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Analyzing the causes and spatial pattern of the European 2003 carbon flux anomaly in Europe using seven models

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Abstract

Globally, the year 2003 is associated with one of the largest atmospheric CO_2 rises on record. In the same year, Europe experienced an anomalously strong flux of CO_2 from the land to the atmosphere associated with an exceptionally dry and hot summer in Western and Central Europe. In this study we analyze the magnitude of this carbon flux anomaly and key driving ecosystem processes using simulations of seven terrestrial ecosystem models of different complexity and types (process-oriented and diagnostic). We address the following questions: (1) how large were deviations in the net European carbon flux in 2003 relative to a short-term baseline (1998–2002) and to longer-term variations in annual fluxes (1980 to 2005), (2) which regions exhibited the largest shift in carbon fluxes during the growing season 2003, and (3) which processes controlled the carbon balance anomaly .

In Western and Central Europe, the anomaly in net ecosystem productivity (NEP) over growing season 2003 was outside the 1σ bound of the carbon flux anomalies for 1980–2005. The estimated growing season anomaly ranged between –29 and –196 Tg C for Western Europe and between 13 and –94 Tg C for Central Europe depending on the model used. All models responded to a dipole pattern of the climate anomaly in 2003. In Western and Central Europe NEP was reduced due to heat and drought. Over Western Russia NEP was decreased in response to lower than normal temperatures and high precipitation. While models agree on changes in simulated NEP and gross primary productivity anomalies in 2003 over Western and Central Europe, models diverge in the estimates of anomalies in ecosystem respiration. Except for two process models which simulate respiration increase, most models simulated a decrease in ecosystem respiration in 2003. The diagnostic models showed a weaker decrease in ecosystem respiration than the process-oriented models.

Based on the multi-model simulations we estimated the total carbon flux anomaly over the 2003 growing season in Europe to range between –0.02 and –0.27 Pg C relative to the net flux in 1998–2002.

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1 Introduction

Globally, the year 2003 is associated with one of the largest atmospheric CO_2 rises on record (Jones and Cox, 2005). This was particularly significant as there was no accompanying large El Nino event that is normally the case in years with high
5 CO_2 increase. Drought periods in mid-latitudes of the northern Hemisphere were suggested to cause additional carbon release to the atmosphere large enough to modify dominant ENSO responses in 1998–2002 (Zeng et al., 2005). During these years, atmospheric model inversions have indicated that the Northern Hemisphere mid-latitudes went from being a sink ($0.7\,\mathrm{Pg\,C\,yr}^{-1}$) to being close to neutral. As terrestrial
10 ecosystems seem to respond to droughts with an increased carbon flux to the atmosphere, frequent droughts may lead to a faster increase in atmospheric carbon dioxide concentration and accelerate global warming. Thus understanding the response of ecosystems to large-scale drought events is an important issue, particularly given that such drought events are projected to occur more frequently in the future (IPCC
15 2007; http://www.ipcc.ch/SPM2feb07.pdf). Western and Central Europe experienced extremely hot and dry conditions during the summer of 2003, while Scandinavia, North-Eastern Europe and Russia had lower than normal temperatures and high precipitation (Zveryaev, 2004; Ding and Wang, 2005; Lucero and Rodriguez, 2002; Trigo et al., 2005; Chen at al., 2007). The Central European "summer drought" caused a de-
20 crease in carbon sequestration over large areas (Reichstein et al., 2006; Schindler et al., 2006; Ciais et al., 2005), whereas areas normally experiencing temperature limitation as the Alps, experienced an increase in carbon sequestration (Jolly et al., 2005). Ciais et al. (2005) showed in a model study that the carbon flux anomaly was rather caused by a drop in the gross primary production than increased ecosystem respira-
25 tion resulting in an anomalous source of 0.5 Pg of carbon to the atmosphere through July–September 2003 relative to the average carbon flux from 1998–2002. Reichstein et al. (2006) conducted a model intercomparison on the 2003 carbon flux anomaly. This model intercomparison included four models, which drivers were not harmonized.

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Differences among the models could not be completely separated from the effect of different inputs. As a result they could not conduct an in depth analysis of the responses of the component carbon fluxes, only stating that both gross primary productivity (GPP) and ecosystem respiration (Reco) were reduced in the year 2003.

In this study, we use five process-based terrestrial ecosystem models (TEMs), one remote-sensing driven model and one artificial neural network to analyze European ecosystem responses to climate variations with special emphasis on 2003. All models are driven with the same input data. This allows us to assess the regional significance of the 2003 anomaly in the European carbon balance together with the uncertainty in its estimates caused by different parameterizations and assumptions used in the different models.

We will address the following questions: (1) how large were the shifts in the regional carbon fluxes during 2003 growing season (May–September) relative to long-term growing season variation?, (2) do the models agree on which regions exhibited the largest shift in carbon fluxes during the growing season 2003? and finally (3) which processes, photosynthesis or respiration, controlled the carbon balance anomaly in the models?

2 Methods

2.1 Model descriptions

In this study, we use five process-based terrestrial ecosystem models of different complexity (Biome-BGC, LPJ, ORCHIDEE, JULES and PIXGRO) and two data oriented models (MOD17+ and NETWORK$_{ANN}$) to simulate carbon fluxes. Except NETWORK$_{ANN}$ all models simulated gross primary productivity and respiration independently. The models also differed by the number of simulated biomes as well as implementation of crop- and crop management. Key features of the models in terms of representing photosynthesis, respiration and the terrestrial water cycle are summa-

rized in Table 1.

Biome-BGC: Biome-BGC is a terrestrial ecosystem model describing the carbon, nitrogen and water cycles (Running and Gower, 1991; Thornton et al., 2002) see details in Table 1. It has been corroborated for a number of hydrological, carbon cycle components and forest management (Cienciala et al., 1998; Churkina and Running, 2000; Churkina et al., 2003; Thornton et al., 2002; Vetter et al., 2005). Biome-BGC is parameterized for seven biomes including evergreen needleleaf (enf), evergreen broadleaf (ebf) (Trusilova et al., 2007[1]), deciduous needleleaf (dnf), deciduous broadleaf (dbf), shrubs (sh), and grass as well as fertilized grasses (C3 and C4 type photosynthesis). The model does not include a special crop phenology, and simulates crops as fertilized grasses with no further management such as harvest. Forest management was not included due to lack of detailed regional forest inventories.

Lund-Potsdam-Jena dynamic global vegetation model for managed Land (LPJmL): LPJmL is a terrestrial ecosystem model describing the coupled carbon and water cycles of natural, semi-natural and anthropogenic ecosystems (Sitch et al., 2003; Bondeau et al., 2007; Zaehle et al., 2007), see details in Table 1. It includes representations of boreal and temperate evergreen needleleaf (enf), decidous needleleaved (dnf), deciduous broadleaf deciduous (dbf), and evergreen broadleaved tree types (ebf), as well as two grass and 11 croptypes. Vegetation dynamics and management are calculated separately for each landcover type. Crop land dynamics were simulated as described by Bondeau et al. (2007), managed forest according to Zaehle et al. (2007). To be consistent with the other models in this comparison, cropland irrigation was not activated, and no land-use change was considered.

ORCHIDEE: The ORCHIDEE biosphere model describes the carbon, energy and water fluxes on a half-hourly basis (Krinner et al., 2005; Viovy, 1996) see details in Table 1. ORCHIDEE differentiates 12 different plant functional types, similar to LPJ, of

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[1]Trusilova, K., Churkina, G., Vetter, M., Reichstein, M., Schumacher, J., Knohl, A., Rannik, U., Gruenewald, T., Moors, E., and Granier, A.: Parameter estimation for the terrestrial ecosystem model BIOME-BGC using non linear inversions, Ecol. Modell., in review, 2007.

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which two are representing C3 and C4-type crops as fertile, but not harvested grassland. Long-term vegetation dynamics, adapted from the LPJ model (Sitch et al., 2003) are not activated for the simulations presented here. ORCHIDEE runs with hourly time-steps climate forcing.

5   **Joint UK Land Environment Simulator (JULES):** JULES is a land-surface model based on the MOSES2 land surface scheme (Essery et al., 2003) used in the Hadley Centre climate model HadGEM (Johns et al., 2006), also incorporating the TRIFFID DGVM (Cox, 2001; Cox et al., 2000), see details in Table 1. The model simulates carbon, water and energy fluxes on 9 sub-grid tiles, including 5 plant functional types:

10   broadleaf and needleleaf trees, C3 and C4 grasses and shrubs. In this study JULES is driven by hourly time-steps (see Table 2 and Table 3). JULES does not simulate crops and crop management and represent these as natural C3 grasses.

PIXGRO: PIXGRO is a canopy flux and, in the case of short-stature vegetation (grassland, crops, tundra, or wetlands), growth model for simulation of carbon and

15   water fluxes (Adiku et al., 2006; Reichstein, 2001; Reichstein et al., 2004), see details in Table 1. The model has been applied on landscape to continental scale and regions (Tenhunen et al., 2007). In this continental scale study, the single-layered canopy model described in Owen et al. (2007) was applied, where canopy capacity for CO_2 uptake for conifer and deciduous forest, for Mediterranean shrublands, for grasslands

20   and tundra and for crops is based on data from flux measurement sites of CarboEurope. PIXGRO uses remote sensing data from MODIS to establish the max LAI for forests and shrublands of each year. Crops are represented as summer and winter grains, root crops and maize. Phenology across the continent is based on temperature climate and principles related to winter dormancy and release from dormancy as

25   elaborated by Zhang et al. (2004). Crops are harvested rather than senescing.

MOD17+: MOD17+ is a semi-empirical relatively data-oriented model (Reichstein et al., 2004, 2003b, 2005a, 2005b); a successor of a remote sensing driven radiation-use efficiency model (Nemani et al., 2003), that has also been implemented for calculating the operational global MODIS-NPP product at 1km resolution (Running et al., 2004),

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see Table 1 for details on how the carbon fluxes are simulated.

NETWORK$_{ANN}$: NETWORK$_{ANN}$ is a completely data-oriented modeling approach based on Artificial Neural Networks (ANNs) (Papale and Valentini, 2003) for details see Table 1. ANN was trained with flux measurements covering 7 different landcovers:
5 deciduous broadleaf forest (11 sites), evergreen needleleaf forests (15 sites), evergreen broadleaf forests and shrublands (6 sites), grasslands and wetland (18 sites), croplands (12 sites). The datasets used in the ANNs training were divided in three subset, training, test and validation sets, with the last one that is not used at all in the training phase but only to assess the ANN generalization ability.

