P7–CARBON BALANCE IN FOREST BIOMES

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Session Website: http://www.plantsci.cam.ac.uk/forestbiomes

P7.1–The Global Imperative and Policy for Carbon Sequestration

R.T.Watson and I.R.Noble (The World Bank)

Human activities are significantly altering the carbon cycle through energy and land-use practices and policies. Governments have acknowledged that this human perturbation to the carbon cycle is changing the Earth's climate and most have signed and ratified the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. Governments have further recognized that Land-Use, Land-Use Change and Forestry (LULUCF) activities can play a vital role in decreasing the net emissions of carbon into the atmosphere through a range of agricultural, rangeland and forestry activities. During the first commitment period industrialized countries have to account for their greenhouse gas emissions and uptakes associated with afforestation, reforestation and deforestation in their national accounts and, in addition, can use a range of other domestic LULUCF activities to meet their Kyoto commitment. They can also gain additional credits through afforestation and reforestation activities in developing countries through the Clean Development Mechanism. However, many of the rules relating to LULUCF activities apply only for the first commitment period. An interesting question is how LULUCF activities will be addressed during the second and subsequent commitment periods. Some governments are arguing for 'wall to wall' accounting of all uptakes and emissions in industrialized countries, whereas others argue for a limited set of site-specific activities. Another question is whether 'wall to wall' emissions can be accurately measured and whether certain factors influencing carbon uptake and release, i.e., increasing atmospheric carbon dioxide concentrations, nitrogen and sulfur deposition rates, climate variability, and forest age structure, can or should be factored out. A third question is whether additional activities in developing countries will be eligible for credit, e.g., agricultural and rangeland activities, and avoided deforestation, and how issues of permanence, leakage, baselines will be addressed.

P7.2–The Role of Forest Biomes in the Global Carbon Balance

J. Grace (University of Edinburgh)

Forest biomes contain large stocks of carbon. They impact upon the natural cycles of carbon, nitrogen and water, and they influence the radiation balance of the planet. They constitute substantial sinks for carbon dioxide. Recent work in tropical, temperate and boreal forests demonstrates the general characteristics of these sinks. They vary seasonally and between years, and they leave their imprint on the atmosphere as changes in the concentrations of CO_2 and its isotopes. They also provide tangible services for humankind in the form of timber products which enter a chain of utilisation. This chain also needs analysis from the point of view of its capacity to enhance the carbon sink. It has been suggested that the sinks will become sources as a result of climate warming and increased drought. The evidence for this is not clear-cut. Management of forest sinks in the framework of the Kyoto Protocol is an important opportunity to contribute to the goals of the Protocol, but there are substantial gaps in our capacity to conduct adequate surveillance as well as in our knowledge of how the carbon cycle works. More work is needed to understand some of the key processes and to elucidate the feed-backs.

P7.3–Global modelling and the need for empirical validation

P. Ciais (LSCE Saclay)

The current sink of CO_2 over land, as detected from atmospheric studies, is substantial, and must thereof be reconciled with ecosystem data. The net sink, or Net Biomes Productivity (NBP) is replaced here in the context of the input of carbon to ecosystems (NPP) over three contrasted regions of the world : Europe, Amazon and Siberia. An analysis of multiple sources of data (atmospheric inversions results, ecological studies, biogeochemical models calculations) indicates that the NPP and carbon turnover times in Europe and Siberia are not compatible with the process of rising CO_2 alone, called CO_2 fertilisation, for explaining the observed NBP value. In Europe, CO_2 fertilisation may account for no more than 15% of NBP, against 25% over Siberia. The rest is attributed to N-deposition, changes in climate, in management and in disturbance regimes. On the other hand, over the Amazon region, almost all of the current NBP estimate can be explained by rising CO_2, although the uncertainties are quite large.

P7.4–Regional-scale measurements of CO_2 and isotope flux through the atmospheric boundary layer

B.R. Helliker, J.A. Berry (Carnegie Institution of Washington), A.S. Denning (Colorado State University), K. Davis (Pennsylvania State University) and P. Bakwin (NOAA, Colorado)

For the past decade, eddy-correlation systems have been established world-wide to quantify carbon dioxide flux and storage at local scales, as well as to test and improve models that simulate these processes. The integrated system of observations and models has been developed as a basis for predicting and interpreting the role of terrestrial ecosystems in the carbon balance of planet earth. One major limitation in this effort to 'scale-up' from ecosystem studies to the globe is the gap in scales at which it is possible to make quantitative measurements. Here we describe a method to estimate regional or intermediate scale CO_2 flux and ^{13}C isotope discrimination using the mean gradients in CO_2 mixing ratio and isotopes between the atmospheric boundary layer and the free troposphere over a forested region in northern Wisconsin (USA). Using monthly flask measurements from a 400 m tall tower in Wisconsin and a mountain top in Colorado, in concert with continuous environmental measurements from the tower, we constructed monthly and annual estimates of the net isotopic signature and CO_2 flux imparted to the free troposphere.

P7.5–Constraining regional carbon dioxide fluxes with surface concentration measurements

J.M. Styles, B.E. Law (Oregon State University) and M.R. Raupach (CSIRO Land and Water)

Carbon dioxide concentrations measured at eddy covariance flux sites have the potential to be used both in isolation and with global inverse models to derive or improve estimates of carbon dioxide fluxes at regional to continental scales. Here we show that the monthly and annual mean of daily surface CO_2 concentration drawdown can be quantitatively related to CO_2 flux measured by the eddy covariance technique above several forested sites spanning a wide range of latitudes. Factors contributing to deviation in slope and intercept from the relationship predicted by a simple atmospheric boundary layer budget include the near-surface vertical concentration gradient and mixing of free tropospheric air into the boundary layer. The relationship found, however, was robust across 20 forested sites at monthly, annual and seasonal resolution. CO_2 drawdown averaged over the 20 sites ranged from -3.3 ± 0.5 ppmv in winter months to -10.2 ± 0.9 ppmv in summer. Interannual variation in summer daytime fluxes averaged across all sites was highly correlated with interannual variation in summer drawdown in CO_2 concentration measured at background monitoring sites within the Globalview-CO_2 network. This suggests that the eddy covariance networks across the globe may be of sufficient breadth and variety to give a reasonable representation of the vegetative influence on global CO_2 concentrations.

P7.6–Integration of Earth Observation data into ecological models

S Quegan (CTCD, University of Sheffield)

Information about several of the terms needed in functional models of vegetation–soil systems is potentially available from airborne and/or spaceborne remote sensing. This includes actual functional terms, such as information on photosynthesis, measurements of the state of the system, such as biomass or soil moisture, and information on system constraints, such as land cover. However, the link between the measurements and the models is rarely straightforward. This has two aspects: (1) the models were not developed with remote sensing data in mind, and hence they have devised other means to infer important variables, such as burnt area; (2) the measurements from remote sensing instruments are usually not direct estimates of what the models are set up to use, but are inferences from measured radiances or backscatter. In addition, there are constraints on the availability of the remote sensing data, as regards access to the appropriate sensors, orbital characteristics and possible loss of coverage due to cloud and darkness. This paper will discuss both how the models could benefit from use of remote sensing data and the extent to which current and/or near future satellite data may be able to meet the needs of the models. It will particularly concentrate on the use of the fraction of absorbed photosynthetically active radiation (fAPAR), biomass and fire. The use of airborne data will also be discussed.

P7.7–Regional measurements of carbon balances

A.J. Dolman (Vrije Universiteit, Amsterdam)

Regional carbon balances fill in the gap between the local scale flux measurements and continental scale atmospheric inversions. They have the advantage that they integrate over large areas that become compatible with the estimates obtained from atmospheric inversion models. They furthermore take full account of the spatial heterogeneity of the surface and the diurnal dynamics of the surface atmosphere exchange in the boundary layer and thus avoid some of the problems with larger scale models. There are several techniques to determine the regional carbon balance. Convective boundary layer budgeting uses the integrating property of the boundary layer to derive the flux from two profiles, taken at different times. Another way is to use aircraft that sample over larger horizontal regions in either Eulerian and Lagrangian (airmass following) patterns. It is now also possible to use low flying aircraft to measure fluxes with good accuracy. Concurrent with these experimental techniques mesoscale models are upgraded to carry CO_2. A new development is the use of inverse models at regional scale. The techniques will be reviewed and the relative advantages and disadvantages for each technique will be discussed. This will be illustrated by examples from several, mostly recent, projects executed around the world.

P7.8–Eddy covariance data assimilation keeps biologically-based multi-layered SVAT model on track

E. Falge (University of Bayreuth)

Contemporary models of ecosystem fluxes require a flood of parameters for radiative transfer, leaf gas exchange, soil and stem respiration, water balance or phenological modules. In large-scale applications, one cannot expect to define those parameters accurately adjusted to each pixel of the area, especially when using multi-layered SVAT schemes. In contrast, one has to work with vegetation types, e.g. with generalized assumptions on leaf physiology, soil properties or even leaving out processes assumed to be less relevant (e.g. seasonality or drought effects). However, simplifying parameters to the most sensitive comes at a cost: the model begins failing to predict appropriately measured fluxes. To overcome this problem, we used a data assimilation technique that allows the combination of Eddy covariance flux observations with a multi-layered SVAT model. We compared the model estimate with the measured flux, and adjusted key model parameters in such a way that modeled fluxes fall into the error bounds of the measured value. We applied the model for five years of meteorological conditions for a Scots Pine, a Beech, and a Norway Spruce forest from the Carbo-EUROFLUX project, and compared the model performance for various time steps of 'adjustment'. As a result, we tried to derive rules how often 'simplified' versions of SVAT models would need to be adjusted by appropriate measurements. As a side product, the method allowed to assess seasonal variation of leaf physiological parameters, drought and/or phenological effects, as derived from Eddy covariance data, providing useful information for future parameterization of land surface schemes.

P7.9–Linking modelling and observations to improve estimates of forest carbon balance

M. Williams (University of Edinburgh), B.E. Law & P. Schwarz (Oregon State University)

Our goal is to produce estimates of ecosystem carbon exchange with quantifiable uncertainty, by linking models and observations. Observations quantify the state and activity of various components of an ecosystem, but it is rarely possible to observe all the critical processes, and observations may be undermined by instrumental weaknesses. Models can provide a coherent description of the system and its interactions, but models tend to oversimplify and may miss key processes and linkages. Data assimilation provides a method to combine models and data to produce a more accurate description of the ecosystem. The model provides the structure of C pools and flows, and incorporates principles such as conservation of mass, while the observations constrain these dynamics. We demonstrate how a Kalman filter can probe model structure, improve model calibration, and generate better estimates of ecosystem C exchange.

P7.10–Assessment of annual CO_2 flux from Russian terrestrial ecosystems by modelling and GIS-approach

I. Kurganova, V. Kudeyaro (Russian Academy of Science, Moscow) and A. Shvidenko (International Institute for Applied System Analysis, Laxenburg, Austria)

Emission of CO_2 from soils is main expense of carbon balance. As a rule, annual carbon dioxide flux (ACDF) from soils is believed to amount to total CO_2 flux during warm or growing season. However, the contribution of cold period to ACDF from boreal soils may be considerable. We collected experimental literature data reporting the annual field measurements CO_2 flux from soils of different European regions (20 ecosystems). Using these data we calculate the contribution of summer CO_2 flux (June–August, F_s) to ACDF. It has been found that the contribution of summer flux to ACDF (C_s) closely correlated with mean annual air temperature and may be adequately quantified by linear ($R^2=0.91$) and polynomial ($R^2=0.95$) regressions. If the summer CO_2 fluxes (F_s) are known, it is easy to calculate ACDF as a function F_s and C_s. Using equations obtained and our Data Base on CO_2 emission from Russian soils we estimated ACDF from 375 different ecosystems. Results of our simulations and the GIS-approach application allowed us to assess total annual carbon dioxide fluxes from Russian territory. ACDF from Russian soils constituted 5.67 Pg C by linear and polynomial model. The heterotrophic and autotrophic annual carbon dioxide fluxes from Russian territory were 2.78 and 2.89 Pg C, respectively. Using GIS approach we developed the maps of total, heterotrophic and autotrophic soil respiration. This study was supported by International Institute for Applied Systems Analysis (YSSP–2001) and Russian Foundation for Basic Researches (projects No 01-04-48468, No 02-04-48623).

P7.11–Carbon balance in China's forests from 1982 to 1998

M. Xu (Rutgers University) P. Gong, Y. Qi, (University of California) and J. Chen, National Institute for Environmental Studies, Japan

Carbon balance of China's terrestrial ecosystem from 1982 to 1998 was estimated based on a GIS-based ecosystem model using satellite (AVHRR) and ground data, such as climate, vegetation, and soil type. The model was calibrated using more than 1000 ground NPP plots and forest inventory plots. Soil heterotrophic respiration was estimated using a steady state approach. We found that China's forest ecosystem was a net carbon source in 1980s and it turned to a net carbon sink since early 1990s suggesting the re-growth of China's young forest is sequestering a significant amount of carbon into the ecosystem from the atmosphere. Tropical and sub-tropical forests are net carbon sinks in winter and net carbon sources in summer, especially for the seasonal rain forest, and the opposite is true for temperate and boreal forests. NPP demonstrated a larger inter-annual variation than soil heterotrophic respiration (Rh).

P7.12–A new model for scaling from leaf lifespan to conifer forest structure and function

C.P. Osborne, S.J. Brentnall and D.J. Beerling (University of Sheffield)

Generic relationships between the lifespan, physiology and biochemistry of leaves have recently been quantified for the first time in contrasting biomes and functional groups. These relationships have important consequences for ecosystem biogeochemical cycles, and therefore offer the potential for simulating large-scale forest properties on the basis of leaf lifespan. We have used the scaling mechanisms involved to develop the University of Sheffield Conifer Model (USCM), a tool for simulating conifer forest carbon balance using data on leaf lifespan, climate and soils as inputs. Simulations of net primary production, carbon partitioning and leaf area index show close agreement with observations from sites across a wide climatic gradient. This indicates the generic utility of our model for modern forests, and adequate representation of the key processes involved in forest function. The new development of a technique for estimating leaf lifespan from the anatomical properties of fossil woods provides a secure basis for extrapolating model simulations to conifer forests of the geological past. Future simulations with our model will therefore examine forest feedbacks on the carbon cycle and palaeoclimate during warm intervals in the Mesozoic and early Tertiary.

