The European Carbon Balance Research Highlights 2007

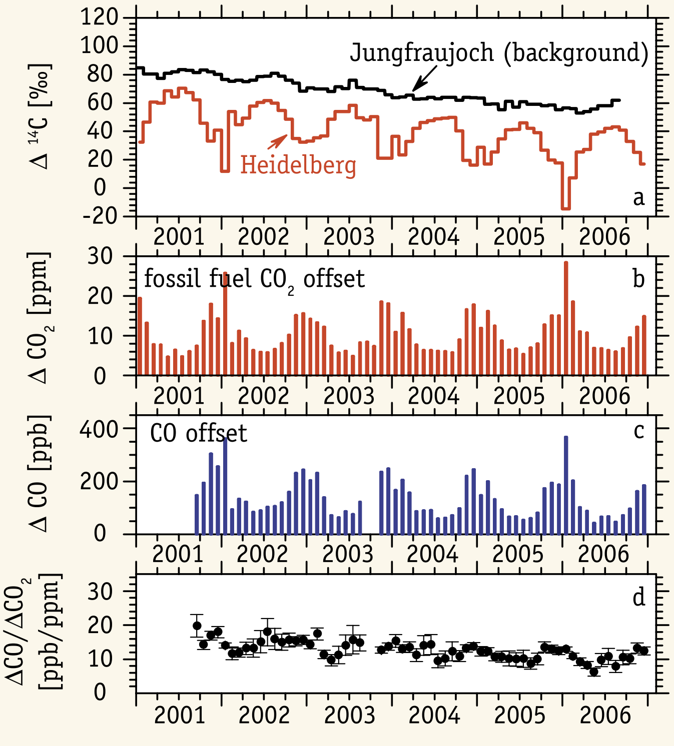
Carbon monoxide as tracer for fossil fuel carbon dioxide emissions over Europe

(Levin and Karstens, 2007a,b; Gamnitzer et al., 2006)

(Gamnitzer U et al. (2006): Carbon monoxide: A quantitative tracer for fossil fuel CO_2? Journal of Geophysical Research 111, D22302, Levin I and Karstens U (2007): Inferring high-resolution fossil fuel CO_2 records at continental sites from combined $^{14}CO_2$ and CO observations. Tellus 59B, 245-250, Levin I and Karstens U (2007): Quantifying fossil fuel CO_2 over Europe. In: Dolman A J, Freibauer A and Valentini R (eds): Observing the continental scale greenhouse gas balance of Europe. Springer, Heidelberg.)

Monitoring fossil fuel carbon dioxide (CO_2) emissions is essential for accurately determining the carbon balance of Europe. CarboEurope-IP researchers developed a new CO-based method to calculate fossil fuel CO_2 offsets (difference in CO_2 concentrations between the Jungfraujoch Background and the Heidelberg measurement site) at a high temporal resolution. Integrated $^{14}CO_2$ observations at CO_2 monitoring sites are used to calibrate continuous CO measurements, which are available at a much larger number of sites. Thus, the regional fossil fuel CO_2 emissions can be estimated at hourly resolution with an uncertainty of about 20-40%.

Europe is responsible for more than 25% of global fossil fuel CO_2 emissions, which are also a large component of the European carbon budget. Separating the fossil fuel from the natural biogenic signal in the atmosphere is a crucial task for quantifying exchange fluxes of the continental biosphere.

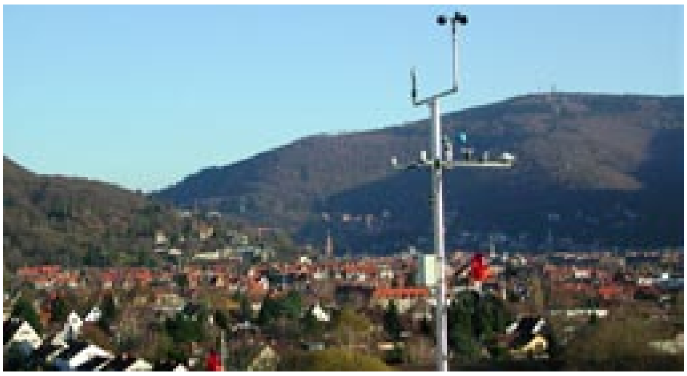


Monthly mean values of $\Delta^{14}CO_2$ in Heidelberg and at the Jungfraujoch. The depleted Heidelberg values - relative to Jungfraujoch - indicate the dilution of atmospheric $^{14}CO_2$ concentrations by burning of ^{14}C-free fossil fuels (a). Fossil fuel CO_2 offset ($\Delta FFCO_2$) in Heidelberg calculated from the $^{14}CO_2$ depletion relative to Jungfraujoch (b). CO offset in Heidelberg relative to the continental background level at Jungfraujoch (c). Monthly mean ratios of the CO/$FFCO_2$ offsets (Levin and Karstens, 2007 extended with unpublished data).