10 ## 2.2 Model inputs

The climate data were obtained with the regional climate model REMO (RE-gionalMOdel, Jacob and Podzun, 1997) forced with global 6-hourly NCEP (National Centers for Environmental Prediction) reanalyses (Kalnay et al., 1996) from 1948 until the current time. The prognostic variables are surface air pressure, temperature, hor-
15 izontal wind components, specific humidity and cloud water. The physics scheme applied is a version of the global model ECHAM4 physics of the Max-Planck-Institute for meteorology adapted for the regional model (Koch and Feser, 2006). The model simulation was computed with additional "nudging of large scales" (von Storch et al., 2000). Thereby the simulated state is kept close to the driving state at larger scales, while
20 allowing the model to freely generate regional-scale weather phenomena consistent with the large-scale state. A more detailed description of the multi-decadal simulation is given in Feser et al. (2001). The atmospheric hourly values were then interpolated to a regular latitude-longitude grid with a grid spacing of 0.25° × 0.25° and aggregated to daily and monthly values as needed by the different models (see Table 2, Table 3).
25 To compare the model-outputs with other input climate drivers, the models used the REMO-derived climate from 1958–2005. The major reason for choosing REMO derived climate data input in this study was the temporal consistency of the model output and its quality (Chen et al., 2007).

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To include the effect of environmental change on the estimates of the carbon-fluxes over Europe we used the annual values of the CO_2 concentrations over the northern Hemisphere. These values were based on ice core data from Etheridge (1996) and atmospheric data from Mauna Loa (Keeling and Whorf, 2005). They cover the time until the end of 2004. The CO_2 concentration for the year 2005 was added by using the annual global trend reported by NOAA/CMDL of 2.08 ppm as an average from January 2004–December 2005, (Table 3).

All models used the same maps of elevation above the sea level, soil texture, soil-depth and land use classification (Table 3). Biome-BGC is also simulating the nitrogen cycle and requires data on reactive nitrogen deposition. We used the atmospheric nitrogen deposition maps as reported by Galloway et al. (2004). For the spin-up runs we used the maximum pre-industrial constant of 0.0002 kg N/m^2/yr (Holland et al., 1999). The nitrogen fertilizer inputs over agricultural areas were calculated according to Freibauer (2003) and the FAO Statistics June 2006 (http://faostat.fao.org/site/422/default.aspx). We added both mineral nitrogen fertilizer as well as the total of manure and slurry from animal husbandry generating Europe-wide fertilization maps for 1961, 1989 and 2002 for the agricultural areas. The fertilization maps were interpolated between the years to describe the annual changes in fertilizer usage over Europe.

2.3 Model simulations

Using the same input drivers all models performed simulations over Europe in the domain bounded by 15° W–60° E and 30° N–75° N. This covers area from Iceland to Ural Mountains and from the Mediterranean Sea to the Barents Sea. Europe has been further divided into four regions (North, West, Central and East; Fig. 1) in order to regionally examine the changes in terrestrial CO_2 exchange.

The process oriented models which also calculate the carbon pools need to spin-up to initialize slow carbon and nitrogen pools. We forced the models in a pre-industrial steady-state using atmospheric CO_2 concentrations (and nitrogen deposition for Biome-BGC) from ~1850 (285.2 ppm, 0.0002 kgN/m^2/yr) and recycling one decade

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of meteorological data that does not exhibit significant trends of temperature and precipitation change over Europe (1958–1967). After establishing the slow pools, we run the models from 1850 to 1957 with transient atmospheric CO_2 using the same decade of meteorological data. The last transient model runs from 1958–2005 use observed CO_2 concentrations and corresponding meteorological data from REMO. Although rising CO_2 levels are responsible for long term net carbon uptake, interannual variability in these simulations is driven solely by climate variations (Harrison and Jones, 2007[2]).These final runs are the basis of our analysis.

The diagnostic models were forced with climate divers from the period 2000–2004 since they rely on remotely sensed input data from MODIS (launch in 2000). PIXGRO was forced with CO_2 and climate drivers only for the period 2002–2003 because this model is computationally very demanding. In this study all models used prescribed land surface types which were held constant during the simulations.

2.4 Analysis of spatial and temporal pattern of the climate and carbon flux anomalies in 2003

Our analysis is based on carbon fluxes simulations from 1980–2005. We define the growing season from beginning of May to the end of September. The carbon fluxes are summed over this period. The carbon flux anomaly $A_{i,j}$ in 2003 for each grid-cell is calculated as

$$A_{j,i} = F_{2003_{j,i}} - \bar{F}_{1998-2002_{j,i}} \tag{1}$$

where F_{2003} denotes total carbon flux over the growing season 2003, $\bar{F}_{1998-2002}$ denotes the total carbon flux averaged over five growing seasons (1998–2002), j and i are the longitude and latitude respectively. In addition we estimate the change in carbon fluxes between the years 2003 and 2002, for better comparison with

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[2]Harrison, R and Jones, C. D.: Competing roles of rising CO2 and climate change in the contemporary European carbon balance, Biogeosci Discuss., submitted, 2007.

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other studies of the carbon-flux anomaly in 2003 (Reichstein et al., 2006; Ciais et al., 2005), and for explaining differences in carbon flux responses between PIXGRO and the other models.

For each of the four European regions (Fig. 1) we also estimated the area weighted carbon flux anomaly for the growing seasons 1980–2005 using the average growing season from 1998–2002 as baseline. We have chosen the period 1998-2002 as a reference for our study because this period has been used in previous studies (Ciais et al., 2005) and also because it is consistent with the time period used by atmospheric inversion models. We only use the model results from the period 1980–2005 as the quality of the climate data for this period is good. In PIXGRO the carbon flux anomaly is based only on the years 2002 and 2003.

To examine the carbon flux anomaly in 2003 relative to the anomalies during growing seasons in 1980–2005, we estimated the anomalies of each growing season (1980–2005) relative to the reference period 1998–2002. Based on these anomalies we derived the mean anomaly for the growing seasons 1980–2005, as well as the standard deviations, and the median. As the anomalies in carbon fluxes simulated by the models varied in magnitude, we normalized the anomalies by dividing them with the standard deviations. In this way we forced the standard deviation of the carbon flux anomaly of each model to be 1, and the analysis of the carbon flux anomaly and its variation could be performed.

The climate anomalies were derived analog to the above described carbon flux anomalies, representing growing season averages for temperature, radiation, VPD and water balance, whereas the growing season sums were estimated for the precipitation.

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3   Results and discussion

3.1   Regional climate and carbon flux anomalies of the growing season 2003

Although all models agreed in the sign of the 2003 NEP anomaly over Western Europe, they disagree on the dominating ecosystem processes causing the anomalous flux. The NEP anomaly in 2003 was driven by an increase in respiration in Biome-BGC and JULES (the increase exceeded the 1σ range). LPJ, ORCHIDEE, MOD17+ and ANN showed that the NEP anomaly in 2003 was driven by the decline in GPP (decrease exceeded the 1σ range). Our analysis suggest that the differences among the models result mainly from the different descriptions of the ecosystem processes and soil water calculations, as well as the inclusion of crops and crop management.

Northern Europe

The 2003 growing season in this region was rather warm and wet relative to the baseline and long-term (1980–2005) means. The growing season 2002 was even warmer (Fig. 2a, Table 4). All models agreed in an increase in GPP in both 2003 and 2002, the increase in 2002 being larger relative to both baseline as well as long-term mean (Fig. 2b, upper panel, Table 4). The GPP anomaly 2003 was outside 1σ for Biome-BGC, LPJ, ORCHIDEE and JULES whereas the data-oriented models showed an increase too, but not as significant. This is mainly due to the increased temperature in this area ($\sim$0.7°C) relative to baseline (Table 4). This is in agreement with Churkina and Running (1998) who showed that the vegetation in the northern latitudes is temperature limited. Northern Europe is dominated by natural vegetation, mainly forests (coniferous and deciduous forests), which may also explain why the models showed good agreement in this region. Biome-BGC, LPJ, ORCHIDEE and JULES estimated a total GPP in the growing season 2003 between 1140 and 1507 Tg where as PIXGRO, MOD17+ and ANN estimated a slightly smaller productivity ranging between 896 and 968 Tg.

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The Reco anomaly in 2003 followed mainly that of the GPP (Fig. 2b, middle panel, Table 4). All models showed an increase in respiration in 2003 relative to both baseline ranging between 76 Tg (JULES) and 7 Tg (MOD17+) and long-term mean ranging between 87 Tg (ORCHIDEE and JULES) and 6 Tg (MOD17+). The increase in Reco in 2002 was even more pronounced, except for LPJ and ORCHIDEE. This is mainly explained by the increased temperature in both 2003 and 2002 (Fig. 2a, Table 4). Biome-BGC, LPJ, ORCHIDEE and JULES showed that the Reco anomaly 2003 was outside of 1σ bound whereas it was still inside the 1σ bound for MOD17+ and ANN. Biome-BGC and PIXGRO estimated the smallest total Reco in the growing season 2003 (801 and 798 Tg respectively) and JULES estimated the largest Reco (1343 Tg) among the process oriented models. The estimated Reco over the growing season 2003 as estimated by the diagnostic models (MOD17+, ANN) was smaller (607 and 683 Tg respectively), but they agree with the majority of models with respect to the sign of the Reco anomaly. The reason for this behavior may be due to the fact that GPP and Reco are calculated independently in the data-oriented models, so that the link between GPP and Reco is not so strong.

The resulting standardized NEP anomaly 2003 in Northern Europe was within the 1σ range for any of the models, being close to baseline, whereas the NEP anomaly 2002 clearly indicates enhanced land carbon uptake. All models except ORCHIDEE agreed in an increased NEP in 2003 relative to baseline. In this region, the increase in temperature and radiation seem to force the increase in NEP due to enhanced photosynthesis (Churkina and Running, 1998) (Fig. 2b and Table 4). All models agreed that the NEP anomaly 2003 relative to 2002 showed a decrease (Table 4). The range of the NEP over the growing season 2003 did not differ much among the models (Biome-BGC, LPJ, ORCHIDEE, MOD17+ and ANN ranged between 340–284 Tg). JULES and PIXGRO estimated least carbon uptake (164 and 98 Tg respectively).

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Western Europe

In 2003 this region experienced a strong heat and drought event with a temperature increase of more than two degrees Celsius with corresponding increase in radiation and VPD and decrease in precipitation (Fig. 2a, Table 4). The models differ in their responses to the climate anomaly in 2003 in their estimation of the GPP anomaly in 2003. All models showed a reduction in GPP in 2003. On the other hand all models agreed in an increase in GPP in 2002 (Fig. 2b, Table 4). The year 2002 was warm, but wetter in this region which is normally water limited. Increased precipitation leads to increased productivity. LPJ, ORCHIDEE, MOD17+ and ANN estimated the largest GPP anomaly 2003 being outside the lower 1σ bound ranging from –326 to –107 Tg. Biome-BGC and JULES also showed a reduction of in GPP 2003 relative to baseline being –49 and –11 Tg respectively (Table 4), but the reduction was not significant (inside the 1σ bound, Fig. 2b). The estimated reduction in GPP 2003 is in agreement with other studies (Reichstein et al., 2006; Schindler et al., 2006; Ciais et al., 2005). Biome-BGC, MOD17+, ANN and PIXGRO estimated the total GPP over the growing season 2003 between 1031 and 1290 Tg. On the other hand LPJ and ORCHIDEE estimated less GPP in the growing season 2003 of 915 and 822 Tg respectively. JULES estimated the highest GPP with 2715 Tg. Relative to the growing season 2002, the GPP anomaly over the growing season 2003 was even stronger (Table 4).