P7.13–Carbon sequestration following afforestation of agricultural soils: comparing oak/beech forest to short rotation poplar coppice combining a process and a carbon accounting model

G. Deckmyn (University of Antwerpen UIA), J. Garcìa Quijano (KULeuven University), R. Ceulemans (University of Antwerpen UIA) and B. Muys (KULeuven University)

To compare the benefits for C-sequestration of afforestation with a multifunctional oak-beech forest vs. a poplar short rotation coppice (SRC), model simulations were run through a serial linkage of a mechanistic model and an accounting model. The process model SECRETS was used to predict growth, C-allocation and soil C. The output from SECRETS was used as an input for the carbon accounting model GORCAM yielding data on C sequestration in wood products, substitution of woodfuel for fossil fuel and total CO_2 emission reduction. Such carbon accounting based on a process model enables a more realistic calculation of forest growth, litter decomposition and soil processes. Moreover, it allows to simulate the influence of climate change on the carbon budget.

Net primary production of an oak-beech forest is low, a stable 2.5 tC/ha year after 150 years, compared to 6.2 tC/ha year for a SRC plantation. But while the yield from the poplar biomass is used as fuel and thus returns quickly to the atmosphere, the yield from the oak-beech forest is used in long-lasting wood products. The C sequestered in the mixed forest (living biomass and soil) over 150 years amounts to 296 tC/ha compared to 191 in the poplar coppice. However, when account is taken of the energy substitution coppice culture reduces emissions with 29 tCO_2/ha year while the mixed forest reduces only 6.88 tCO_2/ha year. These results demonstrate the added value of combining detailed process models with carbon accounting models to improve predictive capacity of model simulations.

P7.14–Fulfilling commitments made at Kyoto: monitoring carbon stocks across New Zealand's ecosystems, including land set aside for carbon credits

D.A. Coomes (University of Cambridge), I. Turney, R.B. Allen, N.A. Scott (Landcare Research, New Zealand) C. Goulding and P. Beets (Forest Research, New Zealand)

We provide an overview of initiatives underway in New Zealand to monitor C-storage in terrestrial ecosystems. Satellite imagery is being used to establish rates of land cover change, while an extensive network of permanent plot is being used to monitor per-hectare changes in carbon storage. The network of permanent plots has been kept simple deliberately. It is being established over the next 5 years on an 8-km grid, and will be re-measured every 10 years. On each plot, the dimensions of all trees, shrubs and coarse woody debris are being measured, and these data are converted to per-hectare C-stocks using regression relationships. C-stocks in fine litter and mineral soil are being quantified on the same sites. Biodiversity and structure is also assessed in to meet the needs of conservationists. We describe a scheme designed to monitor carbon sequestration for carbon credits, in indigenous shrublands and forests.

P7.15–Estimating terrestrial carbon fluxes at a national scale: the UK experience

R. Milne & M. Cannell (CEH Edinburgh)

For the UK the best understood terrestrial carbon flux is that associated with the expansion of forest area over the last 50 years. Modelling methods are described that were used to estimate this uptake of carbon for the Land Use Change and Forestry Sector in the Greenhouse Gas Inventory of the UN Framework Convention on Climate Change. Measurements of losses of carbon from afforested organic soils are also presented and the consequent effect on the net national carbon sink for forests is discussed. These calculations show that the expansion of forests is currently causing about 2.8–4.0 MtC y^{-1} to be removed from the atmosphere, depending on assessment of the situation for planted organic soils. Within these totals about 1.9 MtC y^{1} is being added to living trees, about 0.4 MtC y^{-1} to the stock of wood products and the rest to soils. A map of the variation in the net flux across Great Britain has also been prepared. The value and uncertainty in other UK terrestrial carbon fluxes are summarised. The most important of these, but the least certain, is shown to be that due to the effect of land use change on soils.

P7.16–The carbon balance of biomes: a review of methodologies, approaches and their applications

J. Lloyd, M. Gloor, C, Rödenbeck and M. Heimann (Max Planck Institute for Biogeochemistry, Jena, Germany)

We critically review the advantages and drawbacks of various methodological approaches to estimate terrestrial carbon balances at a range of spatial and temporal scales. The techniques discussed include eddy covariance, sequential biomass and soil carbon inventories, boundary layer budgeting, large scale atmospheric inversions and theoretical estimates from terrestrial carbon cycle models with some emphasis being placed on errors associated with eddy covaraince measurements and the general issue of scaling up stand level fluxes to the regional and continental scales. A second focus is a consideration of the viability of constraining continental scale terrestrial CO_2 balances using long-term measurements of CO_2 concentrations above the continents utilising either tall towers or by means of repeated aircraft sampling within and above the terrestrial boundary layer. We mostly utilise data obtained within and above the two largest forested ecosystems of the world (viz Amazonia and Siberia) as specific examples to show the utility and potential pitfalls of various methodological and scaling approaches generally employed when it comes to considering terrestrial carbon balances.

P7.17–Measurement of carbon exchange between the atmosphere and the boreal forest

A. Black (University of British Columbia), T. Gower (University of Wisconsin), B. Amiro (Canadian Forest Service), F. Kelliher (Landcare Research), D. Gaumont-Guay (University of British Columbia) and P.G. Jarvis (University of Edinburgh)

The boreal forest is the world's second largest forested biome occupying the circumpolar region between 50° and 70° north. This heterogeneous biome stores about 25% of all terrestrial carbon. We review measurements of carbon exchange between the atmosphere and boreal forests, and assess progress in understanding the controlling processes. Relationships between net primary production (NPP) and environmental variables have been determined using data from 24 forest stands with complete NPP budgets. Net ecosystem exchange (NEE), the balance between NPP and heterotrophic respiration measured using the eddy covariance (EC) method, is assessed at 22 sites. Nighttime NEE measurements estimate ecosystem respiration, including heterotrophic and autotrophic components, and, with daytime measurements, gross primary production (GPP). Maximum mid-day GPP values vary from 33 μmol m^{-2} s^{-1} for aspen to 6 μmol m^{-2} s^{-1} for larch stands. Small-scale exchange rate measurements using chambers and soil CO_2 concentration gradient measurements, as well as manipulative experiments such as stem girdling and soil heating are also reviewed. Both aircraft EC flux measurements and convective boundary layer carbon budgets have an important role in validating scaled-up tower-based estimates of regional carbon exchange. Long-term EC measurements, ongoing at 7 boreal sites, have shown the strong impact of spring weather and the growing season water balance on annual NEE. Estimating net biome production, incorporating the effects of disturbance due to forest fires and logging, has progressed significantly in recent years. Following disturbance, summer boreal chronosequence measurements suggest it takes 10 to 20 years before carbon uptake offsets the decomposition rate.

P7.18–Changes in and variability of net primary production across a black spruce fire chronosequence in boreal Canada

B. Bond-Lamberty, C. Wang and S.T. Gower (University of Wisconsin-Madison)

Net primary production (NPP, g C m^{-2} yr^{-1}) was measured in seven different-aged sites comprising a chronosequence of boreal black spruce (*Picea mariana* (Mill.) BSP)-dominated near Thompson, Manitoba, Canada. The sites burned in 1998, 1995, 1989, 1981, 1964, 1930, and 1850, and each site contained separate well- and poorly-drained stands. Tree, understory, bryophyte, coarse root, and fine root components of NPP were measured for three consecutive years. Total NPP was very low (50–100) immediately after fire, peaked at 12–20 years after fire (332 and 521 in the dry and wet stands, respectively) and declined by 50% in the oldest stands. Tree NPP peaked at 37 years after fire, and declined by 15–33% in older stands. Tree NPP came mostly from deciduous seedlings in the younger stands and black spruce in the older stands. Bryophyte NPP was as high as 297 g C m^{-2} yr^{-1} in the poorly drained stands. Belowground NPP was dominated by fine roots and comprised between 5% and 40% of total NPP, with the percentage generally increasing in older stands. Interannual NPP variability declined with stand age, and was higher in the poorly drained stands, and for understory and detritus production. Net ecosystem production (NEP), calculated using soil and woody debris respiration data from previous studies, implied that the youngest chronosequence stands are moderate C sources (−50 to −5 g C m^{-2} yr^{-1}), the middle-aged stands are strong sinks (100–300), and the oldest stands are slight to moderate sinks (2–70).

P7.19–Carbon balance research in a northern larch forest: continuous measurements by multichannel automated chamber systems

N. Liang, Y. Fujinuma and G. Inoue (National Institute for Environmental Studies, Tsukuba)

Net CO_2 flux of a 45–year–old northern larch forest has been taking place continuously throughout tower based approach since September 1999 at Tomakomai site, a model site within AsiaFlux network. Net ecosystem exchange was −2.6 to −3.9 t C ha^{-1} yr^{-1}. Quality checks of carbon flux have been accompanying by eco-physiological measurements of processes contributing to flux, soil CO_2 efflux and woody tissue respiration. We developed a fast-response system with 16 large automatically open and close chambers (90 × 90 × 50 cm) that connected in parallel to a single CO_2 analyzer equipped with a 16-channel gas sampler to continuously measure soil CO_2 efflux since June 2001. Running a measurement cycle through 16 chambers took just 1 h. Measured soil CO_2 efflux was 6.9 t C ha^{-1} yr^{-1}. Heterotrophic respiration estimated from roots removed plots was about 55% of total soil CO_2 efflux. In August 2002, we added a 16–channel automated stem chamber system to continuously measure woody tissue respiration. Woody tissue respiration rate was 1.3 μmol m^{-2} s^{-1} at the end of August, and decreased gradually to 0.2 μmol m^{-2} s^{-1} at the end of October. We have developed a new multichannel automated chamber system and will be installed at Tomakomai flux site to continuous measure CO_2 exchange at the twig level. Our automated chamber systems provide completely independent and simultaneous measurements of stand scale carbon balance, and therefore means to evaluate the reliability of the eddy-flux measurements.

P7.20–Overall greenhouse gas balance from a UK sitka spruce plantation on peaty gley soil

T. Ball, A. Zerva, K.A. Smith and J.B. Moncrieff (University of Edinburgh)

Afforestation of upland peaty gley soils in the UK with species such as Sitka spruce (*Picea Sitchensis*) can cause substantial lowering of soil water tables and thus increase soil aeration. Disturbances such as mounding and ploughing also change the soil physical environment. We hypothesised that CO_2 and trace greenhouse gas fluxes would vary between stands of *P. Sitchensis* of different age as a result.

We measured gas fluxes using closed manual and automatic chambers, with gas analysis by gas chromatography or infrared analyser. Soil temperature, surface moisture content (CS 615 TDR system) and water table depth were also recorded. The CO_2 flux in 2001 was 15 t CO_2/ha/yr at clear-felled sites, and 13 t CO_2/ha^{-1}/ yr^{-1} at the older forest sites. Strong temperature/ flux relationships were found. The results were consistent with eddy covariance data for night time respiration. CH_4 fluxes were highest at clear-felled sites, reaching 7 kg CH_4/ha/yr (log mean, higher values at some microsites). Fluxes increased with rising water tables and temperatures, hence were virtually absent in mature forest stands. N_2O fluxes were highest at the 30-year-old forest site (max 5 kg N_2O/ha/yr), peaking during midsummer, and lower in wet clear-felled sites. Relationships were seen with soil volumetric moisture content and temperature. Based on conservative estimates, the non-CO_2 greenhouse gases raise the net global warming potential (GWP) by up to 10% over that from CO_2 emission alone. In the early stages after clearfelling, methane emission is enhanced, but nitrous oxide emission increases in importance with stand age.

P7.21–Influences of age and climate on the carbon balance of ponderosa pine ecosystems

B.E. Law, M.H. Unsworth, J. Irvine, M.R. Kurpius and P. Schwarz (Oregon State University)

Our goal is to investigate changes in carbon storage and fluxes with stand age, and to understand the influences of climate on processes in ponderosa pine ecosystems in central Oregon, where summer drought is typical. We have a cluster of flux sites in young (YS; 15 y), mature (MS; 60 y) and old (OS; 250+ y) ponderosa pine, and 12 carbon budget plots in different age stands (average ages I=11, Y=45, M=75, O=200). Ecosystem carbon storage was significantly higher in the mature and old stands, where a large portion of the carbon was in live biomass (50 and 70%, respectively). Eddy flux data indicate that gross photosynthesis and NEE were significantly lower at the YS, and NEE was highest at the MS. Modelled annual estimates of ecosystem respiration based on chamber measurements followed the same trend (520, 930, 670 gC m^{-2} y^{-1} at YS, MS, OS respectively), with soil CO_2 efflux accounding for $>70\%$ of ecosystem respiration across all sites. Summer drought had the largest effect on carbon uptake and transpiration at the YS and resulted in age-specific seasonal patterns of the contribution of tree transpiration to total site LE. There was a strong correlation between transpiration and soil CO_2 flux in all three age classes of flux sites, suggesting that water availability similarly influenced both transpiration and activity of mycorrhizal roots and associated microbes.

P7.22–Carbon Exchange of Temperate, Broadleaved, Deciduous Forests

D.D. Baldocchi and L. Xu (University of California, Berkeley)

Temperate deciduous broadleaved forests exist in relatively wet, temperate and highly productive regions. Consequently, they constitute one of the greatest carbon sinks of the terrestrial biosphere. Because this biome spans over 20 degrees of latitude across North America and Europe, substantial spatial variation in assimilatory, respiratory and net carbon fluxes occurs within this forest biome. With the establishment of many long-term eddy-flux measurement sites, through the auspices of FLUXNET and regional networks (Euroflux, AmeriFlux), we have abundant data to examine the biological and physical factors that impose temporal dynamics and spatial differences on carbon budget of temperate deciduous forests. The objective of this report is to survey published data to produce a synthesis of how carbon balances of temperate forests vary on daily, seasonal, annual and interannual time scales. In this analysis, we present data on temperature and light response functions for CO_2 exchange and annual budgets of net carbon exchange from temperate deciduous forests. We also examine the impact of phenology on net annual carbon budgets.