Monitoring fossil fuel CO_2 in the atmosphere is possible using radiocarbon (^{14}C) as a tracer. However, the $^{14}CO_2$ measurements need to be made at very frequent time intervals and with high precision to yield accurate estimates of fossil fuel CO_2. This is an expensive undertaking and, thus, the current network of ^{14}C-based fossil fuel CO_2 observations is very sparse and unevenly distributed. Equally important, the sensitivity of the atmospheric $^{14}CO_2$ level to fossil fuel CO_2 is limited to only slightly less than 1 ppm. Despite these drawbacks, $^{14}CO_2$ measurements have the unique advantage to allow direct estimates of fossil fuel CO_2 which is not possible with any other tracer.

Due to the lack of precise and frequent $^{14}CO_2$ observations, other tracers that could serve as surrogates for fossil fuel CO_2 - particularly CO - have been discussed. The major CO sources are very closely linked to those of fossil fuel CO_2 because any fossil fuel combustion process produces both CO_2 and CO. However, there are other atmospheric sources and also sinks for CO, and the CO/CO_2 emission ratio of different fossil fuel sources can vary by orders of magnitude. The implications for the use of CO as tracer for fossil fuel CO_2 are twofold: Firstly, when CO alone shall be used as a quantitative tracer for fossil fuel CO_2, the CO/CO_2(fossil) ratio of emissions as well as its temporal changes need to be known accurately, and secondly, reliable estimates of the non-fossil sources and the sinks of CO are required as these may change atmospheric CO/CO_2(fossil) ratios by up to 50%.

CarboEurope-IP researchers have validated the reliability of a newly developed CO-based method to calculate hourly fossil fuel CO_2 offsets with a number of high temporal resolution measurements of CO_2, CO and $^{14}CO_2$, so-called "event sampling campaigns", performed in Heidelberg from autumn 2001 to spring 2003. In parallel to the event samples, two-weekly integrated $^{14}CO_2$ measurements have been performed, and from these measurements and concurrent hourly CO observations mean CO/CO_2(fossil) ratios for the times of the events could be determined. These mean ratios have been applied to the hourly CO observations during the events to calculate fossil fuel CO_2 mixing ratios. The CO-based ΔCO_2(fossil) was then



The Heidelberg measurement site.

compared to the ^{14}C-based ΔCO_2(fossil) estimated for the event samples. There is a very good agreement obtained between the CO-based and the ^{14}C-based fossil fuel CO_2 estimates.

