in spruce stands of southern European taiga.

NPPt values for two uneven - aged spruce communities in southern European taiga (into range 65÷161 gC m^{-2} yr^{-1}) are close to those of the total NPP (123 gC m^{-2} yr^{-1}) for boreal conifer forests of Siberia (Schulze et al.,

1999) and average 180 gC m^{-2} yr^{-1} for boreal zone (Lloyd, 1999) but considerably less than average total NPP values for conifer forests of the boreal zone available from literature (Finer, 1989, 1991; Ruess et al., 1996; Oechel et al., 1986; Warnant et al., 1995; Ruimy et al., 1996; Denning et al., 1996; Melillo et al., 1993; Woodward et al., 1995; Gower et al., 1997; Steele et al., 1997).

The NPPt ratio between *Oxalis* and *Sphagnum* stands sort of surprised us. This ratio, however, reflects thinning trends and the form of the log density/log biomass relationship found for the two stands for the period under study.

The NEPt was calculated for the same averaging periods as (NPP minus total carbon losses) according to Whittaker, 1975. These values were -80.5÷-84.5 gC m^{-2} yr^{-1} (or -6.7 ÷-7.0 mol m^{-2} yr^{-1}) for the *Oxalis* stand and 93.9 ÷ 68.6 gC m^{-2} yr^{-1} (or 7.8÷5.7 mol m^{-2} yr^{-1}) for the *Sphagnum* stand (here: the range indicates different methods calculated ANNP; negative sign for NEPt indicates that the carbon losses from thinning and decompose of litter more that the carbon accumulation in total biomass). Consequently, the *Oxalis* stand has been a C- source and the *Sphagnum* spruce stand has been a C- sink averaging the long-term period (from 1972 to early-middle 1990's).

Apart from methodological difficulties arising when calculating ANPP, NPP, and NEP through biomass productivity and thinning and a problem of how representative the study area is, the period over which we average and weather conditions during this period present a separate problem. For example, according to eddy measurements of net ecosystem carbon exchange (NEE) integrated June-September 1998, carbon flux was + 7 mol m^{-2} summer (or + 84 gC m^{-2} summer) for spruce forest of CFR (Schulze et al. 1999). Thus the absolute values of long-term average NEPt and NEE-1998 are same but differ by sign for *Sphagnum* stand. In contrast, in the peak growing season 1999 the *Sphagnum* stand was a C-sink (0.46 and – 0.64 μmol $m^{-2}s^{-1}m$ were average carbon fluxes on a 24-h basis in 1998 and 1999, respectively).

Obtained results showed a great year-to-year variation of NEE for uneven-aged spruce stands in southern European taiga. They also confirm the actuality of the problem of comparison of carbon balance calculations on the base of biomass measurements and measured by the eddy covariance technique even for the single ecosystem level.

8.5.7. CO_2-emission in pine forest and bog in Zotino.

Daily amount of CO_2 emanating from soil under snow of 1.2 m depth was on average 0.5 g m^{-2} day^{-1} in March increasing up to 0.97 g m^{-2} day^{-1} under intensive snowmelt and reaching maximum 6.8 g m^{-2} day^{-1} during summer period.

A dependence of soil respiration rate on snow density, soil temperature and moisture has been found. Daily soil respiration dynamics has been determined under different vegetative phases.

A relationship between CO_2 efflux density and the bog ground layer structure has been determined. So, respiration in the *Sphagnum* synusium did not exceed 0.1 g m^{-2} h^{-1}, while it was 3-fold higher in the *Sphagnum*-carex synusium and 6-fold higher in the subshrub-grass synusium.

Soil respiration in transformed ecosystems (cutting and burnings of different age) is given. Ground cover restoration, leaf and soil N-content at different stages of ecosystems recovery after cutting and forest fire have been assessed. Average soil CO_2 emission density in cutting have been found as following:

Age of cutting	3	10	15	20
CO_2 flux, g m^{-2} h^{-1}	0.18	0.24	0.44	0.31.

8.6. Submitted publications in 1999:

Varlagin, A., Vygodskaya, N., Milukova, I., Sidorov, K., Panfyorov, M., Abrazko, V., Abrazko, M., Sogachev, A., Kolle, O., Kubler, K., Rebmann, C., Arneth, A., Tchebakova, N., Ziegler, W., Shaposhnikov, E., Buchkov, A. and E.-D.Schulze Influence of environmental factors on xylem sap flow, evapotranspiration, and total conductance of uneven-aged spruce *(Picea Abies (L.) Karst.)* stand in Southern taiga in the European part of Russia.

Vygodskaya, N., Abrazko, V., Tchebakova, N., Panfyorov, M., Sidorov, K., Milukova, I., Abrazko, M., Shaposhnikov, E., Varlagin, A., Solnzeva-Elbe, O., Sogachev, A., Munaeva, T., Jeltuchin, A. and E.-D.Schulze. Thinning processes and decomposition of woody biomass of spruce in the southern taiga in European Russia.

Milukova, I., Vygodskaya, N., Kurbatova, Yu., Varlagin, A., Panfyorov, M., Sidorov, K., J.Lloyd, Kolle O., Rebmann, C., Kubler, K., Puzachenko, M. and E.- D. Schulze. Air temperature, humidity and wind effect to nocturnal CO_2 flux for uneven-aged spruce forest and bog ecosystems in the southern taiga in European Russia.