P7.23–Full carbon balance in an eucalypt plantation in Portugal

J.S. Pereira (ISA, Lisbon) G. Pita, J. Silva (IST, Lisbon); A. Fabião, M. Carneiro, C. Nogueira, (ISA, Lisbon),A. Rodrigues (INIA-EFN, Lisbon), M. Madeira and E. Ribeiro (ISA, Lisbon)

The objective of the work was to determine the capacity for carbon sequestration of one eucalypt plantation and to compare net ecosystem exchange estimated from eddy co-variance measurements with the carbon inventory data obtained in situ. At the end of 2001 an eddy co-variance tower belonging to the Carboeuroflux project was installed at the Herdade da Espirra Pegões, Portugal (Lat. 38° 38′ N, Long. 8° 36′ W), in the middle of a second rotation coppiced Eucalyptus globulus plantation (stem age, 8 yrs; LAI, 3.1; average wood increment, 12.4 m^3 ha^{-1}yr^{-1}; soil type, distric Cambisol; average annual precipitation 709 mm; mean annual temperature 16 °C). A Solent 3D sonic anemometer together with an open-path analyser CS7500 Li-Cor were used to measure CO_2 fluxes. A full carbon inventory was performed to determine changes in biomass, litterfall and soil carbon. Soil respiration, temperature and moisture were measured every 3 weeks with an infrared gas analyser EGM–1 of PP–Systems attached to a soil chamber in 80 randomly distributed points near the tower. The net ecosystem exchange (NEE) rate estimated from eddy-flux data will be compared with net primary production (NPP), estimated by the carbon inventory method, minus the modelled heterotrophic respiration.

P7.24–The carbon balance of the tropical forest biome

Y. Malhi (University of Edinburgh)

Deforestation in tropical forests is known to be a major source of carbon, but there is accumulating evidence that mature tropical forests remote from deforestation may be a net carbon sink. Some evidence for a sink comes from atmospheric inversion studies and eddy covariance measurements, but perhaps the strongest evidence now comes from biomass inventories in old growth forests. These inventories are indicating that growth rates in tropical forests are accelerating, increasing both the rate of turnover and the net carbon storage in biomass. The most likely economical explanation for these phenomena seems to be CO_2 fertilisation. There is also evidence that the composition of mature tropical forests may be shifting, and in the long term biodiversity responses to global change may have a greater effect on forest carbon balance than direct biogeochemical responses. The duration and sustainability of any tropical forest carbon sink remains unclear, and is a major research priority.

P7.25–Changes in carbon cycling by Brazilian rain forest: effects of drought on soil, leaves and canopy

P. Meir (University of Edinburgh), R. Vale de Lobo (ISA Lisbon), R. Fisher (Univesity of Edinburgh), E. Sotta (University of Göttingen), A.C. Lola (Federal University of Para), R. Costa, S. Almeida (Emilio Gouldi Meuseu of Para), J. Costa (University of Vicosa), M. Chaves (ISA Lisbon), M. Williams, Y. Malhi and J. Crace (University of Edinburgh)

Amazon forest carbon cycling is strongly affected by seasonality in rainfall at the stand scale. However, mechanistic understanding of the response by rain forests to reduced rainfall is limited. We report here on initial results from a large-scale rainfall exclusion experiment aimed at advancing this understanding. The field site is a forest reserve (Caxiuanã National Forest) in the eastern Amazon, State of Pará, Brazil. An artificial 'roof' was installed at the start of the wet season at approx. 2m to deflect canopy throughfall away from the soil; treatment and control plots were perimeter-trenched to 1–2 m. The roof was removed for the dry season. Our suite of measurements include: soil moisture (to 5 m depth), soil respiration, leaf gas exchange and sap flow. The results, obtained from a pre-treatment calibration period and one year of experimental treatment are analysed in a modelling framework and by comparison to nearby canopy-scale eddy covariance data for non-droughted forest.

P7.26–Components of forest biome carbon balance

E.-D. Schulze (MPI Biogeochemistry, Jena)

The carbon balance at the biome level includes non-respiratory C-losses, such as fire, harvest, dissolved organic and inorganic carbon. These non-respiratory losses are generally neglected in the ecosystem perspective. However, the non-respiratory losses are important (1) for the interpretation of canopy net fluxes, (2) for predictions on how the system will respond to global change, and (3) for management decisions. The carbon balance will be discussed using two contrasting forest system as example, the European Beech, and the Siberian Pine: For Fagus , the ecosystem component fluxes suggest a major Carbon sink. A large fraction of this sink will be harvested, and only a small fraction will remain in the soil, as being detected from the relation between litter fall and mineralization. However, if we try to find this Carbon in soils, we are not able to detect it at time scales of a rotation period. Has this carbon been lost unmeasured by the eddy flux systems? Taking the Siberian Pine forest as example, again the ecosystem will be a major Carbon sink, as measured by eddy covariance, which contributes to growth as well as to the accumulation of soil C, but repeated ground fires take this Carbon as well as possible remnants of black Carbon in the organic layer. Thus, the biome Carbon balance becomes very small. At this moment, the study of biomes cannot explain the large Carbon sink that is inferred from atmospheric measurements.

P7.27–Fractional contributions by autotrophic and heterotrophic respiration to soil respiration in boreal forest carbon budgets

P. Högberg, A. Nordgren, M.N. Högberg, M. Ottosson Löfvenius, Bhupinderpal-Singh (SLU, Umeå), Per Olsson and Sune Linder (SLU, Uppsala)

Soil respiration accounts for roughly two thirds of ecosystem respiration, and can be divided into heterotrophic and autotrophic components. Conventionally, the latter is respiration by plant roots, However, in boreal forests tree fine roots are invariably covered by ectomycorrhizal fungi, which by definition are heterotrophs, but receive, like the roots, sugars derived from photosynthesis. There is also a significant leaching of labile C compounds from the ectomycorrhizal roots. It is, thus, more meaningful in the context of C balance studies to include mycorrhizal fungi and other mycorrhizosphere organisms dependent on the direct flux of highly labile C from photosynthesis in the autotrophic component. Hence, heterotrophic activity becomes reserved for the decomposition of more complex organic molecules in litter. Estimates of the contribution of autotrophic respiration to total soil respiration have been highly variable. Based on recent stand-scale tree girdling experiments we argue that autotrophic respiration accounts for 50–65% of soil respiration in boreal forest. Girdling and studies of the relation between vapour pressure deficit and the $\delta^{13}C$ of the soil CO_2 efflux show that there is a lag of a few days between C-uptake by photosynthesis and autotrophic respiration in the soil. In contrast, bomb-^{14}C estimates and other approaches suggest that it takes years to decades between photosynthesis and the bulk of soil heterotrophic activity. Modellers use temperature as a driver of soil processes and it is often stated that autotrophic soil activity is more sensitive to temperature than is heterotrophic activity. Evidence will be presented that this may not be the case.

P7.28–Carbon isotope exchange between forest and atmosphere

A. Scartazza, C. Mata, G. Matteucci and E. Brugnoli (CNR Porano)

Carbon isotope composition of ecosystem respired CO_2 ($\delta^{13}C_R$), determined by Keeling-plot, is essential to separate net ecosystem exchange (NEE) into photosynthetic and respiratory fluxes. Carbon isotope discrimination (Δ) gives an estimate of WUE. We studied $\delta^{13}C_R$, and WUE in natural ecosystems in Italy to investigate the influence of environmental parameters on the ecosystem carbon budget. We also assessed the contribution of various ecosystem components to the respiratory flux and $\delta^{13}C_R$ and evaluated the role of recent carbohydrates in carbon flux dynamics at the ecosystem level.
NEE was determined by Eddy covariance, and canopy air was collected and analyzed for [CO_2] and $\delta^{13}C$ along vertical gradients. Plant and ecosystem components including leaves, roots, shoots, litter and soil organic matter were all collected on the same days when air sampling was done, and were analyzed for $\delta^{13}C$. Leaf and phloem sap carbohydrates were collected and analyzed to detect short-term changes in photosynthetic discrimination. An increased $\delta^{13}C_R$ was observed in response to increasing VPD and decreasing soil water availability. This was associated with shifts in $\delta^{13}C$ in leaf and phloem sap sugars but without substantial changes in $\delta^{13}C$ in bulk dry matter. The $\delta^{13}C_R$ of ecosystem respired CO_2 and of leaf and phloem sap sugars, showed similar trends in response to the environment, indicating that the photosynthetic isotopic signature was rapidly transferred to respiratory fluxes.

P7.29–Temporal variation in 13C/12C ratio of respired CO_2 and its relation with vapour pressure deficit in deciduous needle-leaf forest ecosystem in east Asia

Y. Takahashi, Y. Tohjima, T. Machida, Y. Fujinuma and G. Inoue (National Institute for Environmental Studies, Tsukuba)

Temporal variation in the carbon stable isotope ratio of CO_2 respired from ecosystem ($\delta^{13}Cr$) had been investigated since July 2000 at Tomakomai Flux Research Site, a core research site of Asia Flux Network. The study site was in an artificial deciduous needle-leaf forest dominated by Japanese Larch (*Larix kaempferi*) and was located in the East Asia where the monsoon and intensive rain climate exercised a unique influence on seasonality of terrestrial ecosystems. The mean age of the forest was about 40 years. Mean annual precipitation around the site was about 1500 mm and precipitation was heavy in early summer usually. *Larix* species are representative for a large portion of the northeast Eurasia. At the site, air samples were collected during 1–2 day at intervals of 2–3 hours from height of 6m from ground using an automated air sampling system. Until the end of 2002, samples were collected during more than 35 time period. $\delta^{13}Cr$ was evaluated from the night-time data using the Keeling plot approach. $\delta^{13}Cr$ observed during the green season of the forest ranged from −26.7‰ (per mille) PDB to −29.2‰ PDB, and its arithmetical mean was −27.8‰ PDB. The temporal variation in $\delta^{13}Cr$ was highly irregular and showed no remarkable trend according to the season. The correlations between $d^{13}Cr$ and environmental variables showed that $\delta^{13}Cr$ had link with vapour pressure deficit of several days earlier. This feature was consistent with that reported for coniferous forests in the North America.

P7.30–Carbon flux to the soil in a range of contrasting tree species and CO_2 concentrations

J. Heath, G. Kerstiens, E. Ayres, M. Possell, R. Bardgett (Lancaster University), P. Ineson (University of York), H. Black, A. Stott and D. Sleep (CEH Merlewood)

Under the Kyoto Protocol, many countries will be allowed to substantially offset carbon emissions with terrestrial ‘carbon sinks’. However, the nature of these sinks is poorly understood and quantified, particularly in the context of rapidly increasing atmospheric CO_2 concentrations. Forest soils – one of the largest terrestrial carbon stores – may have the greatest potential to act as long-term carbon sinks; but directly measuring changes in their carbon content (e.g. in FACE experiments) is difficult due to the problems of detecting small changes in a very large carbon pool, and spatial variability. Six native European tree species, selected for their contrasting ecophysiological traits, were grown at four CO_2 concentrations, ranging from ambient to ambient plus 300 μmol mol^{-1}, with two levels of nutrient supply. The trees were grown in mesocosms containing soil from a C_4-dominated grassland, which had a carbon isotope ratio ($\delta^{13}C$) of −14.7‰; the $\delta^{13}C$ of the tree fine roots (taken as a measure of $\delta^{13}C$ of 'new' carbon added to the soil) ranged from −27‰ (ambient) to −40‰ (ambient+300 μmol mol^{-1} CO_2). The contrasting $\delta^{13}C$ of 'old' and 'new' carbon enables the accurate quantification of carbon fluxes to the soil, even at ambient CO_2. At ambient CO_2, mean fluxes of 'new' carbon to the soil were 1.97g l^{-1} (low nutrients) and 2.14 g l^{-1} (high nutrients); however, at ambient plus 300 μmol mol^{-1} CO_2, carbon fluxes were reduced to 1.13 g l^{-1} and 1.54 g l^{-1} (low and high nutrients respectively) ($P<0.0005$).

P7.31–Agricultural practice, soil carbon storage and CO_2 emissions

P. Smith (University of Aberdeen) and P. Falloon (Rothamsted Research)

Biospheric carbon sinks and sources can be included in attempts to meet emission reduction targets for the first commitment period (FCP) of the Kyoto Protocol (KP). Forest, cropland, and grazing land management and revegetation, including soil carbon sinks and sources, are allowable activities under Article 3.4. Croplands are the largest biospheric source of carbon lost to the atmosphere in Europe annuallu, but the cropland estimate is the most uncertain among all land-use types. There is significant potential within European cropland to decrease the flux of carbon to the atmosphere, and for management to sequester soil carbon. The biological potential for carbon storage in European (EU15) cropland is 90–120 Mt C y^{-1}. The sequestration potential is up to 45 Mt C y^{-1}. The realistically achievable potential may be considerably lower than this due to various constraints, about 20% of the biological potential. Impacts on non-CO_2 trace gases also need to be considered. In order to be used towards meeting emission reduction targets for the FCP of the KP, changes in soil carbon must be measurable and verifiable. Changes in soil carbon can, however, be difficult to measure over a five-year period. Currently, most countries could only achieve a low level of verifiability during the FCP; those with the best-developed carbon accounting systems could deliver an intermediate level of verifiability. Very stringent definitions of verifiability would require verification that would be prohibitively expensive for any country. Carbon sequestration in soil has a finite potential, is non-permanent, and is a riskier long-term strategy for climate mitigation than direct emission reduction. However, improved agricultural management often has additional environmental and economic benefits, which may make sequestration options attractive as part of integrated sustainability policies.

P7.32–Integrating ecosystem carbon fluxes across space and time: the respective role of forest age and disturbances

M. Mencuccini, M. Rayment and J. Grace (University of Edinburgh)

Fluxes of carbon and water between forests and atmosphere vary over spatial and temporal scales longer than the ones normally measured by the eddy covariance technique at a single site. To upscale stand-level fluxes to the landscape, knowledge is required about: a) effects of site-specific properties; b) impact of periodic or occasional disturbances; c) impact of changing stand age. Here we present data for a British chronosequence of Sitka spruce stands in which flux measurements were taken across several age classes including stands recently disturbed by clearfelling. We also present data on carbon stock changes in trees and soil over the same chronosequence, and highlight the limitations and advantages of a) the chronosequence approach, and b) combining measurements of fluxes and stock changes at the landscape scale. Clearfelled stands were net C sources and remained sources for another 10–15 years after planting of the new generation. However, most of the C losses could be attributed to the decomposition of the existing harvest residues from the previous rotation. Consequently, over the cumulated 40-year rotation cycle, this chronosequence was a net C sink. Although this estimation of the cumulative sink strength over 40 years might be expected to be both highly uncertain and biased, the comparison with the stock changes over the same time period revealed a very good agreement. We conclude that on peaty gley soils like the ones we studied here, decomposition of the superficial organic layer is not significantly accelerated by management operations such as clearfelling, and that afforestation on this type of soils results in net C sequestration at the landscape scale.