Biome-BGC and JULES estimated an increase in Reco in 2003 relative to baseline. Reco anomaly simulated by these two models was outside of the 1σ bound (43 and 116 Tg, respectively, Table 4), whereas the LPJ and ORCHIDEE estimated a decrease in Reco relative to baseline (–130 and –23 Tg, respectively, see Fig. 2b, middle panel, Table 4) still being inside the 1σ bound. PIXGRO estimated almost no difference in Reco between 2003 and 2002 (7 Tg, Table 4). The sensitivity of the Reco with respect to 2003 climate conditions seems less pronounced in Biome-BGC and JULES compared with the other process models. Both MOD17+ and ANN estimated a reduction of Reco through the growing season 2003 relative to both baseline and 2002 (–42

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and −44 Tg and −79 and −101 Tg, respectively, Table 4)). The mayor difference to the process-oriented models are the direct description of Reco based on the abiotic input in MOD17+, whereas Reco as estimated by ANN, is just the difference between the estimated NEP (-NEE) and the estimated GPP, without any explicit assumptions about the soil conditions. The 2002 Reco anomaly showed an increase in Reco in all models.

The resulting NEP anomaly in 2003 showed a decrease mostly outside the one σ range, with the exception of Biome-BGC, which showed a less significant decrease in comparison with the other models. All models agreed on negative NEP 2003 anomaly relative to long-term mean, baseline and 2002 shown in Table 4. Given the very different models, this common response among the models reveals a high confidence in the net carbon flux responses to the climate anomaly in this region. This NEP anomaly is caused by the strong increase in temperature, VPD and radiation, and reduction in precipitation (Fig. 2b, Table 4), far outside the 1 σ range for all parameters. The growing season 2003 experienced a severe heat and drought anomaly whereas the growing season 2002 did not show large deviations from baseline with a corresponding NEP anomaly 2002 being closer to baseline estimated by all models. The total NEP over the growing season 2003 differed strongly between the models. Biome-BGC, MOD17+, ANN and PIXGRO estimated the total NEP over the growing season 2003 to 229 Tg, 262 Tg, 357 Tg and 162 Tg respectively (Table 4). LPJ, ORCHIDEE and JULES estimated NEP values of the growing season 2003 close to neutral, the two first even estimated a negative NEP in 2003, −25 Tg and −99 Tg respectively (Table 4).

Central Europe

In Central Europe the GPP anomaly in 2003 was less pronounced than in Western Europe (Fig. 2a, upper panel, Table 5). This is also in agreement with the less pronounced climate anomaly in this region (Fig. 2a). Biome-BGC, LPJ, ORCHIDEE and ANN agreed in a reduction in GPP relative to baseline ranging between −63 and −207 Tg, the three latter also relative to the long-term mean (Table 5). The decrease was even larger relative to the growing season 2002 which ranged between −96 and

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–153 Tg (Table 5). JULES and MOD17+ showed an increase of 61 and 19 Tg respectively for the GPP anomaly in 2003, but agreed in a reduction of the GPP in 2003 versus 2002 (–155 and –121 Tg respectively). PIXGRO estimated the GPP anomaly of 2003 in Central Europe to be –222 Tg.

Biome-BGC and JULES estimated an increase in Reco in 2003 relative to long-term mean (34 and 153 Tg, respectively, Table 5), but being close to baseline (Fig. 2b, middle panel, Table 5). ANN showed a decrease in the Reco anomaly 2003 which was outside the 1σ range (Fig. 2b, middle panel) resulting in a total reduction of –81 Tg (Table 5). All other models estimated the 2003 carbon flux anomaly to be inside the 1σ bound. All models agreed in an increase in the Reco anomaly 2002.

The NEP anomaly in 2003 showed mainly the same pattern as for Western Europe for the models Biome-BGC, LPJ and ORCHIDEE, but the decrease in NEP was not as significant (Fig. 2b, lower panel). Also the climate anomaly over Central Europe showed the same tendency, all parameters showing mainly the same pattern as for Western Europe, only less significant (Fig. 2a, Table 5). JULES, MOD17+ and ANN showed a slightly increased NEP but not outside of the 1σ range (Fig. 2b, lower panel). The NEP anomaly 2002 was slightly less prominent compared with the anomaly 2003 for the models LPJ, ORCHIDEE and ANN, whereas the estimated NEP anomaly 2002 showed a stronger increase for Biome-BGC, MOD17+ and ANN. JULES showed that the NEP anomaly 2002 was more decreased compared with 2003. The total NEP of the growing season 2003 ranged between 523 and 41 Tg depending on model. Biome-BGC, MOD17+ and ANN estimating the largest NEP values (523–473 Tg) and LPJ, JULES and PIXGRO estimating the total NEP of the growing season 2003 between 215–196 Tg. ORCHIDEE estimated a close to neutral NEP for Central Europe in 2003 (41 Tg).

Eastern Europe

All models agreed that the GPP carbon flux anomaly in 2003 relative to baseline was small (Fig. 2b, upper panel). Biome-BGC was the only model which estimated a small

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decrease in GPP in 2003 (−22 Tg, Table 5). LPJ, ORCHIDEE, JULES, MOD17+ and ANN showed an increase in GPP anomaly relative to baseline of 108, 74, 61, 33 and 10 Tg respectively (Fig. 2b, upper panel, Table 5). The estimated GPP through the growing season 2003 ranged between 1378 and 3449 Tg (Table 5). Again JULES estimated the largest GPP 2003, and PIXGRO estimated the least.

The Reco anomaly in 2003 was close to the long-term mean of the anomalies 1980–2005 (Fig. 2b, middle panel). Except Biome-BGC and JULES all models estimated an increase in respiration in 2003. The Reco anomaly in 2002 decreased strongly in all models (being outside of the 1σ range), except for Biome-BGC and JULES which estimated the 2002 anomaly to be close to baseline.

The NEP anomaly in 2003 was inside the 1σ range for all models and did not differ much from the carbon flux anomaly in 2002 (Fig. 2b, lower panel, Table 5). All models agreed in a positive NEP over the growing season 2003 and was estimated between 257 and 552 Tg by the process oriented models, and ranged between 357 and 585 Tg by the data-oriented models. PIXGRO differed strongly estimating a NEP over the growing season 2003 close to 0. All models agreed in the sign of the NEP anomaly in Western Europe, which was also the region with the strongest heat and drought signal as estimated by REMO.

Why do the models differ in their carbon flux responses to the climate anomalies?

The reasons for the different GPP and Reco responses to the climate anomalies among different models can be summarized as follows:

(i) The first reason is various treatment of the crop-/cropland phenology among the models. Biome-BGC, ORCHIDEE and JULES represent the crops with fertilized grasses, super grasses and natural grasses respectively, with no harvest. Thus, GPP is accumulated over the whole period and the grass/crop is left to senescence. This causes a larger standing biomass, which results in larger autotrophic respiration (mainly maintenance respiration) and a higher heterotrophic respiration due to larger litter and soil organic matter pools compared with models including harvest. In contrast

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to Biome-BGC, ORCHIDEE and JULES, LPJ and PIXGRO account for the management of the crops. In LPJ, harvest is determined through a sum over growing degree days (Bondeau et al., 2007) which determines maturity, thereafter the crop is harvested. In 2003 the warm temperatures accelerated the maturity-processes, and crops were harvested earlier compared with not so warm periods. Hence the time for assimilating carbon was also shorter. In addition less biomass is left to senescence and cause less heterotrophic respiration compared with the other models. PIXGRO use a simple climate zone dependence to establish the sawing and harvesting of the crops. The data-oriented models, both MOD17+ and ANN has a direct connection between the abiotic factors and GPP and has no direct coupling with the soil-processes, further the harvesting is implicit through the input data (satellite fAPAR, and measured NEE, respectively).

(ii) The second reason is related to representation of carbon flux responses to droughts in different process-oriented models. This response is a function of the more or less detailed soil structure, biogeochemistry and soil hydrology. Only Biome-BGC utilizes a single bucket soil module, which allows all water not being run-off or evaporated to be available for the plants. The other process models utilize at least a two layer soil model, which allows the upper layer to dry faster than the lower layers. These models have also a differentiated vertical root distribution, where grasses have most of the roots in the upper layer (short rooting depth) and shrubs and trees have deeper rooting depths. In this way the estimated drought effect is stronger in these models than compared with Biome-BGC. In LPJ 80% of the below ground biomass for the grass and crop types, is situated in the upper layer which also experience the largest evaporation and drought stress. ORCHIDEE uses the SVAT-SECHIBA model (Ducoudre er al., 1993; Rosnay and Polcher, 1998), which has a high temporal resolution of the water and energy fluxes (1/2 hourly). Both ORCHIDEE and JULES have a high temporal resolution, daily variation of the input data, hence a short rain shower may be enough to reduce the water stress enough to achieve transpiration and decomposition, daily resolution differed between these two models. This gives ORCHIDEE and JULES a

high temporal resolution of the coupled carbon and water fluxes and hence a stronger sensitivity of Reco to sub daily variations than compared with Biome-BGC and LPJ. JULES utilizes a four layer soil module, and its hydrology was found to perform well in the recent GSWP-2 intercomparison project (Guo and Dirmeyer, 2006). In JULES, the decomposition of soil organic carbon is only sensitive to soil humidity and temperature in the upper 10 cm. Depending on the root distribution, the decomposition and water availability is more or less drought sensitive. JULES seems to be dominated by the temperature signal in the decomposition. PIXGRO has also a high temporal resolution, but the productivity is decoupled from the soil processes (Table 1). PIXGRO estimated almost no change on Reco between 2003 and 2002.

Also differences in the model simulations of evapotranspiration occur due to the differences in soil structure and management. Biome-BGC estimates the conductance as a direct function of VPD, soil-water potential and minimum temperature. In 2003 the VPD estimated by REMO was extremely high, and stomatal conductance was strongly reduced as well as the transpiration. In Biome-BGC higher plant available water causes the microbial activity to increase stronger and increases the decomposition which may lead to increased soil mineral N, which further leads to higher GPP also under water stressed conditions hence reducing the drought reduction in GPP compared with the other models (LPJ, ORCHIDEE, JULES and PIXGRO). JULES estimates an even less reduction in GPP, which shows that this model seems to be less sensitive to drought stress, a direct impact of the differentiated soil water distribution and the below-ground biomass distribution (Table 1).

(iii) The sensitivity of carbon fluxes to drought varies from model to model and can be directly related to the different modeling approaches. Models which simulate crop or grass harvest seem to have higher drought sensitivity than models without harvest which may be due to increased bare-soil evaporation. Also the sensitivity to drought is higher in the models utilizing a two layer soil hydrology model. JULES has a very detailed soil hydrology and seems to be the least drought sensitive model here. It has yet to be determined whether the different model sensitivities to drought are due to the car-

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bon components sensitivity to soil moisture, or different hydrology schemes simulating different soil drying under the same climate forcings. Guo and Dirmeyer (2006) showed that many hydrology models simulate interannual variability of soil moisture better than the absolute values. However, the carbon flux sensitivity to drying will depend on the baseline level as well as the anomaly. Hence, our findings illustrate the need of further model development and model evaluation against site-level measurements and inventories, including soil moisture observations where available, which may reduce the model differences and increase the reliability of the model estimated European carbon balance in the future.