8.7. Workplan 2000:

1. To continue:
2. eddy correlation measurements in the forest and bog in both the CFR and Zotino (jointly with MPI BGC);
3. measurements of xylem fluxes and stomatal conductance in the spruce forest in the CFR;
4. To treat and analyze data obtained in 1998-2000 and prepare publications and database (jointly with MPI BGC);
5. To continue regular aircraft profiling for air sampling in Tver, Syktyvkar, and Zotino;
6. To measure snow cover depth in the CFR in January-March in order to determine water content storage and snowmelt rate;
7. To take arial images of the test sites aiming at selecting windthrow sites and determining their areas;
8. To prepare database of forest taxation data for target Tver region (30x30 km, 100x100 km);
9. To take regular information for Tver region from Russian satellite “Resource” with high spate resolution for last years;
10. To solve the customs issues and facilitate organizing research of all groups in the CFR and Siberia.

To prepare the following publications:

Vygodskaya, N., Milukova I., Varlagin A., Kurbatova, Yu., Panfyorov M., J.Lloyd., O.Kolle, C.Rebman, K.Kubler, Sidorov, K., Sogachev, A., Puzachenko, M., Kozlov, D. Jeltuchin, A. and E.-D.Schulze. CO_2-exchange of spruce forest of European taiga (Picea abies (L.) Karst.) throughout a year (preliminary title, in preparation).

Vygodskaya, N., Panfyorov, M., Milukova, I., Tchebakova, N., Varlagin, A., Sidorov, K., Kurbatova, Yu., J. Lloyd, O.Kolle, C.Rebman, K.Kubler, Abrazko, V., Puzachenko, M., Kozlov, D. and E.-D.Schulze. Seasonal variation of energy and water vapor exchange rates above spruce and pine forests in southern European and middle Siberian taiga (a preliminary title, in preparation).

Tchebakova, N. et al. Seasonal variation of energy, water and CO_2 fluxes in a Siberian pine forest (based on data of 1998, in preparation).

Vygodskaya, N., Kurbatova, Yu., Milukova, I.,, Varlagin, A., Panfyorov, M., Sidorov, K., J.Lloyd., O.Kolle, C.Rebman, K.Kubler, Minaeva, T. and E.-D.Schulze. Energy, water vapor and carbon dioxide fluxes at the bog ecosystem in southern European taiga zone (a preliminary title, in preparation).

Vygodskaya, N., Panfyorov, M., Sidorov, K., Milukova, I., Abrazko, V., Shaposhnikov, E., Varlagin, A.and E.-D.Schulze. Annual tree growth of two spruce forests types (*Picea abies (L.) Karst*.) in European southern taiga (submitted).

Varlagin A., Milukova I., et al. Transpiration, evapotranspiration and CO_2-exchange in spruce stands for soil moisture anomalies in European southern taiga (a preliminary title, in preparation).

Appendix A: CO_2, water vapour and heat exchanges of a Siberian Scots Pine forest.

Interim Report, February 2000 (R. Leuning[1], F. M. Kelliher[2] and O. Kolle[3])

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A.1. Introduction

Understanding of the biophysical processes controlling net ecosystem carbon exchange is needed to improve and validate predictions of global carbon cycle models. Contemporary models of ecosystem function include processes such as light interception, photosynthesis, energy balances, nutrient allocation and response of vegetation to water availability. Evaporation from the soil and soil respiration are also included in varying degrees of complexity.

One common assumption in modelling is that nutrient resources are distributed throughout the canopy to optimise carbon uptake, and has been used by Leuning et al. (1995), DePury and Farquhar (1997), and Wang and Leuning (1998) to calculate net canopy assimilation. To investigate this hypothesis, Livingston et al. (1999) examined the 3-dimensional distributions of intercepted radiation, mean intercellular CO_2 concentrations (using leaf $^{13}C/^{12}C$ ratios) and leaf N content in an open pine forest near Christchurch, New Zealand. The open structure of the canopy meant that variation in concentrations of water vapour and CO_2 within the canopy airspace were small and did not contribute significantly to the variation of intercellular CO_2 concentrations. Livingston et al. (1999) concluded that nutrient resources were not distributed optimally according to the profile of mean absorbed radiation, a result similar to that found for open Eucalyptus forests obtained by Leuning et al. (1991a, b). This contrasts to observations on closed canopies by Hirose and Werger (1987), amongst others. Hollinger (1997) also concluded that nitrogen was not allocated optimally or according to measured irradiance through a closed forest canopy at Maruia in New Zealand. Given the controversy, examined this hypothesis for a forest in central Siberia using a combination of leaf physiological methods and micrometeorology.

Micrometeorological techniques are now available to infer source/sink distributions of various quantities within plant canopies (Raupach, 1987, 1989; Denmead and Raupach, 1993). Leuning et al. (1999) used this so-called Inverse Lagrangian Analysis to deduce the sources and sinks of CO_2, heat and water vapour within a rice canopy and obtained excellent agreement with above-canopy eddy flux measurements. Leuning (1999) extended the earlier analysis to include atmospheric stability to improve night time flux estimates. He also compared predictions of a multi-layer canopy model with source/sink distributions inferred from the inverse analysis and found sufficient differences to warrant re-examination of the model. The ability to use micrometeorological measurements within canopies to verify multi-layer model predictions is a major advance and these techniques were used in the present study.

A.2. Objectives

1. To measure the vertical distribution of resources (light, nutrients) in a tall forest
2. To measure the fluxes of carbon dioxide, water vapour and sensible heat
3. To use the inverse Lagrangian approach to deduce source/sink distributions of CO_2 heat and water vapour within the Siberian forest
4. To compare results with predictions of a multi-layer model and the measured fluxes

A.3. Methods

Site: The observations were made in and above a Scots pine forest about 35 km west of the town of Zotino (61° N, 90 °E) in central Siberia. Measurements were made from 24 June until 15 July 1999. The soil is sandy with low organic and nutrient content and the trees are 20 m tall and are about 120 years old. Leaf area index at the site was estimated to be 2. There are few understorey shrubs and the ground is covered by lichens and

mosses which became progressively more dessicated and brittle during the observation period since no rain fell during this time.