P7.33–The effects of clearcutting and forest management on organic matter content in mineral soils: a chronosequence perspective, Järvselja, Estonia

O. Kull and R. Szava-Kovats (University of Tartu)

Soil organic matter plays an important role in the global carbon cycle. In order to understand better the affects of clear-cutting on organic matter content in soils in spruce forests, a study was performed in Järvselja (SE Estonia) in a forested area of homogeneous soil type and fertility. The study area consisted 10 plots each harvested and replanted at different times since the 1920s. Thus the forest ages in the chronosequence ranged from 0 (freshly harvested) to 80 years (mature forest). Multiple samples were taken in each area and split into two sub-samples, the organic-rich horizon and sandy mineral horizon. Organic matter content was estimated in each sub-samples from Loss-On-Ignition analysis.

Organic matter content in the organic horizon increased with forest age to reach a maximum at about 40 years after which organic matter content declined to the original values in mature forests. The increase in organic matter is about 70% over the very young and mature forest levels. The organic matter content in the mineral horizon reflected a similar pattern, although the peak occurred in 30-year-old forest and exhibited an increase of about 50%. The total organic matter content (the sum of both horizons) shows a maximum at about 30–40 years before decline to mature forest levels. The increase is attributed to both a decline in the amount of acidic litter from spruce and a rapid proliferation of non-spruce species after harvesting. Research will continue to determine the role of forest management and natural processes during forest regeneration.

P7.34–Trace gas and CO_2 contributions of peatlands to GWP

T. Laurila, M. Aurela and A. Lohila (Finnish Meteorological Institute, Helsinki)

Histosols in the boreal and arctic regions are vast pools of carbon which have accumulated from the atmospheric reservoir during thousands of years. Oxidation of dead organic matter is very slow in the anaerobic zone, which is formed by the high water table. A small part of the carbon, which has been taken up by plants, is emitted back to the atmosphere as methane because methanogenetic bacteria thrive in the water-saturated environment. Natural mire ecosystems operate in two directions concerning radiative forcing effect. Carbon accumulation in the anaerobic zone reduces the atmospheric concentration of this most important greenhouse gas. Concurrently methane, which absorbs infrared radiation more efficiently than carbon dioxide, is emitted from the anaerobic zone. The radiative forcing effect of these two gases may be compared using the concept of Global Warming Potential (GWP). Long-term rate of carbon accumulation rates of bogs and fens in the boreal zone are well known. Continuous direct measurements of carbon dioxide and methane fluxes, which represent balances under present climatic conditions, are still very scarce. A very large area of wetlands in Europe has been drained for agriculture or forestry purposes. After draining, organic carbon pool becomes aerobic giving rise to continuous carbon dioxide emissions. Methane emissions mostly cease but agricultural fields become a major source of nitrous oxide. In this presentation, we compare carbon dioxide and methane balances of natural mires to those of managed peatlands using both literature information and our own measurements and estimate related global warming potentials.

P7.35–Trace gas contribution (N_2O, CH_4) of forest soils to GWP balances

R. Brumme, P. Martikainen, C. Potter and L. Verchot (University of Göttingen)

Forest ecosystems has been identified as a sink or a source of carbon depending on the historical forest use, on changing forest management, on liming practice, or on the atmospheric fertilization effects by nitrogen or CO_2. To what extend these effects on the overall global warming potential (GWP) is compensated by the exchange of green house gases between the soil and the atmosphere, like CH_4 or N_2O, is the objective of this study. Although the fluxes of CO_2 are about three magnitudes higher the specific GWP is much lower compared to the trace gases CH_4 or N_2O. We used three different approaches for the up-scaling of chamber CH_4 or N_2O measurements to the biome scale to analyze the potential uncertainties of these global estimates, the simple ‘flux multiply area’, a more complex ‘flux multiply stratified-area’, and model approaches of different complexity. A stratification of the biomes area before the multiply approach may improve the global estimate. We stratified the biome areas e.g. into soil texture classes as the most important factor controlling the CH_4 oxidation in soils or into areas with precipitation >250 mm month^{-1} to separate high N_2O emissions in the tropical wet season from low N_2O emissions in the tropical dry season. These approaches were discussed regarding their reliability and regarding their contribution to the GWP balances.

P7.36–Sustainability of Terrestrial Carbon Sequestration: Conceptual Framework and A Case Study in the Duke Forest with Free Air CO_2 Enrichment

Y. Luo, L.W. White (University of Oklahoma), J.G. Canadell, CSIRO Canberra, and W.H. Schlesinger, (Duke University)

A sound understanding of the sustainability of terrestrial carbon (C) sequestration is critical for the success of any policies geared to stabilize atmospheric greenhouse concentrations. This includes the controversial Kyoto Protocol and/or other greenhouse strategies by individual countries. However, the sustainability of C sinks and pools has not been carefully studied with either empirical or theoretical approaches. This study establishes a theoretical framework to define the sustainability based on C influx and residence time (t). Ecosystem C influx is determined by canopy photosynthetic capacity, which is regulated by leaf photosynthetic capacity and leaf area index. The residence time represents the capacity of an ecosystem to store C in plant and soil pools (i.e., the C-storage capacity). The C-sequestration capacity in an ecosystem is jointly determined by the canopy photosynthetic capacity and the C-storage capacity. The C-sequestration capacity is maintained in a future global change scenario only if neither the canopy photosynthetic capacity nor the C-storage capacity is up-or down-regulated. In that case, the future rate of terrestrial C sequestration is primarily determined by environmental forcing functions. The forcing functions could be the rising of atmospheric CO_2 concentration, forest regrowth, woody plant encroachment, and nitrogen deposition. We applied this framework to the Free-Air CO_2 Enrichment (FACE) experiment in Duke Forest, North Carolina, USA. We estimated C influx with a mechanistic canopy model and residence time via inverse analysis of multiple data sets. Our results indicated that neither canopy photosynthetic capacity nor the C-storage capacity was significantly altered by elevated CO_2 at this forest site. Thus, the current evidence from both experimental observations and inverse analysis suggests that C sequestration in the ecosystem will increase gradually as Ca gradually increases. Nonetheless, the increased C sequestration in terrestrial ecosystems accounts for only a small fraction of anthropogenic C emission.

P7.37–Will agroforestry contribute to atmospheric carbon mitigation? – A FACE experiment on short rotation, intensive poplar plantations

G. Scarascia-Mugnozza (IBAF-CNR), P. DeAngelis (University of Tuscia), R. Ceulemans (University of Antwerpen), G. Taylor (University of Southampton), C. Raines (University of Essex), M.R. Hoosbeek (Wageningen University), D. Godbold (University of Wales), F. Cotrufo (University of Naples II), A. Polle (University of Goettingen) and F. Miglietta (IBIMET–CNR)

This research has combined a fast growing, agro-forestry ecosystem, capable of elevated biomass production, with a large-scale FACE system. This FACE facility utilizes a novel technology, based on the release into the atmosphere, at sonic velocity, of pure carbon dioxide instead of an air–CO_2 mixture. The research activities conducted at the POPFACE site, on the responses of the tree plantation to future atmospheric conditions, have integrated observations at the leaf level, such as photosynthesis, respiration and transpiration, with measures carried out at the whole tree and stand scale, as canopy architecture, light interception and biomass production; finally, also the ecosystem dimension has been analyzed by studying roots productivity and soil processes, host–parasite interactions and Carbon sequestration over the entire crop rotation cycle. The surplus of assimilated carbon for the tree genotypes growing in a CO_2 enriched atmosphere determined a 24% mean stimulation of total biomass production, at the end of the stand rotation cycle. The increase of above-ground biomass production ranged from 15% to 27% while the effect of elevated CO_2 on below-ground biomass was even greater, from 22% to 38%, depending on the genotype. Biomass accumulation over the 3-year study period, under FACE conditions, ranged from 58 to 72 t ha^{-1} of dry matter for *P. x euramericana* and *P. nigra* respectively, while *P. alba* had intermediate results. This is a relevant output of the experiment that allows us to quantify the future productivity and carbon sequestration capacity of these agroforestry plantations in an elevated CO_2 world.

P7.38–Manipulating forest ecosystem carbon sinks by management

S. Linder, J. Bergh, M. Freeman (SLU, Uppsala) and T. Lundmark (SLU, Vindeln)

Until recently the over-riding objective of forest management has been to supply wood to the timber and pulp industries, without considering impacts on the total carbon balance of the forest ecosystems. Over the last decade, as an effect of international conventions, there has been an increasing interest in developing new management strategies which enhance long-term carbon sequestration by forests (including soils). The measures to increase carbon sequestration in forests can include, selection and use of more productive species, improved establishment and harvesting techniques, increased stand density and rotation length, and more intensive management, including fertilisation. It takes, however, a long time before the impact of most of such measures can be quantified and results from old long-term experiments are scarce. The exception is fertilisation where results from old and current experiments show that biomass production in most forest ecosystems can be increased by a factor of two or more. Results from a series of ongoing long-term nutrient optimisation experiments, with different species in contrasting environments, will be presented. To illustrate the carbon mitigation potential, by means of intensive silviculture, a case study for Sweden will be discussed. Although forest ecosystems can be managed to increase the carbon sink strength significantly, such increased carbon uptake can only amount to a partial, temporary offset to anthropogenic emissions.

P7.39–Assessing the potential of forest management strategies in European forests for carbon mitigation

M. Lindner, P. Lasch (PIK Potsdam), S. Sabaté, C. Gracia (CREAF Barcelona), C. Fürstenau, F.W. Badeck and F. Suckow (PIK Potsdam)

Forests play an important role in the global carbon balance. Several management strategies are known to affect the carbon balance of forest ecosystems and could thus have a potential to mitigate the increase of atmospheric carbon dioxide. In this paper results are presented from the EU funded project SilviStrat, which analysed response strategies in forest management to climate change in different European forest regions. Here, investigations from the temperate and mediterranean forest regions using the forest simulation models 4C and Gotilwa+ are presented. Furthermore, comparisons are drawn to other studies from the COST Action E21 *Contribution of Forests and Forestry to Mitigate Greenhouse Effects.* The results indicate that the effects of changing management treatments are site-specific and strongly depending on regional climate change projections. While the management influence on average carbon storage in existing pure stands of the temperate region was rather limited, larger effects could be obtained when also changes in species composition were taken into account. However, uncertainties remain large regarding the temporal trends of carbon accumulation especially in the soils under forest conversion. In the mediterranean region, water limitations are most crucial for carbon sequestration. Management strategies in this region could be adapted to reduce the water consumption of forest stands, which could mitigate productivity losses due to unfavourable climate changes. The overall contribution of forest management strategies in European forests for carbon mitigation appears to be sobering. It may be important, however, to alleviate the adverse effects of climate change.

P7.40–Predicting future changes in forest carbon sinks at ecosystem, biome and global scales

F. Badeck and W. Cramer (PIK Potsdam)

The future potential for carbon sequestration in forests will depend on the transient responses of forest carbon balances to climate forcing, atmospheric CO_2 mixing ratio and nutrient deposition as well as the effects of land use changes and management strategies. Global assessments of the role forests can play as carbon sinks in the course of the coming decades have been performed with global vegetation models. Results on saturating CO_2 fertilization, the time delay in the response of slow soil carbon pools to increases in NPP, sensitivity of lenght of vegetation period and production under stress conditions will be discussed with a special emphasis on the simulations performed with the Lund-Potsdam-Jena dynamic global vegetation model (LPJ). In passing from the ecosystem carbon balance to the biome level the role of disturbances will be illustrated for the case of vegetation fires. Besides potential shifts in the biom distribution, human land use and the use strategies for managed ecosystems exert a strong control over the global sequestration potential. The relevance of land use change for the reconstruction of past global carbon budgets and the sensitivity to future land use change scenarios will be discussed. The limitations to carbon storage in forests due to a future transition from net sink to net source and due to the boundary conditions imposed by human needs will be evaluated in terms of uncertainties related to process representation, climate and land use change scenarios.

P7.41–Carbon Forestry

P.G. Jarvis (University of Edinburgh) and A. Ibrom (University of Göttingen)

Forests worldwide contain about 45% of the global stock of carbon, the larger part of which is to be found in forest soils. Having regard to the importance of the carbon in forests, we consider how to *preserve* the existing stocks of carbon, much of which may have accumulated prior to recent afforestation, and how to *increase* the stock of carbon in our forests, in both trees and soil. On a time scale of years, the standing mass of carbon within an extensive forest being managed for *sustainable* timber production would be constant, but most individual compartments would accumulate carbon through growth of the trees and increase in the soil carbon reservoir, until *disturbance* intervenes. Management operations, such as site preparation, thinning and clear felling lead to immediate, temporary loss of capacity to take carbon from the atmosphere, but may also effectively transfer significant amounts of debris into the soil carbon reservoir. By contrast, forest operations that use heavy machines disrupt the soil and stimulate loss of carbon. For this analysis, we present detailed assessments of different thinning regimes on the carbon budgets of plantations of Norway spruce in Germany and Sitka spruce in Scotland, particularly relevant to plantations established in relation to Article 3.3 of the Kyoto Protocol and likely to be thinned before the second commitment period. We propose new approaches to forestry practice to embrace carbon sequestration – *Carbon Forestry*!

P7.42–The future of carbon storage: synopsis and conclusions

H. Griffiths (University of Cambridge)

This is a time when many young natural scientists (whether at school or as undergraduates) fail to recognise the classic datasets collated by NOAA showing the interannual variablity in atmospheric CO_2 concentration over northern latitudes, superimposed on the steady increase over the past 50 years, and particularly struggle to realise the role of plants in driving such exchanges. Yet it is their future which we have been discussing. Having reviewed the difficulties of turning policy into practice, coupled with the uncertainties associated with measurements across such a wide range of scales, what message should we convey to the next generation? Firstly, of course, learn more about stable isotopes and the way then can be used to partition exchanges whether at global, regional or local scales. Secondly, don't forget about leaf-level processes, which after all present a daily microcosm of those global interannual variations; thirdly, learn how to couple the interplay between soil and carbon transfer from plants, and the effect of temperature and disturbance on carbon storage transfer and release. The use of ^{13}C and ^{18}O stable isotopes to partition exchanges at the global level has not been matched by their application at leaf and canopy scales, which in theory, should be relatively facile. One way to overcome these uncertainties is to use mesocosm measurements, and increase the throughput of mass spectrometric analyses to approach the resolution offered by infra red gas analysers. Finally, of course, we need to be far more effective in communicating both the excitement of the challenges which we face, and the potential for plants to mitigate climate changes processes.