3.2   Spatial patterns of the climate and carbon flux anomalies in 2003

In 2003 the climate anomaly over Europe showed a typical dipole pattern (Fig. 3). Western and Central Europe were exposed to a strong heat and drought anomaly, which was more prominent in western parts than in the central region. Eastern Europe exhibited a cold and wet anomaly. The region between these major anomalies exhibited intermediate conditions. This climate anomaly pattern was also seen in the spatial NEP anomaly in 2003 (Fig. 4).

In 2003 the NEP decreased over large areas of Europe (Fig. 4, areas in red color), showing a clear dipole pattern. These affected areas correspond directly to the climate anomalies over the same time period (Fig. 3). LPJ, ORCHIDEE and PIXGRO estimated greater affected areas (5.18 10^6, 5.42 10^6 and 5.64 10^6 km^2, respectively) than JULES, Biome-BGC, MOD17+ and ANN (4.19 10^6, 4.76 10^6, 3.93 10^6 and 3.37 10^6 km^2, respectively). The three latter models estimated a more heterogeneous pattern over Western and Central Europe. Models agreed well in the spatial pattern of vegetation responses to the cold and wet anomaly. There exist an area with increased carbon sequestration (blue colors) between the dry and warm area, and the cold and wet area. MOD17+, ANN and JULES show the greatest extent of this area in Eastern Europe. All models agreed that the 2003 NEP anomaly was positive over Scandinavia and North Eastern Russia. The spatial pattern of 2003 anomaly estimated by PIXGRO

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differs relative to the other models especially for Northern and North Eastern Europe as the growing season 2002 is used for the anomaly estimate. As shown earlier, the growing season 2002 was exceptionally warm in comparison with both 2003 and baseline for this area (Fig. 2a, Table 4). This caused an increased productivity in 2002

5 relative to 2003. Nevertheless, the strong agreement in the spatial pattern of the net ecosystem productivity anomaly in 2003 among the models of different complexity and structure reveals a high confidence in this pattern. Reichstein et al. (2006) showed that on a transect through Europe most site-measurements of NEP showed a negative averaged monthly NEP anomaly (July–September) as the difference between 2003 and

10 2002. In Germany, southern upper Rhine plain, the measured NEE in August and September 2003 was significantly lower than in 2004 (Schindler et al., 2006). Jolly et al. (2005) also showed that the heat wave in 2003 caused an increased productivity in the Alps, which could also be seen in all models.

3.3 Contribution of the European carbon flux anomaly to the atmosphere in 2003

15 Independent of the reference period (long-term mean, baseline or 2002) all models agreed on a reduction in NEP (Table 6). The estimates of the NEP change from the European terrestrial biosphere over the growing season 2003 relative to baseline (1998–2002) resulted in an additional atmospheric CO_2 source about 0.002–0.27 Pg depending on model. Ciais et al. (2005) estimated the anomaly of the summer 2003

20 (July-September) for Europe to be –0.5 Pg relative to baseline (1998–2002) using OR-CHIDEE. This value is larger than the maximum value in our study (–0.27 Pg, OR-CHIDEE) which can be related to different definitions of the growing season in these two studies (Mai–September in this study, relative to July–September in Cias et al., 2005). The growing season 2002 was obviously not an average year, being more pro-

25 ductive than the long-term mean and the baseline for most of the models. Using this year to estimate the carbon flux anomaly of the growing season 2003, would lead to a high estimate of the anomalous flux ranging between 0.01 and 0.41 Pg. The additional carbon flux from land to the atmosphere resulted from a reduced gross primary

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productivity which reduction was between –0.37 Pg and –0.06 Pg relative to baseline over whole Europe. One model (JULES) estimated an increase in gross primary productivity of 0.19 Pg over the growing season 2003. All models agreed on a reduction of GPP in the growing season 2003 relative to 2002. Biome-BGC, ORCHIDEE and JULES estimated an overall increase in ecosystem respiration in 2003 relative to baseline of 0.06, 0.02 and 0.12 Pg, respectively. The other models LPJ, MOD17+ and ANN, indicated a total decrease of ecosystem respiration over the growing season 2003 of –0.14, –0.003 and –0.12 Pg relative to baseline, respectively.

4 Conclusions

Our multi-model comparison study suggests that land ecosystems of Europe emitted additional 0.02–0.27 Pg of carbon to the atmosphere in response to the drought in 2003 relative to baseline (1998–2002). Our estimates are comparable to the previously reported value (0.5 Pg, Ciais et al., 2005), which was calculated from the ORCHIDEE ecosystem model over a two-month shorter period of time (July–September) and thus yielded a stronger anomaly. Our study shows that a heat/drought anomaly over Western and Central Europe was accompanied by a cold and wet anomaly over Western Russia. All models agreed in the response of the NEP anomaly over both the hot and dry areas as well as the cold and wet areas.

The models differ in their response to the heat and dry anomaly in Western and Central Europe regarding the gross fluxes GPP and Reco. An analysis of the different sensitivities of the simulated carbon fluxes in the models to meteorological conditions as well as the model simulated soil-water content is currently in progress (Vetter et al., 2007[3]). The diagnostic models estimated less variation in Reco compared to the

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[3]Vetter, M., Churkina, G., Jung, M., Reichstein, M., Zaehle, S., Bondeau, A., Chen, Y., Ciais, P., Feser, F., Freibauer, A., Geyer, R., Jones, C. D., Papale, D., Tenhunen, J., Tomelleri, E., Trusilova, K., Viovy, N., and Heimann, M.: Sensitivity analysis of modeled carbon flux anomalies to input climate parameters: A special emphasis on the ecosystem respiration and its

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process-oriented models. The link between GPP and Reco as well as belowground processes should be revisited in the model structure for both, the process-oriented and the diagnostic models. A detailed data-model comparison exercise aims to identify model skill and uncertainties with emphasis on the response to drought (Jung et al., 2007[4]).

An interesting question to explore is how the 2003 drought influences the functioning of land ecosystems in the following years. Previous studies suggested that effect of anomalous climatic events could be detected in ecosystem carbon fluxes for at least 3-5 years after the event's occurrence and ecosystem responses could be discontinuous (Schimel et al., 2005). Given that European ecosystems experienced drought again in 2005 the recovery of ecosystems will most likely take longer and should be investigated in the future.

References

Adiku, S. G. K., Reichstein, M., Lohila, A., Dinh, N. Q., Aurela, M., Laurila, T., Lueers, J., and Tenhunen, J. D.: PIXGRO: A model for simulating the ecosystem CO_2 exchange and growth of spring Barley, Ecol. Modell., 190, 260–276, 2006.

Andren, O. and Paustian, K.: Barley straw decomposition in the field – A comparison of models, Ecology, 68(5), 1150–1200, 1987.

Ball, J. T., Berry, J. A., and Woodrow I. E.: Conductance and its contribution to the control of photosynthesis under different environmental conditions, In: Progress in Photosynthesis Research, Vol. VI, edited by: Binggins, I. J., Martin Nijhof, Dordrecht, 221–224, 1987.

constituents, in preparation, 2007.

[4]Jung, M., Reichstein, M., Le Maire, G., Vetter, M., Zaehle, S., Viovy, N., et al.: The response of photosynthesis to drought in European forests: Investigating the performance of global biogeochemical models using eddy-covariance based data, in preparation, 2007.

Ball, J. T. and Berry, J. A.: The C/C ratio: a basis for predicting stomatal control of photosyntheis, Carnegie Institute Washington Year Book, 81, 88–92, 1982.

Bondeau, A., Smith, P. C., Sönke, Z., Schaphoff, S., Lucht, W., Cramer, W., Gerten, D., Lotze-Campen, H., Müller, C., Reichstein, M., and Smith, B.: Modelling the role of agriculture for the 20th century global terrestrial carbon balance, Global Change Biology, Published article online: 18-Jan-2007, doi:10.1111/j.1365-2486.2006.01305.x, 2007.

Botta, A., Viovy, N., Ciais, P., and Friedlingstein, P.: A global prognostic scheme of leaf onset using satellite data, Global Change Biology, 6, 709–726, 2000.

Chen, Y., Churkina, G., and Heimann, M.: A comparison of regional climate variables between various data sources. Technical reports – Max-Planck-Institute fr Biogeochemie, 8, 2007, ISSN 1615-7400, 2007.

Churkina, G., Tenhunen, J., Thornton, P. E., Elbers, J. A., Erhard, M., Falge, E., Gruenwald, T., Kowalski, A. S., Rannik, U., and Sprinz, D. E.: Analyzing the ecosystem carbon dynamics of four European coniferous forests using a biogeochemistry model, ECOSYSTEMS, 6, 168–184, 2003.

Churkina, G. and Running, S. W.: Investigating the balance between timber harvest and productivity of the global coniferous forests under global change, Climatic Change, 47, 167–191, 2000.

Churkina, G. and Running, S. W.: Contrasting climatic controls on the estimated productivity of global terrestrial biomes, Ecosystems, 1, 206–215, 1998.

Ciais, P., Reichstein, M., Viovy, N. Granier, A., Ogee, J., Allard, V., Aubinet, M., Buchmann, N., Bernhofer, C., Carrara, A., Chevallier, F., De Noblet, N., Friend, A. D., Friedlingstein, P., Grünwald, T., Heinesch, B., Keronen, P., Knohl, A., Krinner, G., Loustau, D., Manca, G., Matteucci, G., Miglietta, F., Ourcival, J. M., Papale, D., Pilegaard, K., Rambal, S., Seufert, G., Sousanna, J. F, Sanz, M.J., Schulze, E. D., Vesala, T., and Valentini, R.:. Europe-wide reduction in primary productivity caused by the heat and drought in 2003, Nature, 437, 529–533, 2005.

Cienciala, E., Running, S. W., Lindroth, A., Grelle, A., and Ryan, M. G.: Analysis of carbon and water fluxes from the NOPEX boreal forest: comparison of measurements with Forest-BGC simulations, J. Hydrol., 212–213, 62–78, 1998.

Cosby, B. J., Hornberger, G. M., Clapp, R. B., and Ginn, T. R.: A statistical exploration of the relationships of soil moisture characteristics to the physical properties of soils, Water Resour. Res., 20, 682–690, 1984.

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Collatz, G. J., Ribas-Carbo, M., and Berry, J. A.: A coupled photosynthesis- stomatal conductance model for leaves of C4 plants, Australian J. Plant Physiology, 19, 519–538, 1992.

Collatz, G. J., Ball, J. T., Grivet, C., and Berry, J. A.: Physiological and environmental regulation of stomatal conductance, photosynthesis and transpiration: A model that includes a laminar boundary layer, Agric. Forest Meteorol., 54, 107–136, 1991.

Cox, P. M.: Description of the TRIFFID Dynamic Global Vegetation Model, Hadley Centre Technical Note 24, Hadley Centre, Met Office, Exeter, UK, 2001.

Cox, P. M., Betts, R. A., Jones, C. D., Spall, S. A., and Totterdell, I. J.: Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model, Nature, 408, 184–187, 2000.