Profiles: Profiles of the concentrations of CO_2, water vapour and temperature within and above the canopy are required to estimate the source/sink strengths for CO_2 water vapour and sensible heat using the Inverse Lagrangian analysis. Profiles of σ_w, the standard deviation of vertical velocity fluctuations are also required for the analysis.

Concentrations of CO_2 and water vapour were measured in air sampled continuously at 9 heights (6 within canopy space, 3 above) and then passed sequentially via a gas-switch through a LiCor 6262 infrared gas analyser. Fine thermocouples (100 μm in diameter) were used to measure temperatures, and net radiation was measured using 1-m long, linear net radiometers. Both quantities were measured at the same heights as the air intakes.

Profile of σ_w were measured using 5 Gill sonic anemometers placed above and within the canopy. The measurements were normalised using the friction velocity, u^*, measured above the canopy.

Eddy flux measurements: Two of the sonic anemometers (one above the canopy, the other at 1.4 m above the ground) were supplemented with fast-response LiCor 6262 gas analysers to measure eddy fluxes of water vapour and CO_2 at the two heights. Sonic virtual temperature was used to measure sensible heat fluxes.

Meteorological data: Quantities measured were:

- Net radiation
- Incoming and reflected solar radiation
- Temperature and humidity
- Windspeed and direction
- Soil heat flux
- Soil temperature
- Tree trunk temperatures

These measurements are needed to check energy closure by the eddy covariance system (sum of sensible and latent heat fluxes compared to Net radiation minus changes in heat storage in the soil and biomass). They are also used as input information to the model for canopy photosynthesis and energy partitioning.

Physiological measurements: Responses of needles to light and CO_2 were made using a LiCor 6400 photosynthesis instrument. Measurements were made on groups of 6 needles at three levels within the canopies of two trees, near the canopy top (18 m) in the middle (at 15 m) and at the crown base (10 m). The results were interpreted in terms of the model of C_3 photosynthesis developed by Farquhar et al. (1980). Responses of needles to temperature and humidity (water vapour deficit) were also measured and the results were interpreted using the combined photosynthesis-stomatal conductance model of Leuning (1995). Needles on which these measurements were made were dried and returned to Jena for analysis of nitrogen concentration.

One tree was felled and its foliage was sampled to determine the biomass and leaf area distribution as a function of depth within the crown. These data are essential for interpreting the results of the Inverse analysis and for translating from the two coordinate frames used: cumulative leaf area and height. Samples of needles were also retained, dried and returned to Jena for nitrogen concentration analysis.

A.4. Results

A.4.1. Profiles

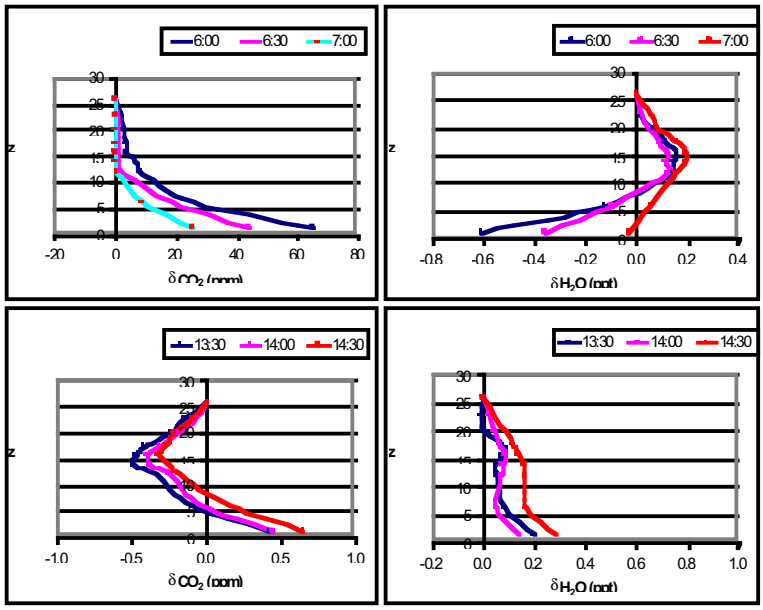

Fig. A.1: Ensemble-average profiles for CO_2 and H_2O concentrations (expressed as mixing ratios). The concentrations are given as the concentration at each level minus that at the reference level of 25.7 m. Both were measured using a a LiCor 6262 infrared gas analyser.

To determine the source/sink distributions for CO_2, water and heat within the canopy, it would be ideal to measure the spatial averages of concentrations at each height across a plane large compared to the spatial variability of the canopy. This is not feasible in practice, so temporal averages are used with the expectation that air reaching the sampling point at the mast is representative of the larger plane. This is satisfactory provided there are no systematic effects associated with a particular sampling point. To increase the number of data contributing to each point in a profile, the data for each corresponding hour for the 21 days of measurement were combined to form an ensemble-average. This procedure yielded 48 half-hourly profiles for the observation period when weather conditions were uniformly fine and sunny.

Ensemble-averaged profiles for CO_2 and water vapour are shown in Fig. A.1 for two times, early morning and mid-afternoon. The morning profiles for CO_2 show a monotonic decrease in concentration with height, with very large gradients in the lowest 10 m. Qualitatively, these profiles indicate strong respiration at the soil surface and also respiration by the canopy. The profiles for water vapour at this time are quite surprising, in that concentrations close to the ground are lower than at the base of the canopy, indicating that water is being absorbed by the groundcover of lichen. The profiles show that there was transpiration by the canopy and that there was a net loss of water to the atmosphere.