P7.43–Long-term measurements of surface fluxes of CO_2, ozone, aerosols, momentum, and sensible and latent heat over a Scots pine forest in Hyytiälä, Southern Finland, 1996–2001

T. Suni, J. Rinne, A. Reissell, N. Altimir, P. Keronen, U. Rannik, M. Dal Maso, M. Kulmala and T. Vesala (University of Helsinki)

We studied the patterns of concentrations and surface fluxes of momentum, latent and sensible heat, carbon dioxide, ozone, and aerosol particles measured by the eddy covariance technique over a Scots pine forest in southern Finland from April 1996 to December 2001. The fluxes exhibit marked seasonal and diurnal differences, and the different properties of the fluxes are clearly manifested in the measurements: The inert nature of CO_2 yields fluxes that follow climatic factors very closely and are relatively constant at night. Fluxes of the reactive ozone depend on radiation by day because of the photochemical production and destruction processes, but also at night the concentrations, fluxes and deposition velocities change as a result of the night sink reactions and of the changes in the boundary layer structure. Because of the highly non-linear characteristics of aerosol particles, the aerosol flux exhibits no clear connection with any climatic variable. The formation of new nucleation-mode particles is reflected in aerosol deposition velocity: The average deposition velocity towards the forest is 3 to 10 times greater on nucleation event days than on other days because small nucleation-mode particles have greater deposition velocities than larger accumulation-mode particles.

P7.44–The Sky Arrow ERA (Environmental Research Aircraft): a new tool for airborne flux measurements

B. Gioli, B. De Martino, F. Miglietta (CNR IBIMET, Florence) and R.W.A Hutjes (Alterra, Wageningen)

The problem of identifying the spatial and temporal distribution of sources and sinks of atmospheric CO_2 is the subject of considerable scientific and political debate. Even though it is now possible to estimate with reasonable accuracy the sink strength of ecosystems at the local scale, difficulties still exists in determining the spatial distribution and areal integration of the sinks at the regional to global scales. The aim of the EU-project RECAB (Regional Assessment of the Carbon Balance in Europe) is to bridge the gap between the local scale flux measurements and continental scale inversion models by a modelling effort and measurement program, focussing on a limited number of selected regions in Europe. This required the establishment of a European facility for airborne measurement of surface fluxes of CO_2 at very low altitude, and a research aicraft capable of doing airborne eddy covariance measurements has been acquired by this project and used at the different RECAB sites. The aircraft is the italian Sky Arrows ERA (Environmental Research Aircraft) equipped with the NOAA/ARA Mobile Flux Platform (MFP) for turbulence measurements. Flux towers were present at each site to provide a validation of airborne eddy covariance measurements. This contribution describes the technology implemented in the aircraft, and reports some results of the comparison made between airborne and ground based flux measurements obtained during the campaigns. This comparison provides a comprehensive validation of the measuring capabilities of the Sky Arrow in a wide range of meteorological and ecological settings, and consequently a wide range of CO_2 flux magnitudes. In addition, it outlines the potential contribution that flux aircrafts may provide to bridge the gap between ecosystems and atmospheric studies of CO_2 exchanges.

P7.45–Modelling the impact of climate change and nitrogen deposistion on carbon sequestration of UK plantation forests

M.B. Murray and J.H.M. Thornley (CEH Edinburgh)

Abstract not supplied

P7.46–Assessment and effects of uncertainties regarding the estimation of large-scale soil carbon stocks and stock changes in boreal and temperate forests

Mats Olsson (Swedish University of Agricultural Sciences), Rainer Baritz (Joint Research Centre, Ispra) and Robert Jandl (Austrian Federal Office and Research Centre for Forests, Vienna)

The size of the soil C pool is determined using wide spread procedures. The quality and comparability of the various assessments depends on various biome-specific site factors and the land use history. Large-scale soil inventories yield extensive data sets, which were used to explore site-specific standard values and uncertainties of C stock estimates. The results can serve as a standardized basis for the QA/QC of other inventory data. The variability of the soil C storage and the error involved with its estimation control the ability of the existing monitoring tools to detect stock changes within certain time intervals. Widespread site degradation and historical humus losses in almost all the European forest land strongly affect the capability to detect and verify large-scale soil carbon changes with the methods and monitoring systems given. Therefore, the uncertainties and precision based on existing commonly applied inventory designs were compared to a bench mark inventory. Main ecological stratifications were tested. It will be presented, how much precision can be increased, and how much sampling density and costs can be reduced by stratified sampling.

P7.47–A landscape approach to estimating soil C stocks and fluxes

S. Lettens, J. V. Orshoven and B. V. Wesemael (Katholieke Universiteit Leuven)

To better understand the impact of terrestrial ecosystems on the mitigation of carbon emissions, knowledge of current stocks and fluxes is required. In this paper, we start from the assumption that soil type, land use and climate determine the C sequestration, therefore stocks can be estimated for each combination of these factors and fluxes predicted when one of these factors changes. Intersection and combination of soil and land use maps for the Belgian territory defines the landscape units (LSU), polygons with ‘homogenous’ soil, climate and land use. Profile data are taken from the ‘Aardewerk database’, a comprehensive database resulting from the National Belgian soil survey (1950–1970). It consists of ca. 13 000 sites with known soil type, map coordinates and land use. For all or part of the horizons organic and inorganic (in $CaCO_3$) carbon content and volume percentage stones were determined. Combination of the site data and the LSU (‘matching’) can be achieved in different ways. Either the position of a profile relative to a LSU (geomatching) or the characteristics that a profile has in common with a LSU (classmatching) are the most important factor. The characteristics considered here for classmatching are land use and soil type. Different matching procedures are compared and aggregated to deliver a C content for almost all LSU. Both organic and inorganic carbon is determined for different soil depths. In the next step the C content of soils in 1990 and 2000 is calculated using recent profile and map data. Comparison of the results determines the sink/source character of a landscape unit.

P7.48–Scaling estimates of net primary productivity from the site to the landscape

F. Raulier, P.Y. Bernier and D. McKenney (Canadian Forest Service, Sainte Foy and Sault Ste Marie)

The measurement of net primary productivity (NPP) and of its component processes is performed at the level of a plot. Yet, applications to the question of influences on carbon sequestration in forests requires that NPP predictions be scaled up from the plot to large landscapes up to the full extent of the world forest. A scaling up exercise of NPP from plot estimates to the Canadian boreal landscape was performed in two steps. In the first step, a validated process-based model of canopy gas exchange (FineLEAP) was used to develop parameter values for a stand-level spatial model of NPP (StandLEAP) for the dominant tree species (black spruce, balsam fir, jack pine and trembling aspen). In a second step, StandLEAP was run on a 30×30m spatial resolution for 5 regions of 1000 km^2 to 2000 km^2 in size distributed across the Boreal Shield of Canada. Results from these simulations were used to obtain parameter values for a simpler model (ForLEAP) to be applied on pixels of 4 km^2. The modelling work is done at three distinct spatial scales (leaf layer, plot and landscape) and three temporal scales (hour, month and year). Propagation of information across scales is formalised by a least-squares fit approach that includes a procedure to drop variables whose influence on NPP is ‘too strongly’ mitigated

when scaling up. This multi-scale approach permits the integration of field results and the validation of estimates at the proper spatial and temporal scales.

P7.49–Carbon assimilation in an amazonian rainforest: a rain exclusion experiment

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Carbon assimilation was investigated in an undisturbed and protected rainforest near the mouth of the Amazon, some 350 km west of Belém, Brazil, in drought-threatened eastern Amazonia, at Caxiuanã National Forest. Two plots of one hectare each were studied, one of them being subjected to partial rainfall exclusion, which started early 2002. Leaf level measurements were made on leaves at different heights of the vertical profile of the canopy (Tower A and Tower B, for control and rain exclusion plots, respectively). There were 8 species accessible from each tower and they were measured over three seasons (the end of the dry season 2001, the end of the wet season 2002 and the end of the dry season 2002). Photosynthesis (A/PAR and A/Ci response curves), leaf water potential and chlorophyll fluorescence were measured in three leaves per tree. The low values of maximal stomatal conductance and photosynthesis observed at the end of the first dry season were reversed at the end of the rainy season, mainly in the top-canopy species, suggesting that many species were enduring water deficits at the end of the first dry season. At the end of the second dry season, a difference in gs_{max} and A_{max} between the two plots was observed, suggesting a treatment effect. An inter-annual variability is discussed in relation with the relative length of the wet vs. rainy season.

P7.50–Does isotopic analysis of nocturnal air drainage reveal ecosystem function at the watershed-scale?

B.J. Bond, M.H. Unsworth, A.C. Mix, K. Alstad, T. Pypker, T. Ocheltree & L. Mahrt (Oregon State University)

Recent studies show that the amount and isotopic composition of ecosystem-respired CO_2 ($\delta^{13}C_R$) is strongly influenced by recent photosynthesis. Therefore, measurements of $\delta^{13}C_R$, which may be accomplished through 'Keeling Plot' analyses, could provide a powerful way to monitor vegetation function. Unfortunately, many of the world's most productive forest ecosystems are in mountainous regions that produce complex airflow patterns, resulting in a) uncertainty in the source area (footprint) of the sampled air, and b) reduced nighttime accumulation of CO_2, making it difficult to obtain an adequate range of CO_2 concentrations for Keeling Plot analysis. However, well-developed night-time cold-air drainage might be used to advantage if the land surface of the drainage could be well-defined and if the drainage were uncoupled from the bulk atmosphere, allowing respired CO_2 to accumulate. In a pilot study, we are examining airflow patterns, CO_2 concentrations and $\delta^{13}C_R$ in two small, deeply incised watersheds in the western Cascade Mountains of Oregon, USA. Cold air drainage predominates at night and often in the daytime. The drainage layer can be very deep (often more than 10 m) and is well mixed; CO_2 concentrations are typically well above ambient (400–450 ppm) and the range is adequate for Keeling Plot analysis. The footprint of $\delta^{13}C_R$ in air sampled at the mouth of the drainage system appears to be much smaller than the entire watersheds. We will be evaluating the degree to which CO_2 in the canopy atmosphere is a binary mixture of tropospheric CO_2 and $\delta^{13}C_R$ – an assumption inherent in Keeling Plot analysis.

P7.51–The importance of soil respiration in a Mediterranean forest

J.P. Banza (ISA, Lisbon), M. Rayment (University of Edinburgh), T.S. David (EFN, Lisbon) J.S. David, J.S. Pereira (ISA, Lisbon)

The role of soil respiration on the CO_2 balance of a Mediterranean evergreen oak forest was inferred from measurements taken with an Eddy–Covariance System at the Mitra site (Évora, Portugal). In the dry summer, soil respiration is very low but a large efflux of CO_2 was detected by the Eddy–Covariance System immediately after the first rains of summer in consecutive years. To evaluate the role of soil moisture in this process, watering experiments were done during the summer of 1999. In these experiments, dry soil was watered to its estimated soil field capacity. Measurements of soil respiration were done in situ with a EGM-1 PP Systems IRGA coupled to a portable, closed soil chamber. The measurements were taken before and after the watering of the plots.

Results showed a large efflux of CO_2 from the soil immediately after the watering, confirming the large efflux of CO_2 detected by the Eddy–Covariance System immediately after summer rain.

At the time of the experiments, the upper layers of the soil were completely dry, and soil respiration was typically zero. The ground vegetation was dead and dry, only some shrubs and trees were green, although their activity is relatively reduced due to drought. As a result there is an accumulation of dry litter and dead fine roots

by the end of summer, which is available for respiration upon wetting.
There is still the question of whether this was purely a CO_2 displacement phenomenon, or if it was essentially due to respiration.

P7.52–Carbon stock and sink capacity in the Portuguese forest

A.P. Correia (ISA, Lisbon), M. Madeira (ISA, Lisbon), J.S. Pereira (ISA, Lisbon), J.M. Pereira (IICT, Lisbon) and M.J. Lima (ISA, Lisbon)

Here we present a first approach that aims to quantify the carbon stocks in the forest vegetation and soils in Portugal mainland. Regarding the vegetation compartment, we compared two contrasting methods that is, information provided by remote sensing techniques (using a vegetation index, http://cybele.bu.edu/biomass/biomass.html), and the national forest inventory data. The soil carbon pools were studied through the construction of a database resulting from the compilation of information from several scientific studies. This information was compared with climatic variables namely precipitation and potential evapotranspiration which seem to be good indicators of plant productivity. A regression analysis revealed a correlation between estimates obtained through remote sensing and national inventory data on a geographical basis. Biomass was estimated from inventory data using alometric equations calibrated for the national forest species. Aboveground biomass values obtained from remote sensing were slightly over estimated in comparison with inventory data. Apparently there is an underestimation of tree density from the forest inventory information, which biased the biomass calculations. On the other hand, the understorey vegetation of understocked forests and shrublands were considered in the national inventory but were not considered in remote sensing data. In relation to the soil compartment, it was concluded that up to 30 cm depth, the carbon content was positively correlated with rainfall and therefore primary productivity. Vegetation type and land use determined carbon accumulation in the soils.

P7.53–Carbon Sink Capacity of Eucalyptus and Pine Plantations in Portugal – a Modelling Approach

A.P. Correia (ISA, Lisbon), J.S. Pereira (ISA, Lisbon), C. Araújo (CELBI, Portugal), M. Madeira (ISA, Lisbon) and A. Fabião (ISA, Lisbon)

To evaluate the sink potential of Kyoto forests and to study the effects of management and the inclusion of land use and soil management in the context of the Kyoto Protocol, we parameterised a stand level model-CO2FIX V 2.0 (Nabuurs et al. 2001, Masera et al. 2002) for the most representative forest species in the Portuguese national territory: Eucalyptus globulus and Pinus pinaster. We used data from managed forests and from field scientific studies. This tool allows the quantification of stocks and fluxes of carbon, based on the carbon cycle that combine the annual growth of the main components of the biomass including the relations between soil organic matter decomposition and forest products. The results allowed a better understanding of the processes underlying carbon accumulation and ultimately, stand carbon sink capacity. It helps to find the 'better management option' under a specific target that can be, for example, the maximisation of wood production or to obtain credit benefits from carbon market trade in the Kyoto context.
Reference: Madeira, M. V., Fabião, A., Pereira, J. S., Araújo, M. C., Ribeiro, C. (2002). Changes in Carbon Stocks in *Eucalyptus globulus* Labill. plantations induced by different water and nutrient availability. Forest Ecology and Management. 171: 75–85.