Cox, P. M., Betts, R. A., Bunton, C. B., Essery, R. L. H., Rowntree, P. R., and Smith, J.: The impact of new land surface physics on the GCM simulation of climate and climate sensitivity, Climate Dyn., 15, 183–203, 1999.

Cox, P. M., Huntingford, C., and Harding, R. J.: A canopy conductance and photo-synthesis model for use in a GCM land surface scheme, J. Hydrol., 212–213, 79–94, 1998.

De Pury, D.G.G., and Farquhar, G.D.: Simple scaling of photosynthesis from leaves to canopies without the errors of big-leaf models, Plant, Cell and Enviroment, 20(5), 537–557, 1997.

Ding, Q. and Wang, B.: Circumglobal teleconnection in the northern hemisphere summer, J. Climate, 18, 3483–3505, 2005.

Ducoudre, N., Laval, K., and Perrier, D.: SECHIBA, a new set of parameterizations of the hydrologic exchanges at the land-atmosphere interface within the LMD atmospheric circulation model, J. Climate, 6, 248–273, 1993.

Essery, R. L. H., Best, M. J., Betts, R. A., Cox, P. M., and Taylor, C. M.: Explicit representation of subgrid heterogeneity in a GCM land-surface scheme, J. Hydrometeorol., 43, 530–543, 2003.

Etheridge, D. M., Steele, L. P., Langenfelds, R. L., Francey, R. J., Barnola J.-M., and Morgan, V. I.: Natural and anthropogenic changes in atmospheric CO_2 over the last 1000 years from air in Antarctic ice and firn, J. Geophys. Res., 101, 4115–4128, 1996.

Farquahar, G., von Caemmerer, S., and Berry, J.: A biochemical model of photosynthetic CO_2 assimilation in leaves of C3 species, Planta, 149, 78–80, 1980.

FAO Statistics June 2006 (http://faostat.fao.org/site/422/default.aspx), 2006.

Feser, F., Weisse, R., and von Storch, H.: Multi-decadal Atmospheric Modeling for Europe Yields Multi-purpose Data, EOS Transactions, 82, 305–310, 2001.

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Friend, A. D., Shugart, H. H., and Running, S. W.: A physiology-based model of forest dynamics, Ecology, 74, 797–797, 1993

Freibauer, A.: Regionalized inventory of biogenic greenhouse gas emissions from European agriculture, European J. Agronomy, 19, 135–160, 2003.

5 Friedlingstein, P., Joel, G., Field, C. B., and Fung, I.: Towards an allocation scheme for global terrestrial carbon models, Global Change Biol., 5, 755, 1998.

Foley, J. A.: An equilibrium model of the terrestrial carbon budget, Tellus, 47B, 310–319, 1995.

Galloway, J. N., Dentner, F. J., Capone, D. G., Boyer, E. W., Howarth, R. W., Seitzinger, S. P., Asner, G. P., Cleveland, C. C., Green, P. A., Holland, E. A., Karl, D. M., Michaelis, A. F.,

10 Porter, J. H., Townsend, A. R., and Vörsömarty, C. J.: Nitrogen cycles: past, present and future, Biogeochemistry, 70, 153–226, 2004.

Gregory, D. and Smith, R. N. B.: Canopy, surface and soil hydrology. Unified Model documentation paper 25, Meteorological Offce, London Rd, Bracknell, Berkshire, RG12 2SY, 1990.

Guo, Z., and Dirmeyer, P. A.: Evaluation of the Second Global Soil Wetness Project

15 soil moisture simulations: 1. Intermodel comparison, J. Geophys. Res., 111, D22S02, doi:10.1029/2006JD007233.u, 2006.

Haxeltine, A. and Prentice, I. C.: BIOME3:an equilibrium terrestrial biosphere model based on ecophysiological constraints, resource availability and competition among plant functional types, Global Biogeochem. Cycles, 10, 693—710, 1996.

20 Holland, E. A., Dentner, F. J., Braswell, B. H., and Sulzmann, J. M.: Contemporary and preindustrial global reactive nitrogen budgets, Biogeochemistry, 46, 7-43, 1999.

Intergovernmental Panel of Climate Change (IPCC): Climate change 2007: Physical science basis. Summary for Policymakers. IPCC, Genf, Switzerland, http://www.ipcc.ch/SPM2feb07.pdf, 2007.

25 Jacob, D. and Podzun, R.: Sensitivity Studies with the Regional Climate Model REMO, Meteorol. Atmos. Phys., 63, 119–129, 1997.

Jacobs, C.: Direct impact of atmospheric CO_2 enrichment on regional transpiration, PhD thesis, Wageningen Agricultural University, 1994.

Johns, T. C., Durman, C. F., Banks, H.T ., Roberts, M. J., McLaren, A. J., Ridley, J. K., Senior,

30 C. A., Williams, K. D., Jones, A., Rickard, G. J., Cusack, S., Ingram, I. M., Crucifix, M., Sexton, M. H., Joshi, M. M., Dong, B. W., Spencer, H., Hill, R. S. R., Gregory, J. M., Keen, A. B., Pardaens, A. K., Lowe, J. A., Bodas-Salcedo, A., Stark, S., and Searl, Y.: The new Hadley Centre climate model HadGEM1: Evaluation of coupled simulations, J. Climate, 19,

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7, 1327–1353, 2006.

Jolly, W. M., Dobberlin, M., Zimmermann, N. E., and Reichstein, M.: Divergent vegetation growth responses to the 2003 heat wave in the Swiss Alps, Geophys. Res. Lett., 32, L18409, doi:10.1029/2005GL023252, 2005.

Jones, C. D. and Cox, P. M.: On the significance of atmospheric CO_2 growth-rate anomalies in 2002-03, Geophys. Res. Lett., 32, L14816, doi:10,1029/2005GL023027, 2005.

Jung, M., Henkel, K., Herold, M., and Churkina, G.: Exploiting synergies of global land cover products for carbon cycle modeling, Remote Sens. Environ., 101, 534–553, 2006.

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K. C., Ropelewski, C., Wang ,J., Leetmaa, A., Reynolds, R., Jenne, R., and Joseph, D.: The NCEP/NCAR reanalysis project, Bull. Am. Meteorol. Soc., 77, 437–471, 1996.

Keeling, C. D. and Whorf, T. P.: Atmospheric CO_2 records from sites in the SIO air sampling network. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A, 2005.

Lloyd, J., and Taylor, J. A.: On the temperature dependence of soil respiration, Functional Ecol., 8, 315–323, 1994.

Koch, W. and Feser, F.: Relationship between SAR derived wind vectors and wind at ten meters height represented by a mesoscale model, Monthly Weather Rev., 134(5), 1505–1517, 2006.

Korner, C., Perterer, J., Altrichter, C., Meusburger, A., Slovik, S., and Zoschg, M.: A simple empirical model to estimate annual dry deposition of atmospheric pollutants in needles of spruce and pine, Allgemiene Forst und Jagdzeitung, 166(1), 1–9, 1995.

Krinner, G., Viovy, N., de Noblet-Ducoudre, N., Ogee, J., Polcher, J., Friedlingstein, P., Ciais, P., Sitch, S., and Prentice, I. C.: A dynamic global vegetation model for studies of the coupled atmosphere-biosphere system, Global biogeochemical cycles, 19, GB1015, doi:10.1029/2003GB002199, 2005.

Lucero, O. A. and Rodriguez, N. C.: Spatial organization in Europe of decadal and interdecadal fluctuations in annual rainfall, Int. J. Climatol., 22, 805–820, 2002.

Lucht, W., Schaaf C. B., and Strahler, A. H.: An Algorithm for the retrieval of albedo from space using semiempirical BRDF models, IEEE Trans. Geosci. Remote Sens., 38, 977–998, 2000.

McGuire, A., Melillo, J., Joyce, L., Kicklighter, D., Grace, A., Ill, B. M., and Vorosmarty, C.: Interactions between carbon and nitrogen dynamics in estimating net primary productivity

EGU

for potential vegetation in North America, Global Biogeochem. Cycles, 6, 101-124, 1992.

Monteith, J. L.: Accomodation between transpiring vegetation and the convective boundary level, J. Hydrol., 166, 251–263, 1995.

Monteith, J. L.: Evaporation and environment, Symposium of the society of experimental biology, 19, 205–234, 1965.

Neilson, R. P.: Vegetation redistribution: a possible biosphere source of CO_2 during climate change, Water, air and soil pollution, 70, 659–673, 1993.

Nemani, R. R., Keeling, C. D., Hashimoto, H., Jolly, W. M., Piper, S. C., Tucker, C. J., Myneni, R. B., and Running, S. W.: Climate-driven increases in global terrestrial net primary production from 1982 to 1999, Science, 300(5625), 1560–1563, 2003.

Orchard, V. A. and Cook, F. J.: Relationship between soil respiration and soil moisture, Soil Biol. Biochem., 15(4), 447–453, 1983.

Owen, K. E., Tenhunen, J., Reichstein, M., Wang, Q., Falge, E., Geyer, R., Xiao, X., Stoy, P., Ammann, C., Arain, A., Aubinet, M., Auerla, M., Bernhofer, Ch., Chojnicki, B., Granier, A., Gruenwald, T., Hadley, J., Heinesch, B., Hollinger, D., Knohl, A., Kutsch, W., Lohila, A., Meyers, T., Moors, E., Moureaux, C., Pilegaard, K., Saigusa, N., Verma, S., Vesala, T., and Vogel, C.: Linking flux network measurements to continental scale simulations: ecosystem CO_2 exchange capacity under non-water-stressed conditions, Global Change Biol., doi:10.1111/j.1365-2486.2007.01326.x, 2007.

Papale, D., Reichstein, M., Aubinet, M., Canfora, E., Bernhofer, C., Kutsch, W., Longdoz, B., Rambal, S., Valentini, R., Vesala, T., and Yakir, D.: Towards a standardized processing of Net Ecosystem Exchange measured with eddy covariance technique: algorithms and uncertainty estimation, Biogeosciences, 3, 571–583, 2006, http://www.biogeosciences.net/3/571/2006/.

Papale, D. and Valentini, R.: A new assessment of European forests carbon exchanges by eddy fluxes and artificial neural network spatialization, Global Change Biol., 9, 525–535, 2003.

Reichstein, M., Ciais, P., Papale, D., Valentini, R., Running, S. W., Viovy, N., Cramer, W., Granier, A., Ogee, J., Allard, V., Aubinet, M., Bernhofer, C., Buchmann, N., Carrara, A., Grünwlad, T., Heimann, M., Heinesch, B., Knohl, A., Kutsch,W., Loustau, D., Manca, G., Matteucci, G., Miglietta, F., Ourcival, J. M., Pilegaard, K., Pumpanen, J., Rambal, S., Schaphoff, S., Seuffert, G., Sousanna, J. F., Sanz, M. J., Vesala, T., and Zhao, M.: Reduction of ecosystem productivity and respiration during the European summer 2003 climate anomaly: a joint flux tower, remote sensing and modelling analysis, Global Change Biol., 12, 1–18, doi:10.1111/j.1365-2486.2006.01224.x, 2006.