Daytime profiles for CO_2 reveal that the soil and lichen cover is a net source of CO_2, while the canopy is a sink for this respiration and for CO_2 from the atmosphere. The daytime profiles for water vapour indicate that both the soil/lichen and the canopy are sources. It is not possible to be more quantitative concerning the magnitude of these sources/sinks without the Inverse Lagrangian analysis, because the concentration profiles observed depend both on the source/sink strengths and the turbulence within and above the canopy. The inverse analysis has not been completed at this stage.

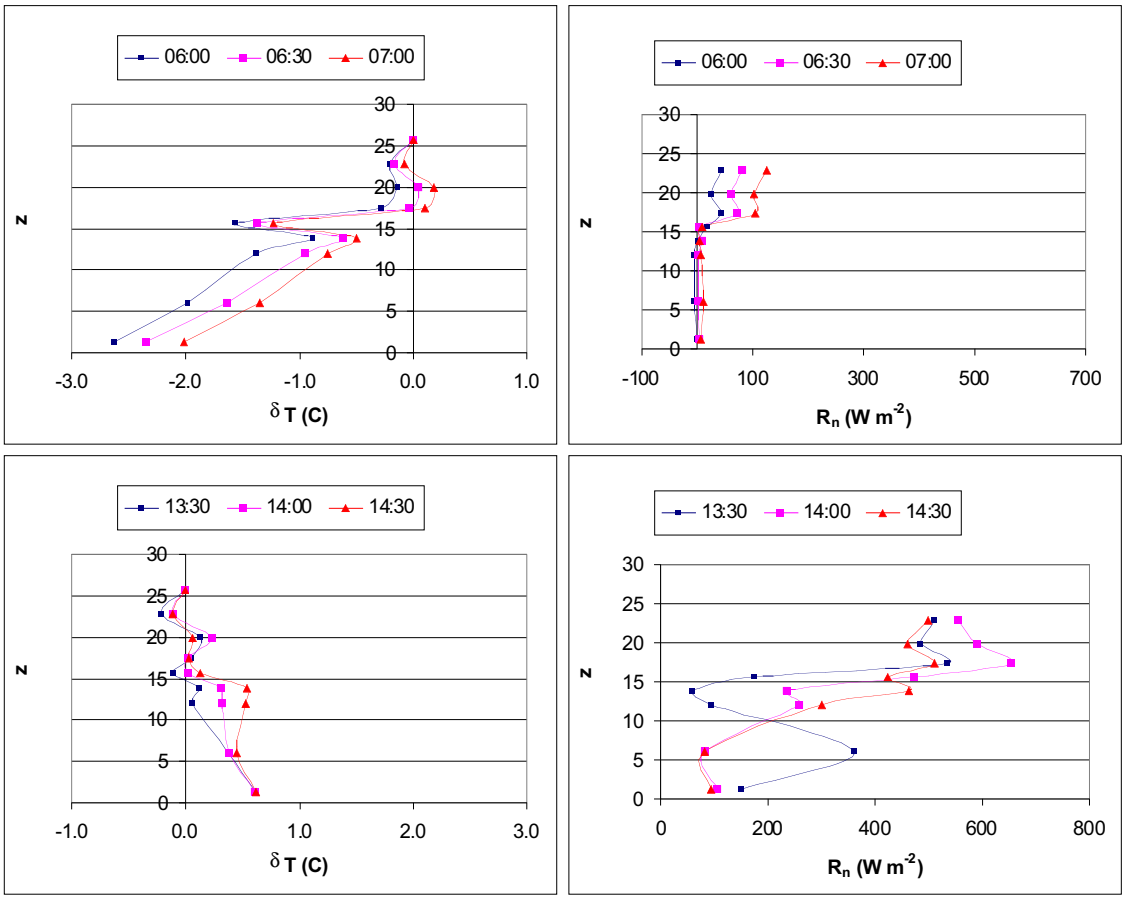

Fig. A.2: Ensemble-average profiles of temperature and net radiation. Temperature was measured using unventilated and unshielded thermocouples (100 µm diam.), and net radiation was measured with 1-m long linear net radiometers.

Fig. A.2 shows ensemble-average profiles for temperature and net radiation for the same periods as in **Fig. A.1**.The profiles for both temperature and net radiation are more convoluted than is the case for CO_2 and water vapour. In the early morning, the temperature profiles suggest that the canopy and the ground are both sinks for heat, although the lower canopy appears to be a source. The temperature gradients are much larger in the morning compared to the afternoon as a result of increased atmospheric mixing during the day. The sign of the profiles has also changed, indicating both the ground and canopy are sources of sensible heat. These results need to be interpreted cautiously because the very fine thermocouples used to make the measurements were not shielded from radiation nor were they ventilated. This is less than ideal and resulted from limitations to electrical power needed to operate ventilation fans at the remote site.

The rather open canopy structure also caused problems in making representative measurements of the distribution of net radiation within the canopy **(Fig. A.2)**. This is most evident for the profile at 13:30h, when the radiometer at 6m was clearly in the sun while those at 12 – 16 m were in the shade. These results are to be expected for sparse canopies at high sun angles, and indicate the difficulties in making representative spatial averages using instruments at fixed positions. The problem is not apparent early in the morning when sun angles are low and the canopy intercepts most of the incoming solar radiation.