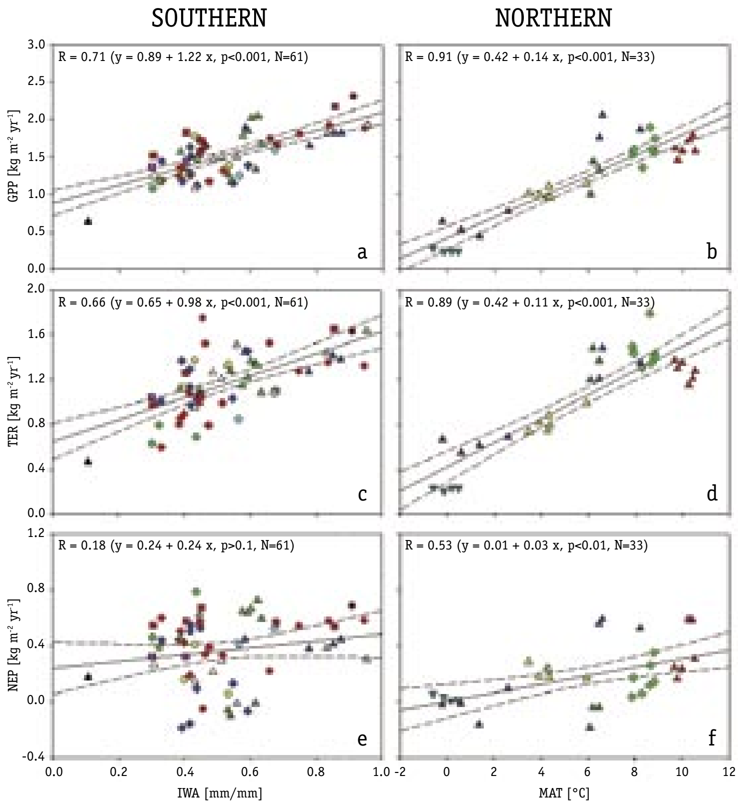
Thus, the calibration of continuous ΔCO measurements with integrated $^{14}CO_2$ observations at CO_2 monitoring sites will allow us to estimate Europe's fossil fuel CO_2 emissions at hourly resolution with an uncertainty of about 20-40%. This estimate would be purely based on observations. Taking advantage of CO observations can also correct the output of atmospheric models used to estimate fossil fuel CO_2 emissions and help to ameliorate shortcomings related to transport and other processes that are so far unaccounted for. As the CO/CO_2 ratios of important fossil fuel sources are changing - which can already be detected in the atmosphere, ongoing $^{14}CO_2$ observations will be indispensable for calibration of CO.

How water availability and temperature control the carbon balance of forest ecosystems - results from experiments

Reichstein et al. (2007)

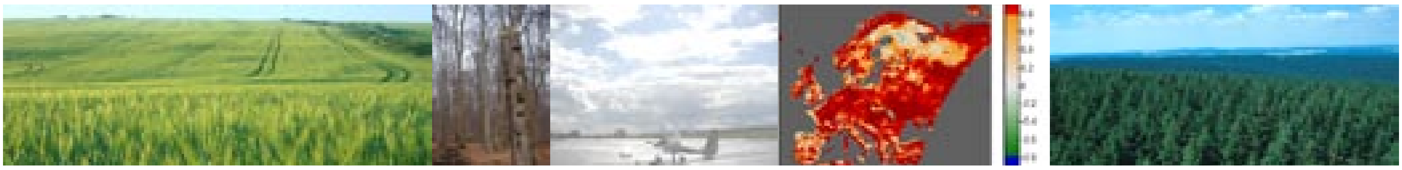
Reichstein M et al. (2007): Determinants of terrestrial ecosystem carbon balance inferred from European eddy covariance flux sites. Geophysical Research Letters 34, L01402.

CarboEurope-IP researchers analysed carbon flux data of 23 European study sites concerning controlling factors for the ecosystem carbon balance. Annual gross primary production (GPP) at southern sites correlates positively with water availability, while variation in GPP at northern sites can be explained to a large extent by air temperature. Generally, the influence of water availability seems to be larger than the temperature effect. Results highlight the possibility that a change in rainfall pattern may affect ecosystem respiration more strongly than GPP, leading to a reaction of the net ecosystem carbon balance that may be counterintuitive given contemporary understanding of the relationships between the carbon balance and climate.



Correlation between index of water availability (ratio of actual to potential evapotranspiration) and annual (a) gross primary production (GPP), (c) terrestrial ecosystem respiration (TER) and (e) net ecosystem production (NEP), and between mean annual temperature and annual (b) GPP, (d) TER, and (f) NEP (Reichstein et al., 2007).

The carbon balance at the ecosystem level (net ecosystem production, NEP) is the difference between carbon uptake by photosynthesis (gross primary production, GPP) and carbon losses via the respiration of plants and soil microorganisms (terrestrial ecosystem respiration, TER). Thus, the response of the carbon balance to climate is the combination of the responses of GPP and TER to climate. It is well established that both GPP and TER increase with temperature and both are limited by water availability. However, the influence of these environmental factors on the overall carbon balance of terrestrial ecosystems is less easy to predict. Nevertheless, in times of changing climate, it is crucial to understand how the carbon balance will likely be influenced by altered temperature and precipitation. Thus, it was the aim of an empirical analysis conducted within CarboEurope-IP to determine the roles of temperature and water limitations on GPP and TER – and thereby NEP – across a range of European forest sites.