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Reichstein, M., Falge, E., Baldocchi, D., Papale, D., Aubinet, M., Bebigier, P., Bernhofer, C., Buchmann, N., Gilmanov, T., Granier, A., Grunwald, T., Havrankova, K., Ilvesniemi, H., Jonous, D., Knohl, A., Laurila, T., Lohila, A., Loustau, D., Matteucci, G., Meyers, T., Miglietta, F., Ourcival, J. M., Pumpanen, J., Rambal, S., Rotenberg, E., Sanz, M., Tenhunen, J., Seuffert, G., Vaccari, F., Vesala, T., Yakir, D., and Valentini, R.: On the separation of net ecosystem exchange into assimilation and ecosystem respiration: review and improved algorithm, Global Change Biol., 11, 1424–1439, 2005.

Reichstein, M., Valentini, R., Running, S. W., and Tenhunen, J.: Improving remote-sensing based GPP estimates (MODIS-MOD17) through inverse parameter estimation with CARBOEUROPE eddy covariance flux data, EGU meeting Nice 2004, Geophys. Res. Abstracts, 6, 01388, 2004.

Reichtein, M., Rey, A., Freibauer, A., Tenhunen, J., Valentini, R., Banza, J., Casals, P., Cheng, Y. F., Grunzweig, J. M., Irvine, J., Joffre, R., Law, B. E., Loustau, D., Miglietta, F., Oechel, W., Ourcival, J. M., Pereira, J. S., Peresotti, A., Ponti, F., Oi, Y., Rambal, S., Rayment, M., Romanya, J., Rossi, F., Tedeschi, V., Tirone, G., Xu, M., and Yakir, D.: Modelling temporal and large-scale spatial variability of soil respiration from soil water availability, temperature and vegetation productivity indices, Global Biogeochem. Cycles, 17(4), 15/1–15/15, 2003a.

Reichstein, M., Tenhunen, J., Ourcival, J.-M., Rambal, S., Maglietta, F., Peressotti, A., Pecchiari, M., Tirone, G., and Valentini, R.: Inverse modeling of seasonal drought effects on canopy CO_2/H_2O exchange in three Mediterranean Ecosystems, Journal of Geophysical Research, 108(D23), 4726, 4716/4721–4716/4716., 2003b.

Reichstein, M.: Drought effects on carbon and water exchange in three Mediterranean ecosystems, Ph.D. Dissertation, University of Bayreuth, Germany, BITOEK Pub. Bayreuth, Germany, 150 pp, 2001.

Richards, L.: Capilliary conduction of liquids through porous mediums, Physics, 1, 318–333, 1931.

Running, S. W. and Gower, S. T.: Forest-BGC, a general model of forest ecosystem processes for regional applications. 2. Dynamic carbon allocation and nitrogen budgets, Tree Physiology, 9, 147–160, 1991.

Running, S. W., Nemani, R. R., Heinsch, F. A., Zhao, M., Reeves, M., and Hashimoto, H.: A continuous satellite-derived measure of global terrestrial primary production, BioScience, 54(6), 547–560, 2004.

Saxton, K. E, Rawls, W. J., Romberger, J. S., and Papendick, R. I.: Estimating generalized

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soil-water characteristics from texture, Soil science society of America, 50(4), 1031–1036, 1986.

Scardi, M.: Advances in neural network modeling of phytoplankton primary production, Ecological modeling Ecological Modelling, 146, 33–45, 2001.

5 Schaaf, C. B., Gao, F., Strahler, A. H., Lucht, W., Li, X. W., Tsang, T., Strugnell, N. C., Zhang, X. Y., Jin, Y. F., Muller, J. P., Lewis, P., Barnsley, M., Hobson, P., Disney, M., Roberts, G., Dunderdale, M., Doll, C., d'Entremont, R. P., Hu, B. X., Liang, S. L., Privette, J. L., and Roy, D.: First Operational BRDF, Albedo and Nadir Reflectance Products from MODIS, Remote Sens. Environ., 83(1-2), 135–148, 2002.

10 Schimel, D. S., Churkina, G., Braswell, R. H., and Trembath, J.: Remembrance of weather past: Ecosystem response to climate variability, in: A history of atmospheric CO_2 and its effects on plants, animals, and ecosystems, edited by: Ehleringer, J. R., Cerling, T. E., and Dearing, M. D., Springer-Verlag, Berlin, 2005.

Schindler, D., Türk, M., and Mayer, H.: CO_2 fluxes of a Scots pine forest growing in the warm
15 and dry southern upper Rhine plain, SW Germany, European Journal of Forest Research, 125, 201–212, 2006.

Sitch, S., Smith, B., Prentice, I. C., Arneth, A., Bondeau, A., Cramer, W., Kaplan, J., Levis, S., Lucht, W., Sykes, M., Thonicke, K., and Venevski, S.: Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic vegetation model, Global
20 Change Biol., 9, 161–185, 2003.

Sprugel, D. G., Ryan, M. G., Brooks, J. R., et al.: Respiration from the organ level to the stand, in: Resource Physiology of Conifers: Acquisition, Allocation and Utilization, edited by: Smith, W. K. and Hinckley, T. M., Academic Press, San Diego, 25–299, 1995.

Storch, von H., Langenberg, H., and Feser, F.: A Spectral Nudging Technique for Dynamical
25 Downscaling Purposes, Monthly Weather Review, 128, 3664–3673, 2000.

Tenhunen, J., Geyer, R., Banza, J., Besson, C., Carreiras, J., Dinh, N. Q., Herd, A., Mirzae, H., Otieno, D., Owen, K., Pereira, J. S., Reichstein, M., Ribeiro, N., Schmidt, M., and Xiao, X.: Assessing ecology, vulnerability and ecosystem services of Mediterranean oak woodlands, in: Science and Practice of Ecological Restoration, edited by: Aronson, J., Pereira, J. S.,
30 Pausas, J., Island Press, Washington, D.C., in press, 2007.

Tenhunen, J., Geyer, R., Adiku, S., Tappeiner, U., Bahn, M., Dinh, N.Q., Kolcun, O., Lohila, A., Owen, K., Reichstein, M., Schmidt, M., Wang, Q., Wartinger, M., Wohlfahrt, G., and Cernusca, A.: Influences of landuse change on ecosystem and landscape level carbon and wa-

ter balances in mountainous terrain of the Stubai Valley, Austria, Global Planetary Change, accepted, 2007.

Thornton, P. E., Law, B. E., Gholz, H. L., Clark, K. L., Falge, E., Ellsworth, D. E., Goldstein, A. H., Monson, R. H., Hollinger, D. Y., Falk, M., and Falk, J. P.: Modelling and measuring the effects of disturbance history on carbon and water budgets in evergreen needleleaf forests, Agric. Forest Meteorol., 113, 185–222, 2002.

Trigo, R. M., Garcia-Herrera, R., Diaz, J., Trigo, I. F., and Valente, M. A.: How exceptional was the early August 2003 heatwave in France, Geophys. Res. Lett., 32, L10701, doi:10.1029/2005GL022410, 2005.

Verburg, P. J., Laresen, J., Johnson, D. W., Schorran, D. E., and Arnone III., J. A.: Impacts of an anomalously year on soil CO_2 efflux in experimentally manipulated tallgrass prairie ecosystems, Global Change Biol., 11, 1720–1732, doi:10.1111(j.1365-2486.2005.01032.x, 2005.

Vetter, M., Wirth, C., Bottcher, H., Churkina, G., Schulze, E. D., Wutzler, T., and Weber, G.: Partitioning direct and indirect human-induced effects on carbon sequestration of managed coniferous forests using model simulations and forest inventories, Global Change Biol., 11, 810–827, 2005.

Viovy, N.: Interannuality and CO_2 sensitivity of the SECHIBA-BGC coupled SVAT-BGC model, Phys. Chem. Earth, 21, 489–497, 1996.

Woodrow, I. E. and Berry, J. A.: Enzymatic regulation of photosynthetic CO_2 fixation in C3 plants, Annual Review of Plant Physiology and Plant Molecular Biology, 39, 533–594, 1988.

Zaehle, S., Bondeau, A., Carter, T., Cramer, W., Erhard, M., Prentice, I. C., Reginster, I., Rounsevell, M. D. A., Sitch, S., Smith, B., Smith, P. C., and Sykes, M.: Projected changes in terrestrial carbon storage in Europe under climate and land-use change, 1990-2100, Ecosystems, in press, 2007.

Zeng, N., Quian, H., Rödenbeck, C., and Heimann, M.: Impact of 1998–2002 midlatitude drought and warming on terrestrial ecosystem and the global carbon cycle, Geophys. Res. Lett., 32, L22709, doi:10.1029/2005GL024607, 2005.

Zhang, X., Friedl, M. A., Schaaf, C. B., and Strahler, A. H.: Climate controls on vegetation phenological patterns in northern mid- and high latitudes inferred from MODIS data, Global Change Biol., 10, 1133–1145, 2004.

Zveryaev, I. I.: Seasonality in precipitation variability over Europe. J. Geophys. Res., 109, D05103, doi:10.1029/2003JD003668, 2004.

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Table 1. Detailed description of the major ecosystem processes being simulated by the participating models.