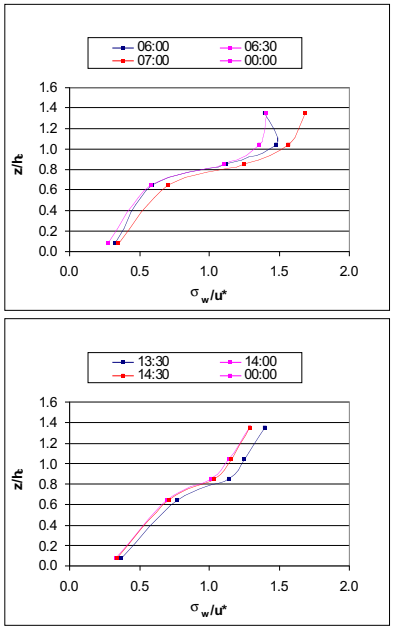

Fig. A.3: Profiles of standard deviation of vertical velocity normalised by the shear stress, σ_w/u^*, plotted as a function of normalised height z/h_c, where h_c is the canopy height.

Profiles of σ_w, normalised by the shear stress above the canopy, u*, are plotted as a function of normalised height in **Fig. A.3**. There is considerable variation in σ_w/u^* during the day, both within and above the canopy. This may result from differing atmospheric stability levels and is the subject of further analysis.

A.4.2. Fluxes

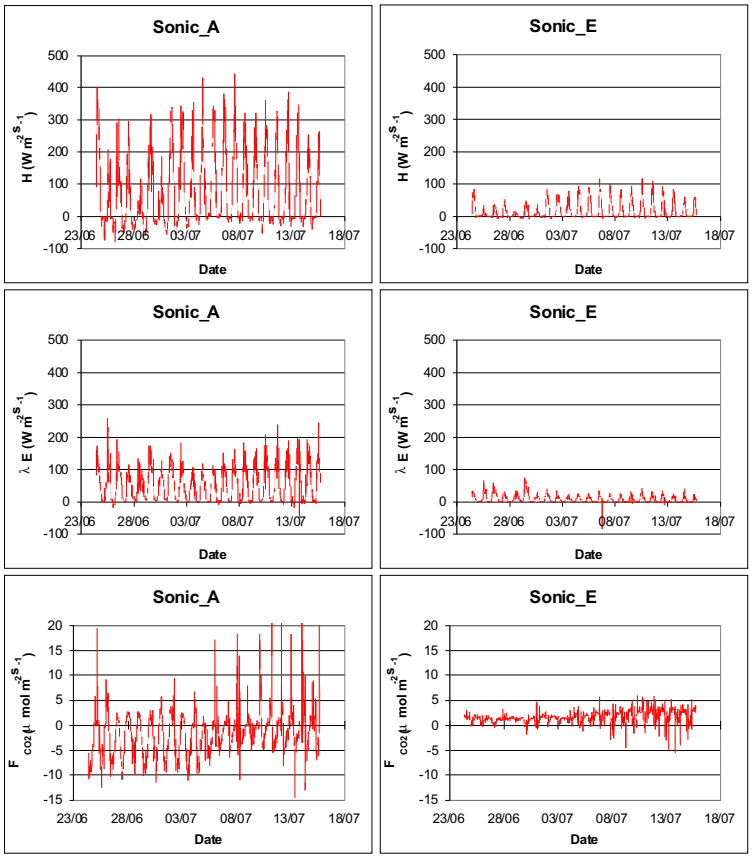

Fig. A.4: Time series of fluxes for heat, water vapour and CO_2 measured above the canopy (Sonic A at 25.7 m) and above the ground (Sonic E at 1.4 m).

Fluxes of sensible heat, water vapour and CO_2 measured above the canopy at 25.7 m and above the ground at 1.4 m are shown in **Fig. A.4**. Peak fluxes of sensible heat were typically twice those of latent heat, indicating the canopy was under some degree of water stress. This is consistent with the low water holding capacity of the sandy soil, and the depth to the ground water table being in excess of 2 m.

Sensible heat fluxes above the canopy exceeded 300 W m^{-2} during the day, while fluxes below the canopy were generally < 100 W m^{-2}. According to the eddy covariance measurements, heat fluxes near the ground were positive, or weakly negative which is consistent with the daytime temperature profiles shown in **Fig. A.2**, but not with the early morning profiles. Similar observations apply to the fluxes and profiles of water vapour. The early morning profiles suggest downward transfer while the eddy covariance measurements show fluxes close to zero. One explanation is that turbulence levels are low at these times, allowing for strong concentration gradients even though source/sink strengths are small. Further work is necessary to resolve this issue. This will be done during the Inverse Lagrangian analysis.