P7.54–Carbon balance of a two years old short-rotation tree plantation in Zwijnaarde

I. Vande Walle, N. Van Camp, R. Lemeur and N. Lust (Ghent University)

In the Kyoto Protocol, 'Land Use, Land Use Change and Forestry', as described in Articles 3.3 and 3.4, offer an opportunity to demonstrate atmospheric CO_2 removals through carbon (C) sequestration in terrestrial ecosystems. Land use change through afforestation of former agricultural land might be an interesting tool for C sequestration, especially in Europe. A short rotation tree plantation was established in March–April 2001 at former agricultural land (Zwijnaarde–Belgium) to investigate the carbon sequestration related to this type of land use change. The total carbon storage in the above- and belowground biomass compartments of 8 short rotation plantation plots is assessed. It concerns two plots of birch, maple, poplar and willow. The carbon stored in the stems and branches, roots and leaves are determined four-weekly. In the same plots, the soil respiration is measured forthnightly using an automatic dynamic closed-chamber system. Measurements started in May 2001, some weeks after the establishment of the plantation. The total amount of carbon taken up by the plants can be compared with the amount of CO_2 leaving the system via soil respiration. The carbon balance of these plantation plots is then compared to that of two reference plots: one which has been tilled but not planted with trees, and one reference plot which has neither been tilled nor planted. In this way, it is possible to get an idea of the influence of the planting of trees on the carbon balance of a certain land area.

P7.55–Carbon dynamics and budget in a *Miscanthus sinensis* grassland in Japan

Y. Yazaki (Gifu University), S. Mariko (University of Tsukuba), N. Saigusa (National Institute of Advanced Industrial Science and Technology) and H. Koizumi (Gifu University)

Grassland ecosystems are one of the important components of the global carbon cycle because of their vast area. However, its contribution to the global carbon budget has not been adequately clarified. In this study, the carbon dynamics and budget for two years (2000–2001) were investigated in a *Miscanthus sinensis* grassland which is widely distributed in Japan. Plant biomass began to increase from May and reached a maximum level in September, and then decreased towards the end of growing season (October). CO_2 flux from soil (SR; soil respiration) also exhibited seasonal variations that reflected seasonal changes in soil temperature and root respiration (RR). In 2001, the contribution of RR to total SR varied from 29% in May to 53% in September. In order to determine the net ecosystem production (carbon budget), annual net primary production (NPP), SR and RR were estimated. The NPP was estimated at 1207 and 1140 gC m^{-2} in 2000 and 2001, respectively. On the other hand, annual SR was estimated at 1378 gC m^{-2} in 2000 and 1542 gC m^{-2} in 2001, and RR was 649 and 695 gC m^{-2} in 2000 and 2001, respectively. Moreover, some of the carbon fixed as net production (457–459 gC m^{-2}) is removed by mowing in autumn in this grassland. Therefore, the annual carbon balance was estimated to be -48 gC m^{-2} in 2000 and -235 gC m^{-2} in 2001. These results suggest that the *M. sinensis* grassland may act as a source of carbon.

P7.56–The controls on plant and soil organic matter contributions to wintertime ecosystem CO_2 production in a sub-arctic birch forest in Sweden

P. Grogan (Cranfield University) and S. Jonasson (University of Copenhagen)

Northern ecosystems contain extensive soil carbon pools that could provide a significant positive feedback to global climate change if warming stimulated CO_2 release by enhancing bulk soil organic matter decomposition. Wintertime respiration is important in this context because CO_2 production from snow-covered ecosystems can be a substantial component of annual net carbon balance. Furthermore, wintertime activity is important because global climate models predict that the most rapid rises in regional air temperature will occur at high latitudes during winter, and will be accompanied by enhanced snowfall. In this manipulative field study, the relative contributions of plant and bulk soil organic matter carbon pools to wintertime ecosystem CO_2 production within the understorey of a Swedish sub-arctic birch forest were investigated. We measured wintertime CO_2 production rates on several occasions from control plots, and from plots that had been clipped in the previous growing season to disrupt plant activity. Respiration derived from recently-fixed plant carbon (i.e. plant respiration, and respiration associated with rhizosphere exudates and decomposition of fresh litter) was the principal source of CO_2 production, while respiration associated with decomposition of bulk soil organic matter was low and appeared relatively insensitive to temperature. These results suggest that warmer winter soil temperatures in northern forests may have a much greater impact on the cycling of recently-fixed, plant-associated carbon pools than on the depletion of bulk soil carbon reserves, and consequently that there is a low potential for significant initial feedbacks from boreal forest ecosystems to climate change during winter.

P7.57–Seasonal and interannual differences in carbon balance of contrasting tree species

M.D. Morecroft (Centre for Ecology and Hydrology), V.J. Stokes (Forest Research), and JI.L. Morison (University of Essex)

Within the same biome, even the same site, different tree species may have very different patterns of carbon uptake. It is important to understand these differences in order to predict the impacts of changing species composition on regional carbon balances and guide management to maximise carbon sequestration. Research over the last 10 years at Wytham Woods (UK) has investigated these differences. Using a large scaffolding 'walkway', leaf scale measurements of gas exchange have been made in the canopies of mature pedunculate oak (*Quercus robur*) and sycamore (*Acer pseudoplatanus*) trees. This has revealed substantial differences between species in their seasonal pattern of photosynthesis, with oak developing photosynthetic capacity much more slowly than sycamore and not reaching maximum rates until between 50 and 70 days after bud break. Year-to-year differences in photosynthetic rates were also found with sycamore showing reduced rates in drought conditions. The impact of these factors on tree carbon balance can be quantified and tested against measurements of tree growth at the site.

P7.58–Estimates of 'locally missing carbon' from six contrasting species under four CO_2 concentrations and two nutrient regimes

M. Possell, G. Kerstiens, J. Heath, E. Ayres (University of Lancaster), A. Stott and D. Sleep (CEH Merlewood)

On a global scale much research has gone into quantifying the sources and sinks of carbon. At the terrestrial ecosystem level however, carbon sequestration is a complex resultant of plant photosynthesis, respiration, growth, litter production, root exudation and volatile organic compound emission. How changes in atmospheric CO_2 concentrations affect these processes and by how much, is a matter of on going research. Indeed, elevated CO_2 generally increases plant biomass production less than it increases ecosystem CO_2 uptake, so there is a need to identify and quantify these alternative sinks. In this poster we demonstrate a novel technique that quantifies the amount of carbon lost by six species of north European tree species, grown under four different CO_2 concentrations and two nutrient regimes, to these sinks as a whole. This technique calculates a lifetime water-use efficiency from biomass and water usage data of individual plants, and compares them with the weighted average of 'instantaneous water use efficiency' (i.e. the water use efficiency of carbon assimilation). This 'instantaneous water use efficiency' is inferred from the carbon isotope ratio of leaves, using Farquhar's standard model of carbon discrimination during carbon assimilation. The difference between the two water use efficiencies, multiplied by the amount of water used by the plants during their lifetime, gives an estimate of the 'missing' carbon, which is likely to be dominated by respiration.

P7.59–Growth and gas exchange of six contrasting tree species under four CO_2 concentrations and two nutrient regimes

G. Kerstiens, J. Heath, Z. Pickup, E. Ayres, M. Possell (University of Lancaster) and P. Ineson (university of York)

Tree species vary very widely in their growth response to elevated CO_2 concentrations. These differences are poorly understood and as yet largely unpredictable. We wanted to test the hypothesis that differences between closely related species in their relative stimulation of growth by elevated CO_2 follow their differences in shade tolerance (1). Seedlings of three pairs of woody species of contrasting shade tolerance, each pair from a different family, were grown individually in large containers under current ambient plus 0, 100, 200 or 300 μmol mol^{-1} CO_2 and two nutrient regimes from spring 2001 to late autumn 2002. We used pedunculate oak (*Quercus robur*) and European beech) *Fagus sylvatica*), silver birch (*Betula pendula*) and hornbeam (*Carpinus betulus*) and Scots pine (*Pinus sylvestris*) and silver fir (*Abies alba*). Even though assimilation rates were generally increased in elevated CO_2, growth responses (in terms of final biomass and relative growth rate of basal stem diameter) were mostly very small or absent, and no consistent interspecific patterns with regard to CO_2 effects emerged. The nutrient treatments clearly affected growth in all species except the conifers. Stomatal conductances decreased under elevated CO_2. Further analysis of CO_2 effects on measured seasonal water consumption rates and leaf areas of individual plants will show whether CO_2 concentrations affected whole-plant transpiration rates and transpiration efficiencies.

(1) Kerstiens, G. 2001. Meta-analysis of the interaction between shade-tolerance, light environment and growth response of woody species to elevated CO_2. Acta Oecologica 22, 61–69.

P7.60–Contribution of autotrophs to soil respiration in forest and grassland

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The contribution of autotrophs (plant roots) to the total soil respiration (TSR) was investigated in 1998–1999 in Prioksko-Terrasny Biosphere reserve, Moscow Region, Russia (54° 50′N, 37°35′E) on soddy-podzolic soil. The measurement of TSR were carried out in mature mixed forest with the tree aged up to 100 years and in grassland 47 years after abandonment of arable soil. The relative contribution of roots, soil and litter to TSR was determined in laboratory experiment by incubation of the samples of litter, soil with roots and root-free soil. Both the specific root respiration and contribution of roots to TSR varied significantly depending on sampling date, i.e. virtually on soil moisture, temperature, and growth stage of the plants. The specific respiration of roots varied from 2×10^{-3} to 1.1 mg CO_2-C/(g×h), with higher values in grassland compared to the forest ecosystem. The contribution of root respiration to TSR was 1–20% and 10–60% in forest and grassland, respectively. The minimal values were observed in winter season, the maximal – during intensive growth of plants (in June–July). Annual respiration in grassland and respiration of fine roots in forest contributed to 33 and 15% of TSR, respectively.

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P7.61–Century-time scale adaptation of plants to climate change: separating physiological and climate signals from stable isotopes of tree rings

A. Augusti, T. Nicol and J. Schleucher (Umeå University)

Stable isotopes in tree-rings are used to study long-term adaptation of plants to environmental changes, because they are the only part of the plant that can store information about the past life. Hydrogen isotopes in precipitation have a climate signal. This signal should be present in tree rings, but could not be isolated yet, because physiological isotope effects perturb it. This problem can be solved if the intramolecular deuterium distribution (that is the abundance of deuterium at each individual C–H) can be measured, then climate and physiological signals can be extracted. Two years old oaks and spruces were watered with deuterium-enriched water from March to October. The rationale was to create a deuterium gradient between trunk and leaves, which allows us to separate climate and physiology. Leaves were collected during vegetative season, and trunk parts were collected at the end of the vegetative season. We measured intramolecular deuterium distribution of leaf sucrose and of glucose from cellulose of the last tree ring by Nuclear Magnetic Resonance (NMR). Due to the design of our experiment, we observe deuterium enrichment in specific positions of the glucose molecule, which demonstrates enzymatic exchange of hydrogen between glucose units and trunk water during cellulose synthesis. The hydrogen at carbon 2 exchanges most, followed by carbons 4 and 5. This means that carbon 2 adopts the climate signal of trunk water, and it can be used for climate reconstruction. From the non-exchanging positions, physiological signals can be derived.

P7.62–Is there carbon isotopic fractionation during dark respiration in trees?

C. Mata, A. Scartazza & E. Brugnoli (CNR Porano)

The net carbon ecosystem exchange in a forest is determined by the carbon dioxide assimilated by photosynthesis and that released by respiration. During photosynthesis it is know than there is discrimination against the ^{13}C and that this discrimination does consistently vary with environmental conditions. During dark respiration fractionation as so far been considered not significant and so it has not been included into isotopic carbon balance models, even though there is data claming consistent respiratory fractionation in some non-arboreal species, in studies done at the leaf level in a closed gas exchange system. The knowledge about respiratory fractionation and its extent would be of great value to quantify carbon fluxes with isotopic methods and to improve greatly the precision of presently used methods. In this work we investigated whether there is consistent dark respiratory fractionation at the branch level in saplings of *Quercus ilex* grown in a greenhouse and studied in an open system gas exchange setup. The $\delta^{13}C$ of the air in and out of the branch chamber was analyzed as well as the $\delta^{13}C$ of leaf soluble sugars to determine precisely if there is fractionation for or against ^{13}C.

P7.63–Does photorespiration alter atmospheric CO_2 isotopic composition?

G.J. Lanigan and H. Griffiths (University of Cambridge)

The fractionation factor operating during photorespiration leads to the production of CO_2 depleted in ^{13}C, and we have resolved this factor for three *Senecio* species of contrasting life-form (*S. squalidis*, *S. cineraria* and *S. greyii*). Whilst the impact on leaf organic material will be dependent on the extent of refixation and rate of assimilation, the extent of coupling from photorespiration and leaf gas exchange to the atmosphere will alter daytime CO_2 isotopic signals. The effect of photo-respiratory fractionation on the carbon isotope composition of air in a mesocosm (240 litre volume) was studied using stands of the *Senecio* species.The rate of photorespiration was manipulated by altering the O_2 partial pressure (pO_2) and Keeling plots were generated under these treatments as well as under standard nocturnal conditions. These measurements were carried out both on shoot material only and on whole plants. The effect of photorespiratory fractionation on the carbon isotope composition of the chamber atmosphere and the implications for the deconvolution of daytime Keeling plots will be discussed.

P7.64–Evaluation of four methods separating rhizomicrobial respiration from root respiration in non-sterilised soils

Y. Kuzyakov (Hohenheim University)

Partitioning the root-derived CO_2 from the soil into root respiration and rhizomicrobial respiration is very important for determining the carbon and energy balance of rhizosphere. Only four methods have been suggested to separate root and rhizomicrobial respiration in non-sterilised soils: isotope dilution, the model rhizodeposition technique, modeling of $^{14}CO_2$ efflux dynamics, and exudate elution. All four methods are based on the ^{14}C pulse labeling of shoots and subsequent monitoring of $^{14}CO_2$ efflux from the soil. However, the basic principles of these methods as well as the results observed in the original papers differ from one another. This study describes the assumptions, principles and shortcomings of all four methods and presents the separation of root and rhizomicrobial respiration by growing *Lolium* on a loamy Haplic Luvisol by means of all four methods observed under the same conditions.

In spite of alternative principles, the isotope dilution and the $^{14}CO_2$ dynamics methods showed similar results: root respiration accounts for 39% and 45% of root-derived CO_2, respectively, and the rhizomicrobial respiration accounts for 61% and 55%. The exudate elution underestimated the rhizodeposition and showed that at least 19% of root-derived CO_2 is produced by exudate decomposition. The exudate elution method is the only procedure allowing physical separation of both flows. The model rhizodeposition technique underestimated rhizomicrobial respiration. In conclusion, root respiration contributes 40–50% and rhizomicrobial respiration 50–60% to the root-derived CO_2. The longer the period of $^{14}CO_2$ monitoring after the pulse labeling, the greater the contribution of rhizomicrobial respiration to the root-derived CO_2.