Researchers of CarboEurope-IP analysed annual sums of GPP, ecosystem respiration and NEP derived from eddy covariance data measured from 1996 to 2003 in relation to simple climatic indices, resulting in a total of 93 annual data sets. The sites occupy different climate zones and include both managed and almost unmanaged forests of different age classes.

Mean annual temperature and an index of water availability were related to the CO_2 fluxes derived from eddy covariance with a stratified linear regression. The data set was split into two groups: In northern regions (latitude above 52°N), GPP and TER were determined by mean annual temperature, whereas in southern areas water availability was considered to be the main controlling factor.

The simple stratification of the data yielded strongly different controls at northern and southern sites. Annual GPP at the southern sites correlates positively and significantly with the index of water availability (ratio of actual to potential evapotranspiration), while variation in GPP at the northern sites can be explained to a large extent by mean annual air temperature. This different control on GPP is expected, since the northern sites are rather cool (mean annual temerature between -2 and 11°C) and rarely water-limited, while the southern sites are warmer and relatively more water-limited. Ecosystem respiration at both southern and northern sites correlates similarly with the water availability and temperature, respectively. This response almost completely compensates for the GPP response and results in very weak correlation between NEP and climate indices.

Generally, the influence of water availability is larger than the temperature effect: On an annual time scale, NEP is positively influenced by the index of water availability at northern sites and negative at southern sites. Similarly, TER increases with higher water availability, while temperature has no such effect. Thus, variation in NEP appears more related to variation in GPP and water availability than to TER and temperature. This result highlights the possibility that with respect to changing climate a change in rainfall pattern may affect respiration more strongly than gross productivity, leading to an hitherto unforeseen reaction of the net ecosystem carbon balance: NEP at southern sites may decrease under moister conditions, because ecosystem respiration reacts more strongly to the higher water availability than GPP.

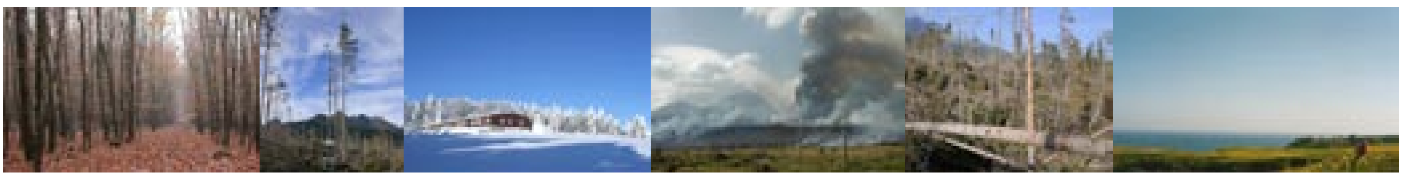
Causes and patterns of the 2003 summer drought - a model intercomparison

Vetter et al. (2007)

Vetter M et al. (2007): Analyzing the causes and spatial pattern of the European 2003 carbon flux anomaly in Europe using seven models. Biogeosciences Discussions 4, 1201-1240.

CarboEurope-IP researchers used seven models to analyse European ecosystem responses to climate variations with special emphasis on 2003. The study showed that a heat/drought anomaly over Western and Central Europe was accompanied by a cold and wet anomaly over Western Russia. This climate anomaly pattern was also seen in the spatial net ecosystem production (NEP) anomaly in 2003. While the models mostly agreed on the sign of the 2003 NEP anomaly, they found different ecological reasons for this phenomenon.

Globally, the year 2003 is associated with one of the largest atmospheric CO_2 rises on record. Drought periods in mid-latitudes of the Northern Hemisphere were suggested to cause the additional carbon release to the atmosphere. During these years, atmospheric model inversions have indicated that the Northern Hemisphere mid-latitudes went from being a sink (0.7 Pg C yr^{-1}) to being close to neutral. As terrestrial 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.



CarboEurope-IP researchers used five process based models (BIOME-BGC, LPJ, ORCHIDEE, JULES, PIXGRO) and two data oriented models (MOD17+, $NETWORK_{ANN}$) to analyse European ecosystem responses to climate variations. This allows to assess the regional significance of the 2003 anomaly in the European carbon balance together with the uncertainty in its estimates caused by the different models. The following questions were of special interest for the scientists:

How large were the shifts in the regional carbon fluxes during 2003 growing season relative to long-term variation?