A.5. Physiological measurements

A.5.1. Photosynthesis

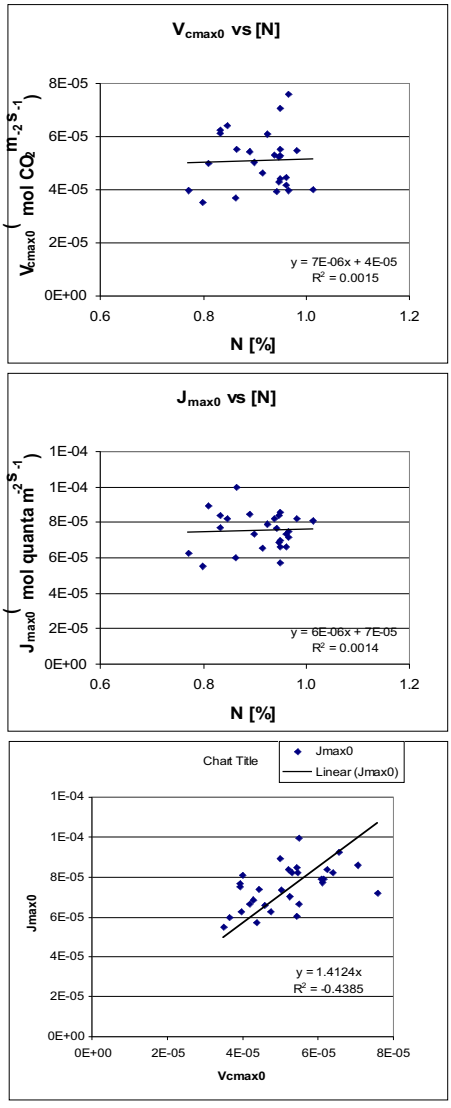

Fig. A.5: Plots of V_{cmax0} and J_{max0} as a function of needle N concentration (% on mass basis). Also shown is the correlation between J_{max0} and V_{cmax0}.

Light and CO_2 response curves measured on needles within the canopy were analysed using a non-linear parameter estimation algorithm to fit key parameters of the C_3 model developed by Farquhar et al. (1980). Nitrogen concentrations were also measured on the needles used for the photosynthesis measurements.

No significant variation with canopy depth was observed for the parameters V_{cmax0} (the maximum rate of Rubisco activity at the reference temperature of 20 °C), J_{max0}, the maximum electron transport rate and R_{d0}, day respiration **(Tab. A.1)**. There was also no correlation between needle nitrogen concentration and either V_{cmax0} or J_{max0} **(Fig. A.5)**. It should be noted that both the range and magnitude of the N concentration is very low, with N concentrations typically between 0.8 and 1.0% on a mass basis. **Fig. A.5** also shows that the slope of the correlation between J_{max0} and V_{cmax0} is 1.4, which is considerably lower than the value of 2.0 observed by Wullschleger (1993) in a literature survey of over 100 plant species.

Table A.1. Summary of parameter values for the Farquhar et al. (1980) model of C_3 photosynthesis for needles in the top, middle and bottom of the Scots pine canopy, which extended from 20 to 10 m.

Canopy level	*Parameter*	*Mean*	*Standard Dev*	*No. obs*
Top	V_{cmax0} (μmol CO_2 m^{-2} s^{-1})	49.1	10.8	12
	J_{max0} (μmol quanta m^{-2} s^{-1})	75.2	10.9	
	R_{d0} (μmol CO_2 m^{-2} s^{-1})	0.8	0.2	
Mid	V_{cmax0}	49.8	11.2	8
	J_{max0}	71.4	12.5	
	R_{d0}	0.5	0.2	
Bottom	V_{cmax0}	56.4	8.7	10
	J_{max0}	77.0	10.2	
	R_{d0}	0.9	0.2	

A.5.2. Humidity response

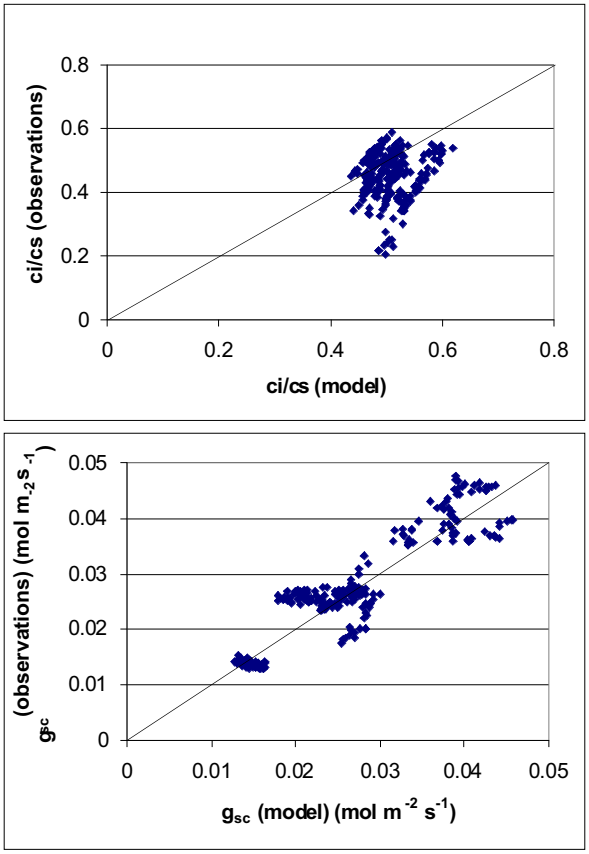

Fig. A.6: (a) Comparison of c_i/c_s, the ratio of intercellular CO_2 concentration to that at the needle surface, as observed using the Licor 6400 photosynthesis instrument and predicted using the stomatal model of Leuning (1995). (b) comparison of observations and model predictions of stomatal conductance for CO_2. Note the very low values of c_i and g_{sc}.

Measurements were also made to determine the response of the needles to changes in atmospheric humidity. The results were interpreted using the combined stomatal-conductance and photosynthesis model of Leuning (1995) and are shown in **Fig. A.6**. Both g_{sc} and c_i/c_s were very low and the model was able to capture only part of the variation in both. Stomatal conductance in Scots pine appears to be insensitive to changes in light, CO_2 or humidity levels, at least on the time scales of 5 –10 minutes allowed for stability to be achieved for the light and CO_2 response curves, and the 15 minutes allowed for reaction to changes in humidity level. As a consequence, a change in irradiance, for example, will cause the biochemical component of photosynthesis to respond leading to changes in c_i without a corresponding change in g_{sc}. This is contrary to Leuning's model which implicitly requires g_{sc} to change in such a manner that c_i remains approximately constant.