P7.65–Seasonal variation of soil CO_2 fluxes at a cool-temperate deciduous forest

M. Lee (NIES, Tsukuba), K. Nakane (Hiroshima University) and H. Koizumi (Gifu University)

Over a period of 2 years, CO_2 flux at the soil surface (soil Fc) was studied at a cool temperate Quercus/Betula forest in Japan. Soils Fc were measured using an open-flow gas exchange system with an infrared gas analyzer in snow-free season from August 1999 to September 2001. Measured daily average flux rates increased from spring (240–320 mg CO_2 m^{-2} h^{-1}) to summer (840–1150 mg CO_2 m^{-2} h^{-1}) and then decreased during autumn (50–650 mg CO_2 m^{-2} h^{-1}). Soil Fc showed no significant diurnal trend on fine days except thaw. However rainfall events caused a significant increase in soil Fc. On a storm day (a heavy fall of rain with strong winds) in autumn, soil Fc fluctuated from 100 to 260 mg CO_2 m^{-2} h^{-1} between before and during the storm. The soil Fc decreased over a quarter during the first snow-clad in November 1999 between the soil and snow surface. The estimated root respiration rate using a trench method was highest in early summer (June) and then decreased. However, soils Fc kept the high values during the summer (July–September). The results suggest that the factors controlling the seasonal change of soil Fc differ between the soil and root respiration. Generally, temperature and soil water content account for seasonal variation in soil Fc. However, the study shows that the seasonal variation, which is affected by other factors such as weather conditions/biotic factor, is very important at a shorter time-scale to more precise estimation of carbon emission.

P7.66–Temporal and spatial changes in the soil CO_2 efflux in a mixed temperate forest (Vielsalm, Belgium)

D. Perrin, E. Laitat, M. Yernaux, Q. Mezösy, M. Aubinet (University of Agricultural Science of Gembloux)

Assessing the global C-budget in a temperate forest requires a better understanding of CO_2 efflux, which is thought to represent 60–80% of ecosystem respiration. Closed-dynamic-chamber systems were used to analyse the soil CO_2 efflux in a mixed temperate forest in the Vielsalm area, situated in North-east Belgium, where Douglas fir and beech are associated in small patches. Two independent systems were implemented to study both temporal and spatial changes: on one hand the temporal variability of the soil efflux was thoroughly analysed at a limited spatial scale; on the other hand, the spatial variability of the soil efflux was measured during short term campaign. Temporal analysis is based on automatic measurements performed every half-hour from 1999 to 2002 on 6 collars. Empirical models describing the soil CO_2 efflux response were fitted to the measurements and evaluated. For the spatial analysis, soil efflux was measured during a short-term campaign in summer 2002 at 150 spots (by 75 both under beech and Douglas fir). Measurements were analysed against soil litter depth, soil carbon and nitrogen content by layer, number of roots in soil below collars and proximity of stumps. The major factors affecting the temporal variability were the soil temperature and water content. A dependence of the soil efflux to the number of day after significant precipitation was also found. The main factors affecting the spatial variability were the tree composition and the litter depth.

P7.67–Spatial variation of soil respiration rate in tropical rain forest and agroforest in Malaysia

M. Adachi (Gifu University), Y. Bekku (Tsuru University), W. Rashidah (Forest Research Institute Malaysia), T. Okuda (NIES, Tsukuba), H. Koizumi (Gifu University)

Revealing spatial variation and its underlying mechanism of soil respiration rate (SR) is one of the central interests in studies of global carbon dynamics. We measured the spatial variation of SR and its environmental determinants in three types of tropical forest ecosystems, i.e, primary forest, secondary forest and oil palm plantation at Pasoh Forest Reserve, Peninsular Malaysia. In

August 2000, SR and environmental factors (soil temperature, soil water content, carbon and nitrogen content of soil, biomass of fine root and microbe) were measured in 64 to 128 m^2 study plots which contains 16 to 32 sub-plots in each forest. Mean SR of the primary and secondary forests and oil palm plantation were 948, 707 and 966 mg CO_2 m^{-2} hr^{-1}, respectively. The coefficient of variation of SR varied 44 to 78% in the three ecosystems. In the primary forest, SR showed a positive correlation with fine root biomass ($r=0.759$), and a negative correlation with soil water content ($r=-0.373$). In the secondary forest, it showed a positive correlation with soil carbon content ($r=0.371$), and a negative correlation with soil water content ($r=-0.526$). In the oil palm plantation, SR correlated positively with soil carbon content ($r=0.847$), fine root biomass ($r=0.558$) and microbial biomass ($r=0.609$). Although mean SR in the three ecosystems did not differ significantly, the environment factors affecting spatial variation of SR were different among the three forest ecosystems.

P7.68–CO_2 emission from forest ecosystems of Russian South Taiga

V. Lopes de Gerenyu, I. Kurganova, L. Rozanova, D. Sapronov, T. Myakshina and V. Kudeyarov (Russian Academy of Science, Moscow)

The Russian forest lands occupy 882 million ha and total CO_2 emission to atmosphere amounts 2.78 Pg C per year. So, even the small inaccuracy in the magnitude of soil respiration of forest ecosystems can result in the significant mistakes of the carbon balance evaluation. Annual and seasonal dynamics of CO_2 emission from two forest ecosystems on sandy Albeluvisols and clay Phaeozems were studied in situ (Russia, Moscow region) from November 1997 through October 2002. The annual CO_2 fluxes averaged 624 and 555 g C m^{-2} from sandy Albeluvisols and clay Phaeozems respectively. The coefficients of variation for annual CO_2 fluxes caused by weather conditions ranged from 21% to 28%. We found significant linear trends ($R^2=+0.74$–0.92, $P<0.01$) describing the relationship between annual CO_2 fluxes and annual precipitation. The contribution from the cold period (with snow, November–April) to the annual CO_2 flux was substantial and constituted 25%. The CO_2 fluxes averaged 43% of the total ACDF in summer, 28% in autumn, 19% in spring and 10% in winter. The high positive correlation between mean daily CO_2 emissions and mean daily soil temperatures (0–5 cm layer) for the whole observation period was found ($R^2=+0.53$–0.62; $P<0.001$). The temperature coefficient Q_{10} constituted 2.8 and 3.0 for Phaeozems and Albeluvisols, respectively. The effect of soil moisture in CO_2 emission was different: significant positive correlation were found during the summer season and negative-during the winter season.

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P7.69–CO_2 emission from forest soils during freezing and thawing

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Freezing and subsequent thawing of soils have been known to cause an increase in CO_2 emissions from soils. In the laboratory study the undisturbed columns forest soils (Luvisol, loamy silt, Niedersaschsen, Germany) adjusted at two different moisture contents were subjected to two freezing–thawing cycles. To simulate freeze and thaw events in the soil the temperature in the freezer was changed from +10 °C (initial level) to −5 °C (freezing period, 8 days) and to +10 °C. Carbon dioxide emissions from the forest soils at 10 °C were 35.1 and 43.8 mg C m^{-2} h^{-1} at 65% ('dry' soil) and 100% ('wet' soil) water holding capacity, respectively. In the totally frozen soil the CO_2 flux never decreased to zero and amounted to 6 to 13% of the initial level, indicating that microbial community was still active at −5 °C. Significant burst of CO_2 emission during thawing periods was observed. The extra CO_2 fluxes caused by release of nutrients after freezing processes during two cycles were 2.17 and 1.03 g C·m^{-2} in the dry and wet soils, respectively. The part of extra CO_2 flux to total CO_2 flux was appreciable: 7.2% in the dry and 16.1% in the wet forest soils. The negative correlation between C content of microbial biomass (0–4 cm layer) after two FTC and part of extra CO_2 fluxes to total CO_2 fluxes point out microbial origin of extra CO_2 fluxes.

P7.70–Model estimation of net primary production in forest understory, Sasa senanensis. —Comparison of Monsi–Saeki model and geometrical canopy photosynthesis model

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Light distribution pattern is a critical input for canopy photosynthesis models. The model by Monsi & Saeki (1953; M–S model) assumed random leaf distribution and exponential decrease of photosynthetic photon flux density (PPFD) in a canopy with cumulative leaf area index (LAI) toward the ground. However, light distribution in a canopy is highly heterogeneous due to non-random leaf distribution, and it fluctuates daily and seasonally especially in forest understory.??We examined how the difference of light distribution models affects the estimation of photosynthesis in a forest understory vegetation. We measured stand architecture of bamboo grass, *Sasa senanensis* with a 3-D digitizer for six plots (80 × 80 cm) with different LAI, and light environment under various sky conditions in a cool-temperate deciduous forest of central Japan. Light interception and photosynthesis of the canopies were estimated by M–S model and a geometrical photosynthesis model Y-plant (Pearcy & Yang 1996). In M–S model, daily course of PPFD above forest canopy assumed a sine curve, and PPFD in a canopy was estimated by multiplying the daily course and diffuse transmittance. In Y-plant model, direct and diffuse PPFD and corresponding photosynthetic rates for the individual leaves were estimated by hemispherical photograph and 3-D leaf distribution. Daily PPFD estimated by the two models were close. Under an open sky, daily photosynthesis of the canopies was similar between the two models. However, under a maturated forest canopy in summer, daily photosynthesis in M–S model was 2.5–3.2 times larger than in Y-plant. This large difference was brought by higher instantaneous PPFDs throughout a day in the M–S model.

P7.71–Contribution of different sources to carbon dioxide emission from planted soils

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The total CO_2 efflux from planted soil originates from four main sources: 1) root respiration, 2) microbial decomposition of exudates, sloughed root cells and other rhizodeposits (rhizomicrobial respiration), 3) microbial decomposition of plant remains, and 4) microbial decomposition of soil organic matter (SOM). These four sources contribute to different extent to the atmospheric CO_2 concentration. The first two sources (root-derived CO_2) represent a short cycle of plant-assimilated C in the atmosphere–plant–soil cycle. Therefore, the root-derived CO_2 does not contribute to a change in atmospheric CO_2. The microbial decomposition of plant remains (third source) represents the CO_2 efflux from the short-term storage of assimilated C, and therefore its contribution to a change in atmospheric CO_2 is marginal. The last CO_2 source, microbial SOM decomposition, is the major terrestrial process that affects the atmospheric CO_2 concentration and which is mainly initiated by land use changes, deforestation, etc. The methods used for the separation and independent estimation of C from each source of CO_2 efflux from non-sterilised soil under field and laboratory conditions are reviewed. The principles, advantages and shortcomings of methods based on the application of carbon isotopes (^{13}C, ^{14}C, ^{13}C natural abundance, pulse and continuous labelling) are presented. The most uncertainty exists for the estimation of root respiration and rhizomicrobial respiration in non-sterilised soils.

P7.72–Soil pH – An important general controller on C-sequestration in forest soils

R. Brumme (University of Göttingen)

The German forest carbon stock has been estimated to 2.25 Gt C and nearly half of this amount is stored in the soil. Recent inventories indicate that the above-ground C-stock of European forest is not constant as a result of human activities. To what extend the human impact has changed the below-ground C stocks is hardly detectable by inventories or experimental studies. One of the most important factor which has been changed by human activities is the soil pH which is responsible for carbon sequestration by changing litter decomposition and vertical distribution in the soil profile. The soil pH has been changed drastically within the last decades indicated by repeated measurements. Especially soils in the former exchanger buffer range changed up to 2 pH units. To access past and to predict future changes in the soil C- and N-stocks about 420 forest soil profiles were arranged according to the soil pH. This figure indicate high C-and N-stock in the carbonate and Al/Fe buffer range whereas soils in the exchanger/silicate buffer range had low C- and N-stocks. The information about past and expected future soil acidification together with the C-stock/pH relationship was used to estimate past and expected future C-sequestrations in Germany.

P7.73–Impacts of a range of atmospheric CO_2 concentrations and tree species on C and N cycling in soils

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The current increase in atmospheric CO_2 concentration is considered to be one of the most important long-term aspects of global change. Understanding how ecosystems will respond to this change, with regard to nutrient cycling and pools, sources and sinks of carbon is essential if meaningful models are to be constructed and regulations on carbon emissions imposed. We investigated the impact of a range of atmospheric CO_2 concentrations and tree species on microbial biomass and activity in soil, as well as on nutrient cycling rates. Six tree species (beech, oak, hornbeam, birch, fir and pine) were grown at 4 CO_2 concentrations (ambient plus 0, 100, 200 and 300 ppm CO_2) and two nutrient concentrations (unfertilised and fertilised) for two growing seasons. The trees were grown in specialised growth chambers (solar-domes) which experience near-ambient light and temperature conditions whilst allowing atmospheric CO_2 concentration to be closely controlled. Although significant effects of atmospheric CO_2 concentration were detected, most of the variation in soil microbial biomass and nutrient cycling was explained by tree species and fertilisation. This suggests that forest tree species composition and soil nutrient status are the dominant factors controlling soil processes related to nutrient and carbon cycling, and hence soil C storage.

P7.74–Calculations to the impact of climate conditions on the carbon balance of forest ecosystems in north-eastern lowlands of Germany

H. Jochheim (Institute of Landscape System Analysis, Muencheberg)

The terrestrial ecosystem model BIOME-BGC was calibrated at the basis of measurements within 6 pine forest ecosystems of the level-II stands of Brandenburg, Germany. These stands are characterised by low annual precipitation rates of 500–650 mm a^{-1} in combination with mainly sandy soils. Therefore the water availability plays an important role in the determination of forest growth. The simulated wood increment was compared to tree ring analyses. Correlations between water stress events of the last 50 years and wood increment could be simulated with the model in some of these forest stands. Additionally the effects of the increasing temperature during the last 50 years on the beginning of the vegetation period and the associated changes in the carbon budget of the ecosystems were simulated. In regional applications of the model the effects of different climatic scenarios for a catchment area of the north-eastern lowlands of Germany were analysed.