The comparison suggests that land ecosystems of Europe emitted additional 0.27-0.03 Pg of carbon to the atmosphere in response to drought in 2003. This estimates are comparable to the previously reported value of 0.5 Pg.

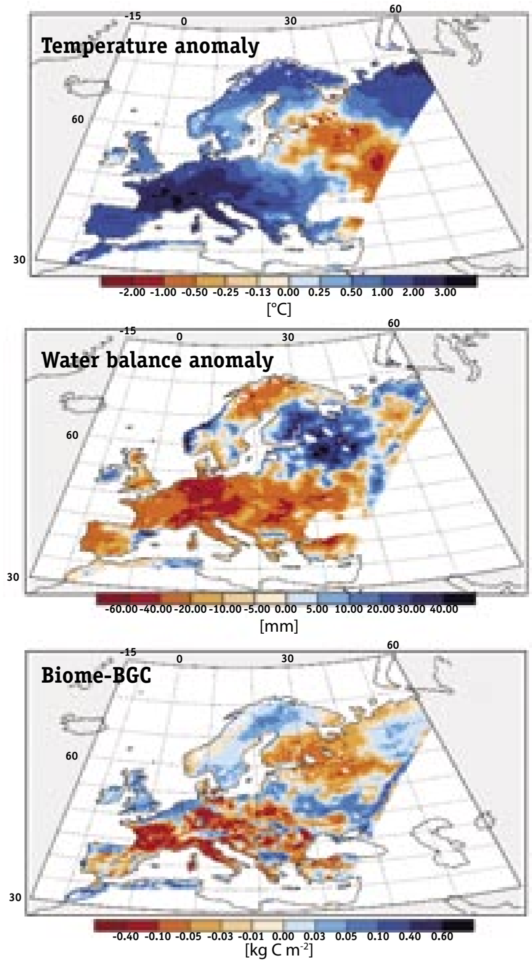
Do models agree on which regions exhibited the largest shift in carbon fluxes during the growing season 2003?

The study showed that a heat/drought anomaly over Western and Central Europe was accompanied by a cold and wet anomaly over Western Russia. This pattern was also seen in the spatial NEP anomaly in 2003. Models agreed well in the spatial pattern of vegetation responses to the cold and wet anomaly and showed increased carbon sequestration over Scandinavia and Russia. All models also showed a decrease in NEP in Western and Central Europe, the extent of the affected areas differing slightly between the models.

Which processes – photosynthesis or respiration controlled the carbon balance anomaly in the models?

The tested models disagree on the dominating ecosystem processes behind this event. The largest differences are related to the response of ecosystem respiration (TER) to the heat and drought in Western and Central Europe.

The fact that seven different models agreed on the extent and spatial pattern of the NEP anomaly in 2003 supports the reliability of the models results and their prognostic value. Like the experimental study on environmental controls of the carbon balance, this model comparison also showed the importance of accurately determining the influence of the soil water status on the overall carbon balance of terrestrial ecosystems.



Anomaly of temperature, water balance and NEP (BIOME-BGC) relative to the baseline (1998-2002). Red areas show reductions, blue areas show increases (Vetter et al., 2007).

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CarboEurope-IP in brief

***CarboEurope-Integrated Project* (IP) is a European research project within the 6th Framework Programme of the EU. Over a period of five years (2004-2008), CarboEurope-IP engages 67 partner institutes in 17 countries plus about 30 associated partners, thus involving around 150 scientists and their PhD-students. The project with a budget of more than 30 million Euros, 16 million Euros of which are support from the European Commission, is coordinated by the Max-Planck-Institute for Biogeochemistry in Jena.**

The overarching aim of CarboEurope-IP is to understand and quantify the present terrestrial carbon balance of Europe and the associated uncertainty at local, regional and continental scale.

Integrated observations via a harmonized multi-platform atmospheric observation system and 100 ecosystem research sites are used to understand ecosystem responses to climate, land use and management. Together with advanced modelling of fossil fuel emissions and biosphere carbon exchange using a multiple constraint approach, CarboEurope-IP produces policy-relevant products like regional spatial and temporal patterns of the European carbon balance: It provides scientific instruments to monitor and verify the national reports under the UN climate change convention and to control the performance of mitigation.