A.5.3. Further analysis

As outlined in the Introduction and Objectives, a key reason for making the above measurements was to estimate source/sink strengths for CO_2, water vapour and heat using the Inverse Lagrangian analysis. This work still needs to be done, noting the above reservations concerning the complex shapes of the various profiles. Another objective was to compare predictions of a canopy model with eddy flux measurements. The ground work has been done in terms of the leaf-level physiological measurements but the model still needs to be run. Once these tasks are completed, the work will be written up in a form suitable for publication.

Appendix B: Flux data quality based on energy balance closure

B.1. Zotino, pine forest, June 8 – October 2, 1998

1.1. $(H + LE) = a_1 (Rn – G - S_H) + a_2$

Half - hourly averages, S_H is sensible heat storage

117 days are whole period

Conditions	Number of half-hourly data	a_1	a_2	R^2
1. Whole period, no conditions (day -and nighttime, 24 hours)	4852	0.71	5.73	0.93
2. Whole period, $u^* > 0.4$ m s^{-1} (day -and nighttime, 24 hours)	2741	0.74	0.76	0.92
3. Whole period, u* > 0.4 m s^{-1} and PAR > 0 (daytime)	2556	0.74	0.20	0.91
4. Whole period, u* > 0.4 m s^{-1}, PAR >0 (daytime) and no rain	2363	0.73	5.34	0.92
5. Whole period, u* > 0.4 m s^{-1}, PAR >0 (daytime); Rn>0; and no rain	1876	0.73	7.74	0.88
June	523	0.77	5.16	0.89
July	699	0.70	17.06	0.87
August	442	0.67	13.78	0.85
September	212	0.83	-12.03	0.83

Variable averaged for 24 hours (Ave ±SE, where SE = SD * square root $(1-R^2)$), W m^{-2}:

Rn = 114.6 ± 4.02; (LE+H+G) = 36.86 + 46.1 + 3.14 = 86.10 ± 3.50.

1.2. $(H + LE) = a_1 (Rn-G) + a_2$

Half-hourly averages, no storage

Month Conditions: 1) PAR>0 (day); 2) u* >0.4 m s^{-1}; 3) no rain	Number of half-hourly data	a_1	a_2	R^2
1. June	523	0.75	6.10	0.92
2. July	699	0.70	14.30	0.93
3. August	442	0.68	4.0	0.90

Tver, the CFR, spruce forest and bog, 1998, 1999

a) $(H + LE) = a_1 (Rn – G - S_H) + a_2$

b) $(H + LE) = a_1 (Rn – G) + a_2$

Half-hourly averages, S_H is sensible heat storage

Fluxes are rejected by stationarity test. Storage of latent heat is not included.

Conditions	Number of half-hourly data	a_1	a_2	R^2
1.1) Forest, May 27 – September 30, 1998, all data	3869	0.81	-7.2	0.90
a	3869	0.79		0.90
	3869	0.79	-5.5	0.90
b	3869	0.78		0.89
1.2) Bog, June 13 – October 12, 1998, all data	3104	0.59	8.6	0.90
	3104	0.62		0.89
a	3104	0.59	8.8	0.89
b	3104	0.61		0.89
1.3) Forest, November 1, 1998 – Febraury 22, 1999	1341	0.46	-10.8	0.13
	1341	0.41		0.08
a	1341	0.50	-11.4	0.16
b	1341	0.45		0.11
2. Forest, March 3 – August 31, 1999, all data	4709	0.69	4.8	0.91
a	4709	0.70		0.91
	4709	0.68	6.9	0.90
b	4709	0.69		0.90
Bog, March 26 – August 31, 1999, all data	6702	0.55	12.40	0.65
a	6702	0.59		0.64
b				

3. Forest, May 27 – September 30 1998				
A. All half-hourly data				
3.1) u*>0.25 m s $^{-1}$	3131	0.85	-16.9	0.91
a	3131	0.80		0.90
3.2) u* > 0.4 m s $^{-1}$	2372	0.87	-23.9	0.90
a	2372	0.81		0.90
3.3) V > 2 m s $^{-1}$	1767	0.87	-24.3	0.91
a	1767	0.81		0.90
3.4) L < 0 m	1615	0.83	-8.2	0.86
a	1615	0.81		0.86
3.5) no rain	3463	0.81	-2.8	0.91
a	3463	0.80		0.91
3.6) V > 2 m s $^{-1}$, no rain	1510	0.86	-16.8	0.91
a	1510	0.82		0.91
B. Daytime, PAR>0	2588	0.84	-14.5	0.89
a	2588	0.80		0.88
V > 2 m s $^{-1}$, no rain	1111	0.87	-20.6	0.89
a	1111	0.82		0.89
C. Nighttime, PAR = 0, V > 2 m s $^{-1}$, no rain	311	0.17	-40.3	0.04
a	311	0.81		0.01

4. Forest, November 1, 1998 – February 22, 1999				
A. All half-hourly data				
4.1) u*>0.25 m s $^{-1}$	1166	0.55	-13.3	0.16
b	1166	0.48		0.11
4.2) u* > 0.4 m s $^{-1}$	915	0.62	-15.9	0.14
b	915	0.53		0.06
4.3) V > 2 m s $^{-1}$	694	0.61	-19.2	0.11
b	694	0.51		0.01
4.4) L < 0 m	398	0.30	26.0	0.17
b	398	0.60		0.01
4.5) no precipitation	1309	0.50	-10.6	0.17
b	1309	0.46		0.12
4.6) V > 2 m s $^{-1}$, no precipitation	667	0.62	-18.2	0.11
b	667	0.52		0.01
B. Daytime, PAR>0	552	0.54	-12.9	0.24
b	552	0.43		0.19
V > 2 m s $^{-1}$, no precipitation	277	0.67	-21.1	0.23
b	277	0.45		0.12
C. Nighttime, PAR = 0, V > 2 m s $^{-1}$, no precipitation	229	0.47	-13.5	0.04
b	229	0.95		0.01