Model: Homepage http://	Biome-BGC	LPJ http://www.pik-potsdam.de/lpj/	ORCHIDEE http://www.ipsl.jussieu.fr/~sipsl/doc/doc_main.html	JULES http://www.jchmr.org/jules/index.html	PIXGRO	MOD17+	ANN
Photosynthesis	Photosynthesis of C3 and C4 plants after De Pury and Farquhar (1997), and Woodrow and Berry (1980), dependent on leaf nitrogen content	Net Photosynthesis based on Farquhar's model simplified by Collatz et al. (1992) + optimum canopy distribution of nitrogen (Haxeltine and Prentice, 1996) (leaf respiration is subtracted).	Photosynthesis based for C3 plants and Collatz et al. (1992) for C4 plants	Photosynthesis according to Collatz et al. (1991) for C3 and Collatz et al. (1992) C4	Net Photosynthesis according to the methodology in Owen et al. (2007) and needs input of max LAI estimated from MODIS (leaf respiration is subtracted)	Photosynthesis according to Reichstein et al. (2004), empirical dependency of assimilation to climate parameters from CARBOEUROPE network	Photosynthesis is simulated with Artificial Neural Network, methods in (Papale and Valentini, 2003; Scardi et al., 2000), trained with 62 CarboeuropeIP sites Eddy covariance data treated according to Papale et al. (2006); Reichstein et al. (2005). All networks use a Levenberg -Marquardt training algorithm and transfer functions see Reichstein et al. (2006)
Stomatal conductance	Calculated as a dependence on soil water potential, minimum temperature, VPD and photon flux density according to Korner et al. (1995)	Calculated as a function of potential photosynthesis rate and water stress (Haxeltine and Prentice, 1996)	Ball et al. (1987) based on Ball and Berry (Ball et al., 1982)	Based on Jacobs (1994) and Cox et al (1998,1999), including soil-moisture dependence	Calculated according to Ball and Berry (Ball et al., 1982)		
Ecosystem respiration (Reco) Autotrophic respiration (AR) Heterotrophic respiration (HR)	Reco: AR + HR. AR: Sum of maintenance (MR) and growth (GR) respiration. MR: calculated separately for leaf, stem and roots, dependent on tissue nitrogen content and temperature (Ryan, 1991). GR: calculated for each plant compartment as production costs (30% per carbon produced) HR: decomposition of litter and soil, related to chemical composition (cellulose, lignin, humus), C:N ratios, mineral nitrogen availability, soil moisture (Andren and Paustian, 1987), Orchard and Cook (1983), and temperature (Lloyd and Taylor, 1994)	Reco: AR + HR AR: sum of maintenance (MR) and growth (GR) respiration. MR: using fixed C:N ratios following the method in Ryan (1991) and Sprugel (1995). GR: production costs per carbon produced (25%) HR: based on an empirical Arrhenius dependence of temperature (Lloyd and Taylor, 1994). Decomposition depends on tissue type and moisture (Foley, 1995)	Reco: AR + HR AR: sum of maintenance (MR) and growth (GR) respiration. MR: calculated as a function of temperature, biomass and fixed C:N ratios. GR: calculated for each plant compartment as production costs (28%) HR: Modified Arrhenius dependence on temperature (Lloyd and Taylor, 1994) Detailed description in (Krinner et al., 2005; Viovy, 1996)	Reco: AR + HR AR: sum of maintenance (MR) and growth (GR) respiration. MR: stem and root dependent on temperature and mean canopy nitrogen content proportional to LAI and canopy height, leaf MR: additional moisture dependent (Friend, 1993). HR: soil moisture dependence according to McGuire et al. (1992) Detailed description in Essery et al. (2003)	Ecosystem respiration based on Reichstein et al. (2005), decoupled from productivity and dependent on soil temperature and soil moisture	Ecosystem respiration based on Reichstein et al. (2003b), adding short term dependence on GPP, adding Arrhenius type temperature dependence according to methods in (Reichstein et al. 2005), added quasi steady state: Reco_avg=0.95xGPP over the period, Long-term mean being affected, inter annual variability is conserved.	Ecosystem respiration is estimated as the difference between NEP, (-NEE) and GPP, NEE being simulated with the same methods as described above for GPP based on the 62 CarboeuropeIP sites.
Evapo-transpiration	Computed daily using the Penman-Monteith combination equation (Monteith, 1965)	Total evapotranspiration (Monteith, 1995)	Bulk formula to formulate surface fluxes (Ducoudre et al., 1993)	Evapotranspiration according to Reichstein (2001) and Reichstein et al. (2003b)			
Water balance	Single bucket model: Precipitation balanced with evapotransiration and runoff, snowpack	Two bucket model adapted from (Neilson, 1993), precipitation balanced with runoff and drainage, snow-pack	Two bucket model with variable depth, precipitation balanced with drainage and runoff	Multi-layer soil model based on Richards (1931), temperature conductivity (Cox et al., 1999), modified by snowpack, hydrology (Gregory and Smith, 1990)	Three layer soil model, rooting depth (50 cm short, 150 cm tall, vegetation), empirical function of soil water depletion established from CarboEurope observation sites during the dry year 2003		
Nitrogen dynamics	Simulated explicit, described in (Running and Gower, 1991; Thornton et al., 2002).	Not explicitly simulated	Not explicitly simulated	Not explicitly simulated	Not explicitly simulated		

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Table 2. Overview of the models participating in this study and the temporal resolution of the REMO derived climate-drivers needed. Hourly input (h), daily input (d), and monthly input (m). ORCHIDEE and JULES used different sub-daily resolutions in their simulations.

Model	temperature	Precipitation	radiation	humidity
TEMs				
Biome-BGC	d	d	d	d*
LPJ	m	m	m	m
ORCHIDEE	h	h	h	h
JULES	h	h	h	h
PIXGRO	h	h	h	h
Diagnostic models				
MOD17+	d	d	d	d*
ANN	d	d	d	d*

*VPD

Table 3. Model input data (land surface, climate data, atmospheric CO_2 concentration, atmospheric nitrogen deposition and nitrogen fertilization) used by the terrestrial ecosystem models in this study.

Parameter	Source
Albedo	MODIS (MOD43B) (Lucht et al., 2000; Schaaf et al., 2002)
Elevation	GTOPO 30; http://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html
Soil depth	TERRASTAT – Global Land Resources GIS Models and Databases, FAO Land and Water Digital Media Series # 20
Soil texture	Global Soil Data Products CD-ROM (IGBP-DIS)
Landcover	SYNMAP (Jung et al., 2006)
Water holding capacity pedo transfer functions	Cosby et al. (1984), Saxton et al. (1986)
Temperature (max,min, daily average)	REMO Feser et al. (2001), Koch and Feser (2006), Jacob and Podzun, (1997), Kalnay et al. (1997), Storch et al. (2000)
Precipitation Short wave solar downward radiation Vapor pressure deficit (VPD) Relative humidity	
Atmospheric CO_2 concentration	Etheridge (1996) Keeling and coworkers, as deposited on the ORNL CDIAC data repository, in 2004
Atmospheric nitrogen deposition Nitrogen fertilization	Galloway (2004), Holland (1999) Freibauer (2003), http://faostat.fao.org/site/422/default.aspx

Table 4. Regional estimated carbon fluxes of the growing season (Mai–September) [Tg C] for long-term mean (LT), baseline period 1998–2002 (BL) as well as the years 2002 and 2003 with corresponding anomalies relative to long-term mean (LT), baseline (BL), and the year 2002, respectively. The models MOD17+ and ANN estimated long-term mean for the years 2000–2004 and baseline for the years 2000–2002. Bold numbers denotes a negative anomaly; hence the value of the year 2003 is smaller than the value of the respective reference period.

Model[a]	NEP [Tg C]							GPP [Tg C]							Reco [Tg C]							Climate			
	B	L	O	J	M	A	P	B	L	O	J	M	A	P	B	L	O	J	M	A	P	T [°C]	P [mm]	VPD [pa]	R [Wm⁻²]
North																									
LT	314	276	337	165				1038	1211	1336	1422				724	936	998	1256				10.9	409	456	158
BL	330	276	366	164	326	286		1074	1251	1404	1431	926	951		745	974	1038	1267	600	665		10.9	417	429	155
2002	382	395	491	193	382	316	156	1197	1392	1569	1580	995	1007	976	815	997	1078	1387	612	691	820	12.0	375	522	166
2003	339	300	340	164	339	284	98	1140	1304	1426	1507	946	968	896	801	1004	1085	1343	607	683	798	11.6	428	477	160
2003-LT	25	24	3	**-1**				102	93	90	86				77	68	87	87				0.7	11	48	5
2003-BL	9	24	**-25**	0	13	**-2**		65	54	22	76	20	16		56	30	48	76	7	18		**-0.4**	53	**-45**	**-6**
2003-2002	**-43**	**-9**	**-151**	**-29**	**-43**	**-32**	**-57**	**-57**	**-88**	**-143**	**-73**	**-49**	**-39**	**-80**	**-14**	7	8	**-44**	**-6**	**-7**	**-22**	0.7	20	21	2
West																									
LT	271	132	31	128				1019	1113	930	2639				748	981	899	2511				19.1	251	1493	230
BL	322	170	61	153	356	386		1130	1240	1005	2727	1425	1281		809	1070	944	2574	1070	895		19.1	271	1447	228
2002	353	181	82	147	364	359	399	1171	1290	1052	2764	1435	1276	1276	818	1109	969	2616	1071	917	877	18.7	293	1381	224
2003	229	**-25**	**-99**	25	262	357	162	1081	915	822	2715	1290	1173	1031	852	940	921	2691	1028	816	869	21.1	198	1838	238
2003-LT	**-42**	**-158**	**-130**	**-103**				62	**-198**	**-108**	77				104	**-40**	22	180				2.0	**-53**	344	8
2003-BL	**-92**	**-196**	**-160**	**-128**	**-94**	**-29**		**-49**	**-326**	**-184**	**-11**	**-136**	**-107**		43	**-130**	**-23**	116	**-42**	**-79**		2.0	**-74**	391	11
2003-2002	**-124**	**-207**	**-181**	**-123**	**-102**	**-2**	**-237**	**-90**	**-375**	**-230**	**-48**	**-145**	**-103**	**-245**	34	**-169**	**-48**	74	**-44**	**-101**	**-7**	2.4	**-95**	457	15

[a] B: Biome-BGC; L: LPJ; O: ORCHIDEE; J: JULES; M: MOD17+; A: ANN; P: PIXGR

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Table 5. Regional estimated carbon fluxes of the growing season (Mai–September) [Tg C] for long-term mean (LT), baseline period 1998–2002 (BL) as well as the years 2002 and 2003 with corresponding anomalies relative to long-term mean (LT), baseline (BL), and the year 2002, respectively. The models MOD17+ and ANN estimated long-term mean for the years 2000–2004 and baseline for the years 2000–2002. Bold numbers denotes a negative anomaly; hence the value of the year 2003 is smaller than the value of the respective reference period.

Model[a]	NEP [Tg C]							GPP [Tg C]							Reco [Tg C]							Climate			
	B	L	O	J	M	A	P	B	L	O	J	M	A	P	B	L	O	J	M	A	P	T [°C]	P [mm]	VPD [pa]	R [Wm⁻²]
Central																									
LT	505	300	170	187				1702	1468	1488	3599				1197	1168	1318	3413				18.5	305	1345	218
BL	535	284	135	151	510	490		1789	1495	1495	3701	1879	1628		1254	1210	1360	3549	1369	1138		18.9	314	1399	219
2002	559	231	77	141	584	496	156	1857	1392	1463	3916	2018	1662	1499	1298	1207	1386	3775	1434	1166	1147	19.7	326	1469	222
2003	473	215	41	196	523	508	98	1704	1304	1334	3762	1897	1565	1277	1231	1073	1293	3666	1374	1057	1072	19.9	260	1578	230
2003-LT	**-32**	24	**-129**	9				2	**-181**	**-154**	162				34	**-96**	**-25**	153				1.4	**-45**	233	12
2003-BL	**-62**	24	**-94**	44	13	18		**-85**	**-207**	**-161**	61	19	**-63**		**-23**	**-138**	**-67**	16	5	**-81**		0.9	**-54**	179	11
2003-2002	**-86**	**-9**	**-36**	55	**-61**	**-13**	**-147**	**-153**	**-151**	**-129**	**-155**	**-121**	**-96**	**-222**	**-67**	**-135**	**-94**	**-210**	**-60**	**-109**	**-75**	0.2	**-66**	109	8
East																									
LT	578	382	510	228				2101	1860	2290	3377				748	981	899	2511	1055	870		14.8	359	807	187
BL	559	333	447	196	578	386		2084	1763	2192	3388	1784	1895		809	1070	944	2574	1070	895		14.9	337	890	189
2002	526	328	386	241	540	359	-28	2005	1531	2022	3398	1688	1718	1276	818	1109	969	2616	1071	917	877	15.1	263	1045	194
2003	552	345	454	257	585	357	3	2062	1872	2265	3449	1817	1905	1031	852	940	921	2691	1028	816	869	15.1	350	806	189
2003-LT	**-26**	**-37**	**-56**	29				**-38**	11	**-24**	72				104	**-40**	22	180				0.3	**-9**	**-1**	1
2003-BL	**-7**	11	7	61	7	**-29**		**-22**	108	74	61	33	10		43	**-130**	**-23**	116	**-42**	**-79**		0.2	13	**-84**	0
2003-2002	26	16	68	16	45	**-2**	31	**-58**	341	244	51	129	187	**-245**	34	**-169**	**-48**	74	**-44**	**-101**	**-7**	0.0	87	**-239**	**-5**