P7.75–Climate change in Mediterranean Portugal: simulation of climate change effects on the carbon stock of a *Quercus ilex* ssp. *ballota* stand

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We studied the growth and carbon balance of a *Quercus ilex* ssp. *ballota* adult stand, under different scenarios of climate change and forest management. The stand is located near Évora, southern Portugal (38°32′26″ N, 8°00′01″ W), and consists of an open oak woodland, typical of southern Iberian Peninsula. Tree density is rather low, 67 trees/ha, and the average tree cover is ca. 32%. Climate is Mediterranean, with an average mean temperature of 15.4°C and 665 mm of average annual precipitation. To simulate the growth and the various scenarios, we use the process-based model GOTILWA. The model was run for the present conditions with the Hadley Centre Regional Model (HadRM2) control data set (constant CO_2 concentration of 323 ppmv), and for the future climates with data sets derived from the HadRM2 control run using GOTILWA's climate change module. Field measurements of photosynthesis, stomatal conductance and water potential were used to parameterize the model. The effects of climate change and management regimes are presented and discussed.

P7.76–Above and belowground carbon stocks in Flemish forests—quantification and uncertainty

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Countries are allowed to offset their emission reduction targets by increasing biological carbon (C) sequestration in terrestrial ecosystems including forests. This imposes a demand for sound inventory systems based on traditional, continuous forest inventories and for regional specific C calculation methods. As in many countries few allometric relationships per tree species or forest type exist in Belgium. Therefore reported biomass expansion factors (BEFs) that are established for large species groups and spatial areas, are required to gain information on the C stocks. The use of such BEFs is foreseen in the IPCC guidelines in those cases where no biomass information is readily available. But the questions rise which of the different existing BEFs are suitable, and to what extend these 'general' BEFs give an accurate result for the Flemish case? Based on recently collected, regional forest inventory data (1997–1999), a comprehensive overview is given of the C stocks in above and belowground forest biomass and soil layer for the Flemish forests. An indication is given of the accuracy in using reported, general BEFs for the quantification of the above and belowground biomass. This new information will improve the national communications for Belgium, which were up till now neither transparent, nor consistent and revealed a serious lack of data. This exercise is part of the CASTEC project (**CA**rbon **S**equestration potential in Belgian **T**errestrial **EC**osystems: quantification and strategic exploration) of Ghent University and CLO, financed by the Belgian OSTC.

P7.77–Carbon balance in a mixed hardwood Kyoto-reforestation in northern Italy

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This research was carried out in a 38-ha, mixed hardwood plantation in a flat rural area in northern Italy (Nonantola, MO). This forest was established in 1992 with EU funding and can be considered a Kyoto forest. The dominant species are peduncolate oak (Quercus robur) and narrow ash (Fraxinus angustifolia). During 2001 and 2002 we measured: carbon dioxide and water vapor fluxes by an eddy covariance system; photosynthetic capacity in the upper canopy of oak and ash trees (A_{max}, J_{max} and Vc_{max} from A/Ci curves); soil respiration. Whereas 2001 was characterized by a prolonged drought in the summer, during 2002 water availability was relatively abundant along the whole growing season. In both years, carbon assimilation rapidly increased in late April. In May and June, LE at midday was half of the available energy and Fc reached the maximum levels of assimilation (~ -20 μmol CO_2 m^{-2} s^{-1}) and of nighttime respiration (~ 6 μmol CO_2 m^{-2} s^{-1}). In July, while leaf area registered its maximum, forest assimilation started to decrease and was not symmetrical between morning and afternoon. In August 2001 LE decayed drastically and both leaf photosynthesis, soil respiration and evapotranspiration were strongly reduced. By contrast, during August 2002 this trend was less evident. Differences in photosynthetic rates between the two examined species suggest that ash has a higher photosynthetic potential but is more susceptible to drought than oak. Whereas soil respiration was affected mainly by soil moisture during 2001, soil temperature was the main controlling factor during 2002.

P7.78–Partitioning soil respiration using experimental manipulation and stable isotopes

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We used the experimental manipulations of the international DIRT network (detritus input, removal, and trenching) to calculate an annual carbon budget in an old growth coniferous forest in central Oregon (HJ Andrews LTER site), USA. We compare those data, based on soil respiration and litterfall rates, with similar data for two mixed deciduous forests in the Northeastern USA, where the seasonality of precipitation is different (summer rain compared with summer drought in Oregon), and to data of Rey et al. (Global Change Biology 2002) who have a similar experimental design in a mixed oak forest in Italy (summer drought but 3-times drier than the site in Oregon). Data from Oregon suggest 23% of the annual CO_2 flux is from root respiration, 54% of the flux is due to microbial respiration during decomposition of SOM plus belowground detritus, and 23% of soil respiration is decomposition of aboveground litter. Data from the other sites range from 14% to 33% of soil respiration from roots, 30% to 56% from SOM and root detritus, and 22% to 37% from aboveground litter. Carbon-13 of organic matter, litter, and respired CO_2 were measured to determine if the isotopic approach could be used to partition soil respiration. Initial soil respired $\delta^{13}CO_2$ data looked extremely promising. Unfortunately, natural variability in $\delta^{13}C$ of inputs (litter, roots, moss, SOM from different depths) was found to be too high to use the original approach. A natural tracer study will commence at the Oregon site this summer (June 2003).

P7.79–Partitioning of NEE and mesophyll conductance: It's in the isotopes

U. Seibt (MPI for Biogeochemistry, Jena), L. Wingate (University of Edinburgh) and J. Lloyd (MPI for Biogeochemistry, Jena)

Measurements of concurrent fluctuations in concentration and isotopic composition of CO_2 in canopy air provide independent information on ecosystem gas exchange. To use this information for constraining the component fluxes of photosynthesis and respiration, two methods of partitioning net ecosystem CO_2 exchange are available, referring either to isofluxes of one-way turbulent exchange (Lloyd et al. 1996) or to isofluxes of net turbulent exchange (Bowling et al. 2001). Both methods rely on observations of the δ13C signature of ecosystem respiration. Partitioning solutions are derived from theoretical descriptions of photosynthetic 13C discrimination. Here, a new approach is developed based on one-way isofluxes, taking advantage of the simultaneous availability of δ13C and δ18O signatures of CO_2 in canopy air. The reliability of the different partitioning approaches is tested using data obtained from eddy flux and chamber measurements in Griffin Forest, UK. The two methods based on one-way isofluxes achieve the best agreement with assimilation rates from chamber measurements. We also investigate the sensitivity of partitioned assimilation rates to the specific formulation of photosynthetic discrimination, i.e. including only stomatal conductance or both stomatal and mesophyll conductance. We find that neglecting the influence of mesophyll conductance on 13C discrimination might result in an overestimation of assimilation rates by up to 50%.

Bowling DR et al. (2001) Global Change Biology 7: 127–145.
Lloyd J et al. (1996) Australian Journal of Plant Physiology 23: 371–399.

P7.80–Net ecosystem exchange: some complexity unravelled using gas exchange and stable isotope methods, but more revealed?

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The one-way flux of gross photosynthesis (FA) in pole-stage plantations, typically constitutes the largest flux of carbon between vegetation and the atmosphere[1]. Quantification of FA can be difficult because of the respiratory counter flux (FR). De-convoluting the net ecosystem exchange (NEE) of CO_2 into the component processes is commonly tackled using eddy covariance measurements of nocturnal NEE and its relationship with temperature. Alternatively, flux estimates for the component processes may be constrained with chamber measurements and biomass inventory. More recently, methods are being developed which exploit the natural difference in δ13C between plant carbon and atmospheric CO_2, but validation of assumptions underlying this method are necessary with appropriate datasets. This study presents data collected from a Sitka spruce plantation in the UK during July 2001 using all the above methods. Diurnal patterns and estimates of FA were comparable in magnitude and timing between methods and tightly coupled with irradiance, vapour pressure deficit and temperature. Daily maxima for FA ranged from -20 to -30 micro-mol/m^2 s and were similar to other published studies[1]. Estimates for FR were variable between methods, depending on e.g. inhibition of day respiration and effects of low turbulence. This study highlights the necessity for improvements in the measurement and modeling of respiratory fluxes within ecosystems, especially during the day where most of the uncertainty still remains.

[1]Jarvis, P.G. In: Resource Capture by Crops, (eds. J.L. Monteith, R.K. Scott and M.H. Unsworth), pp 351–374, 1994. [2]Bowling D.R et al. (2001) Global Change Biology 7: 127–145.

P7.81–Elevated CO_2 reduces stomatal conductance in mature deciduous forest trees

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Reduction of stomatal conductance (g_s) is a well-known response of plants to elevated CO_2, which can lead to a decrease in plant water use. There is strong evidence that stomata of woody species are generally less responsive to CO_2 enrichment than herbaceous plants. In the context of globally increasing atmospheric CO_2, it is therefore of interest to predict how water use of forest trees and whole forest ecosystems will be affected. Results of mature trees being entirely exposed to elevated CO_2 are scarce. Although responses of trees are assumed to be species-specific, there is a lack of observations on diverse systems. Using the Swiss Canopy Crane (SCC) and a new CO enrichment technique (web-FACE, Pepin and Körner 2002) we examined the stomatal response of six broadleaved tree species in a highly diverse mature forest stand. Overall g_s was reduced by 13 % in response to CO_2 enrichment. Responses were most pronounced in *Prunus*, *Carpinus* and *Acer* and negligible in *Fagus*, *Tilia* and *Quercus.* These results agree with sapflux measurements on the same site. We conclude that depending on species dominance, the water use of deciduous forests is affected by elevated CO_2. Species-specific responses to CO_2-enrichment will lead to a biodiversity-effect in the long run.

Pepin, S and Körner C (2002). Web-FACE: a new canopy free-air CO_2 enrichment system for tall trees in mature forests. Oecologia 133(1): 1–9.

P7.82–Respiration of ecosystem components in a Mediterranean holm-oak coppice

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Puechabon station is a holm-oak coppice located in the South of France, where carbon balance has been monitored since 1998 with eddy covariance measurements. This method provides the balance between CO_2 uptake by photosynthesis and CO_2 release by respiration activity. To better understand this carbon balance an evaluation of the different respiration components is necessary. In this paper two different methods of soil and trunk respiration are compared: a multichannel CO_2 continuous measurement open system and a dynamic closed system LiCor6400-09. Measurements of soil and trunk respiration were recorded during five days per month in February, September and November 2001 and in May 2002. The relations between respiration activity and environmental conditions (soil and trunk temperatures, soil water content) as well as plant transpiration were analysed over different seasons. The relative importance of soil and trunk respiration for carbon balance are evaluated and compared with the ecosystem integrated eddy-flux measurements. Both methods presented comparable respiration results for both soil and trunk. Daily patterns of respiration are driven by temperature with different range of variation according to the seasons. Soil respiration is constrained by low temperature in winter and low soil moisture in summer, spring and autumn show the highest respiration values. Trunk respiration is also driven by temperature and reflects the plant physiological activity. Soil respiration significantly influences carbon balance, while trunk respiration shows a minor contribution.

P7.83–Comparative carbon fluxes from mid and late-successional forests in the Upper Midwest, USA

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We measured Net Ecosystem Exchange (NEE) of CO_2 in a mid-successional northern hardwood forest and a late-successional undisturbed old-growth hemlock-northern hardwood forest in the Upper Midwest, USA with the primary objective of examining the role of forest stand age as a determining factor in storage of atmospheric CO_2. The late-successional site is located within one of only two remaining large tracts of old-growth forest in the region and trees range in age from current year regeneration to greater than 350 years old. The paired mid-successional stand is approximately 70 years old. NEE of CO_2 was measured by the eddy-covariance/surface layer budget method.
Component CO_2 fluxes (photosynthesis; stem, branch, leaf, and soil respiration) were measured with portable infrared gas analyzers. Preliminary data from the old-growth stand at Sylvania, MI indicate that during the period from October 2001–October 2002 the site was a net carbon sink. Spring and summer of 2002 had abundant precipitation, average temperatures, and no insect outbreaks resulting in favourable growing season conditions. The annual NEE for Sylvania of -161 gC m^{-2} yr^{-1} is less than reported NEE for other old-growth sites (e.g. Metolius, OR, USA -266–324 gC m^{-2} yr^{-1}; Howland, ME, USA -210 gC m^{-2} yr^{-1}), but similar to another mature forest site within the same region (Pellston, MI -1.67 gC m^{-2} yr^{-1}). NEE at Sylvania is lower than at its paired mid-successional site, Willow Creek, WI, USA (-400 gC m m^{-2} yr^{-1}).

P7.84–How much inert carbon is in boreal forest soils?

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Boreal forest fires frequently reduce organic carbon (OC) stocks, but convert some to degradation-resistant black carbon (BC). Little is known on how fires change the amount, composition, and distribution of carbon within soils. In Siberian Scots pine forests, we investigated soil carbon dynamics along three chronosequences with time since stand replacing fire under different surface fire frequencies (low, medium, high), and how a surface fire changed the molecular structure of carbon (^{13}C-MAS NMR). The organic layer contained the highest BC amounts (max. 72 g m^{-2}, representing 99% of total BC stocks in organic layer and 1 m mineral soil), but BC did not accumulate with time, because it was consumed by intense fires. We used BC stocks in the organic layer as a proxy for the intensity of the last fire and estimated the OC amounts remaining after the last fire (0.7 kg OC m^{-2}) and accumulating with time since the last fire (0.014 kg OC m^{-2} $year^{-1}$). Maximum stocks were 2.3 kg OC m^{-2} 140 years since fire, with no differences among chronosequences. In the mineral soil, frequent fires increased OC stocks (0–0.25 m: 0.6 (low) to 1.1 (high) kg OC m^{-2}), while BC stocks were small (0–0.25 m: 0.1 g m^{-2} (low)). OC in unburned organic layer was mainly present in (di-)O-alkyl (polysaccharides) and few aromatic structures (e.g. lignin), probably due to dominant input of lichen. The BC formed consisted of heterocyclic macromolecules and small clusters of condensed carbon which were probably less degradation-resistant than generally assumed.

P7.85–Carbon Dioxide Observations at a Boreal Site in Finland

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Seasonal variations and source areas of CO_2 were studied by utilizing air parcel back trajectories and tropospheric concentration measurements at a boreal GAW-site in Pallas, Finland, locally and regionally characterized with very limited number of pollution sources. Fluxes of carbon dioxide to the forest were also measured in the Pallas region using eddy covariance technique. The average growth rate of CO_2 concentrations was about 1.9 ppm/year according to a six-year long measurement period starting in October 1996. The annual cycle of CO_2 showed concentration difference of about 18 ppm between the summer minimum and winter maximum. The diurnal cycle was most pronounced during July and August. The variation between daily minimum and maximum was about 5 ppm. According to trajectory analysis the site was equally affected by continental and marine air masses. Source areas of CO_2 could be detected during summer in the northern parts of the Central Europe.