5. Forest, April 19- August 31 1999				
A. All half-hourly data				
5.1) u*>0.25 m s $^{-1}$				
a	3444	0.72	-3.3	0.90
	3444	0.71		0.90
5.2) u* > 0.4 m s $^{-1}$				
a	2462	0.73	-3.0	0.88
	2462	0.72		0.88
5.3) V > 2 m s $^{-1}$				
a	1628	0.73	-1.8	0.90
	1628	0.72		0.90
5.4) L < 0 m				
a	2584	0.70	4.6	0.80
	2584	0.71		0.80
5.5) no rain				
a	4558	0.69	6.4	0.91
	4558	0.70		0.91
5.6) V > 2 m s $^{-1}$, no rain				
a	1555	0.72	0.8	0.90
	1555	0.72		0.90
B. Daytime, PAR>0				
a	3693	0.70	1.0	0.89
	3693	0.70		0.89
V > 2 m s $^{-1}$, no rain				
a	1395	0.72	2.2	0.87
	1395	0.73		0.87
C. Nighttime, PAR = 0, V > 2 m s $^{-1}$, no rain				
a	160	0.41	-20.4	0.37
	160	0.70		0.14

6. Bog, June 12 – October 10, 1998				
A. All half-hourly data				
6.1) u*>0.25 m s^{-1}				
a	1527	0.62	4.5	0.90
	1527	0.63		0.90
6.2) u* > 0.4 m s^{-1}				
a	350	0.65	-5.8	0.91
	350	0.64		0.91
6.3) V > 2 m s^{-1}				
a	2339	0.60	6.9	0.90
	2339	0.62		0.89
6.4) L < 0 m				
a	2165	0.60	7.6	0.86
	2165	0.62		0.86
6.5) no rain				
a	2596	0.59	11.4	0.90
	2596	0.62		0.89
6.6) V > 2 m s^{-1}, no rain				
a	1913	0.59	10.5	0.90
	1913	0.63		0.89
B. Daytime, PAR>0				
a	2492	0.59	8.7	0.88
	2492	0.62		0.87
V > 2 m s^{-1}, no rain				
a	1627	0.59	12.0	0.87
	1627	0.63		0.87
C. Nighttime, PAR = 0, V > 2 m s^{-1}, no rain				
a	186	0.20	-0.7	0.29
	186	0.22		0.28
D. excluding errors in calibration by H_20; total conditions: no rain + 1.5 h after precipitation, excluding half-hourly data with condensation	2882	0.57	13.42	
6.7) all data b	2367	0.57	13.31	
6.8) PAR> 0, daytime b	515	0.10	0.80	
6.9) PAR = 0, nighttime b	1106	0.60	12.70	
6.1.1) all data, u* > 0.25 m s^{-1} b	220	0.61	11.12	
6.1.2) all data, u* > 0.4 m s^{-1} b	1950	0.58	11.58	
6.1.3) all data, L<0 m (unstable) b	68	0.65	12.08	
6.1.4) all data, L>1000 m b				
(near neutral)	864	0.18	4.05	
6.1.5) all data, 0 <L< 1000 m(stable) b				

7. Bog, June-August 1999				
(excluding errors in calibration by H_20; total conditions: no rain + 1.5 h after precipitation, excluding half-hourly data with condensation)				
7.1) all data June b				
July b	1204			
August b	1118	0.57	8.61	
	963	0.76	9.69	
		0.71	7.43	
7.2) PAR>0 June b				
(daytime) July b	944			
August b	904	0.57	6.95	
	725	0.76	7.81	
		0.71	5.69	
7.3) PAR=0 June b				
(nighttime) July b	260			
August b	214	0.40	6.72	
	238	0.40	5.30	
		0.10	0.61	
7.1.1) all data June b				
$u^* > 0.25$ m s^{-1} July b	315			
August b	384	0.56	16.99	
	263	0.77	19.57	
		0.71	12.28	
7.1.3) all data June b				
L<0 m (unstable) July b	788			
August b	746	0.57	8.92	
	668	0.78	2.12	
		0.73	3.43	
7.1.5) all data June b 0<L<1000 m (stable) July b	404			
August b	359	0.01	0.40	
	283	0.47	8.85	
		0.19	2.19	

WIND DIRECTION (WD) (for horizontal wind speed over 2 m s^{-1})

	Forest 27.05.-30.09.98		Forest 19.04.-31.08.99		Bog 13.06.-12.10.98		Bog 01.05.-31.08.99	
	n	a_1	n	a_1	n	a_1	n	a_1
WD = 0 – 45°	**169**	**0.59**	303	0.72	**34**	**0.49**	574	0.62
WD = 45 – 90°	65	0.61	94	0.71	44	0.55	184	0.63
WD = 90 – 135°	156	0.77	**218**	**0.64**	132	0.60	341	0.63
WD = 135 – 180°	249	0.81	155	0.68	173	0.63	381	0.62
WD = 180 – 225°	490	0.78	241	0.69	**243**	**0.64**	**446**	**0.58**
WD = 225 – 270°	**341**	**0.87**	226	0.78	287	0.61	622	0.60
WD = 270 – 315°	**159**	**0.87**	**200**	**0.81**	290	0.63	603	0.62
WD = 315 – 360°	139	0.78	192	0.76	83	0.63	**486**	**0.67**