[a] B: Biome-BGC; L: LPJ; O: ORCHIDEE; J: JULES; M: MOD17+; A: ANN; P: PIXGR

Table 6. Total European carbon fluxes [Pg] and their anomalies calculated for the growing season (Mai–September). The calculated fluxes are averages over 1980–2005 (long-term mean), over 1998–2002 (baseline), and total sums for the years 2002 and 2003. Corresponding estimated anomalies are calculated relative to longterm mean, baseline and 2002 for Biome-BGC, LPJ, ORCHIDEE, JULES, MOD17+, ANN and PIXGRO. Bold numbers denote that the carbon fluxes over the growing season 2003 were smaller than over the respective reference period.

|	Biome-BGC	LPJ	ORCHIDEE	Model JULES	MOD17+	ANN	PIXGRO
			GPP				
Long-term mean	5.86	5.65	6.04	11.04			
baseline	6.08	5.75	6.10	11.25	6.01	5.76	
2002	6.23	5.65	6.10	11.66	6.14	5.66	5.00
2003	5.99	5.38	5.85	11.43	5.95	5.61	4.58
2003-long-term mean	0.13	**−0.27**	**−0.20**	0.40			
2003-baseline	**−0.09**	**−0.37**	**−0.25**	0.19	**−0.06**	**−0.14**	
2003–2002	**−0.24**	**−0.27**	**−0.26**	**−0.22**	**−0.19**	**−0.05**	**−0.42**
			Reco				
Long-term mean	4.19	4.56	5.00	10.33			
baseline	4.33	4.68	5.09	10.58	4.24	3.94	
2002	4.41	4.52	5.07	10.94	4.27	3.89	4.12
2003	4.39	4.54	5.11	10.79	4.24	3.83	4.11
2003-long-term mean	0.20	**−0.02**	0.12	0.46			
2003-baseline	0.06	**−0.14**	0.02	0.21	**−0.003**	**−0.12**	
2003-2002	**−0.02**	0.03	0.04	**−0.14**	**−0.03**	**−0.06**	**−0.01**
			NEP				
Long-term mean	1.67	1.09	1.05	0.71			
baseline	1.74	1.06	1.01	0.66	1.77	1.81	
2002	1.82	1.13	1.04	0.72	1.87	1.78	0.88
2003	1.59	0.83	0.74	0.64	1.71	1.79	0.47
2003-long-term mean	**−0.08**	**−0.26**	**−0.31**	**−0.07**			
2003-baseline	**−0.15**	**−0.23**	**−0.27**	**−0.02**	**−0.06**	**−0.03**	
2003–2002	**−0.23**	**−0.30**	**−0.30**	**−0.08**	**−0.16**	0.01	**−0.41**

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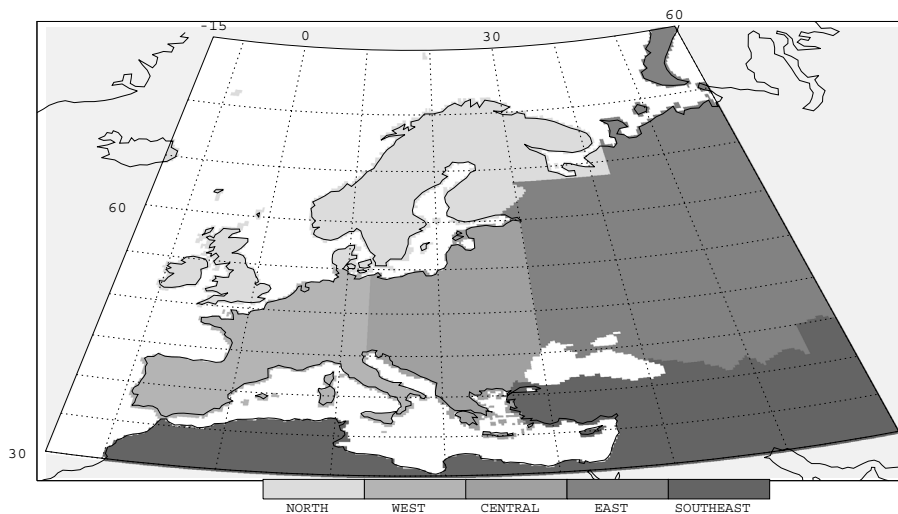
Fig. 1. View of different regions of Europe: Northern Europe, Western Europe, Central Europe, Eastern Europe.
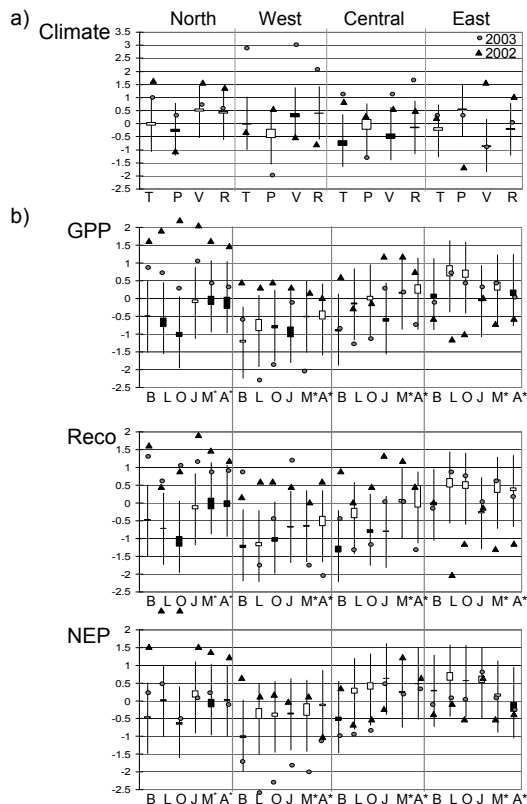
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Fig. 2. Standardized area weighted **(a)** climate anomalies relative to baseline. T-temperature, P-Precipitation, V-Vapor pressure deficit, R-Radiation. **(b)** carbon flux anomalies relative to baseline. Climate and carbon anomalies are aggregated over four regions of Europe and values are dimension less. B: Biome-BGC; L: LPJ; O: ORCHIDEE; J: JULES; M: MOD17+; A: ANN, Grey dots: anomaly in 2003 relative to baseline 1998–2002. Black triangles: anomaly in 2002 relative to baseline 1998–2002. White boxes: average value greater than median. Black boxes: average values less than median. * baseline: 2000–2002.

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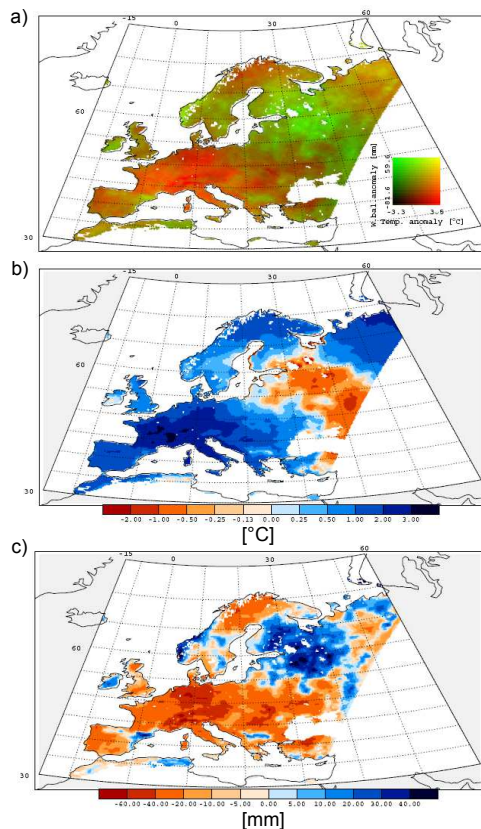
Fig. 3. The spatial pattern of the temperature and water balance anomalies through the growing season 2003 over Europe relative to baseline (1998–2002). **(a)** Combined spatial pattern: red areas show heat and draught, green areas show cold and wet anomaly. **(b)** Temperature anomaly 2003: blue areas an temperature increase relative to baseline, red areas a decrease. **(c)** Water-balance anomaly 2003: blue areas: increase in water-balance relative to baseline, red areas: decrease.
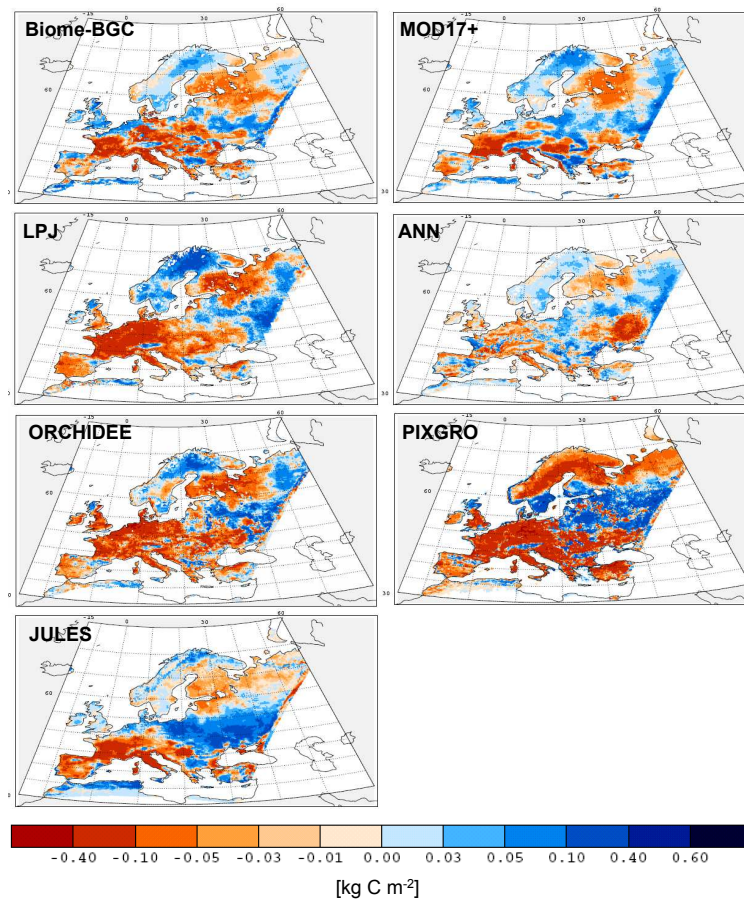
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Fig. 4. Anomaly in net ecosystem production in 2003 relative to baseline (1998–2002). Red areas show reduction in NEP. Blue areas show increase in NEP. For MOD17+ss and ANN the anomaly is calculated relative to the average between 2000 and 2002 (MODIS started December 1999). PIXGRO shows the difference in NEP between 2003 and 2002.