EUROPEAN-WIDE REDUCTION IN PRIMARY PRODUCTIVITY CAUSED BY THE HEAT AND DROUGHT IN 2003

Ph. Ciais[1], M. Reichstein[2,3], N. Viovy[1], A. Granier[4], J. Ogée[5], V. Allard[6], N. Buchmann [7], M. Aubinet[8], Chr. Bernhofer[9], A. Carrara[10], F. Chevallier [1], N. De Noblet[1], A. Friend[1], P. Friedlingstein[1], N. Gobron[17], T. Grünwald[9], B. Heinesch[8], P. Keronen[11], A. Knohl[12,13], G. Krinner[14], D. Loustau[5], G. Manca[2,*], G. Matteucci[15,**], F. Miglietta [16], J.M Ourcival[17], K. Pilegaard[18], S. Rambal[19], G. Seufert[17], J.F. Soussana[6], M.J. Sanz[10], E.D. Schulze[12], T. Vesala[11], and R. Valentini[2]

(1) Laboratoire des Sciences du Climat et de l'Environnement, LSCE, F-91191, Gif sur Yvette, France

(2) Dept. of Forest Environment and Resources, DISAFRI, University of Tuscia, Italy

(3) Potsdam Institute for Climate Impact Research, Telegrafenberg C4, D-14473 Potsdam

(4) Ecologie et Ecophysiologie Forestières, Centre de Nancy, 54280 Champenoux, France.

(5) Functional Ecology and Environmental Physics, Ephyse, INRA, Villenave d'Ornon, France

(6) Grassland Ecosystem Research, INRA, 234, Av. du Brézet, Clermont-Ferrand, F-63039, France

(7) Institute of Plant Sciences, Universitätsstrasse 2, ETH Zentrum LFW C56, CH-8092 Zuerich, Switzerland

(8) Faculté des Sciences Agronomiques, Av. de la Faculté d'Agronomie 8, B-5030 Gembloux Belgique

(9) Department of Meteorology, Institute of Hydrology and-Meteorology, Technische Universität Dresden, D-01062 Dresden, Germany

(10) Fundacion CEAM C/ Charles Darwin, Parque Tecnologico de Paterna, 46980 Valencia, Spain

(11) Department of Physical Sciences, University of Helsinki PO-Box 64, Finland

(12) Max Planck Institute for Biogeochemistry, Postfach 10 01 64, D-07701 Jena, Germany

(13) Dept. of Environmental Science Policy and Management, Ecosystem Science Division, University of California, Berkeley, USA

(14) Laboratoire de Glaciologie et Géophysique de l'Environnement, 54, rue Molière, F-38402 - Saint Martin d'Hères, France

(15) Institute for Environment and Sustainability, Joint Research Center European Commission, TP 280, I-21020 Ispra, Italy

(16) IBIMET-CNR, Ple delle Cascine, 18, I-50144 Firenze, Italy

(17) Dream CEFE-CNRS, 1919 route de Mende, F-34293 Montpellie, France

(18) Biosystems Department, Risø National Laboratory, 4000 Roskilde, Denmark

ABSTRACT

Future climate warming is expected to enhance plant growth in temperate ecosystems and to increase carbon sequestration. But although severe regional heatwaves may become more frequent in a changing climate, and their impact on terrestrial carbon cycling is unclear. Europe experienced a particularly extreme climate anomaly during 2003, with July temperatures up to 6°C above long-term means, and annual precipitation deficits up to 300 mmy^{-1}, that is 50% below the average. We used the 2003 heatwave as a 'laboratory assistant' to estimate the impact on terrestrial carbon cycling.

We collected measurements of ecosystem carbon dioxide fluxes, remotely sensed radiation absorbed by plants, and country-level crop yields. The presence of an extensive network of instrumentation for the monitoring of ecosystem fluxes at this time, with continuous records of CO_2, water, and energy fluxes helped us to quantify the spatial and temporal patterns the 2003 climate anomaly across different ecosystems and at various locations over the European continent. We analyzed CO_2 fluxes from 14 forest sites and 1 grassland site for 2002-2003, with 2003 an (almost) normal year being taken as a reference.

Particularly large reductions in GPP were found at temperate deciduous Beech and northern Mediterranean forests, together with strong reductions in canopy conductance. In 2003, conductance reached for instance only 15% of its 2002 value at Hesse, a Beech forest in eastern France. These productive temperate and Mediterranean forests proved to be highly affected by extreme drought and/or heat. Moreover, GPP did not entirely recover from the summer stress during the remainder of the growing season. Parallel to the productivity drop, respiration tailed off with the drought, rather than accelerating with the temperature rise. Finally, we found that the water use efficiency of plants did not change significantly under the extreme stress conditions.

For croplands, we analyzed harvest data (crop yield) from country-level statistics. In each country, harvest was converted to crop Net Primary Productivity (NPP) using allometric relationships. These data indicate a pronounced crop NPP decrease in 2003 in those agricultural regions affected by heat (Northern Italy, France) but also by drought (Ukraine, Romania). Especially in South-eastern Europe, the impacts of drought were very important. Winter crops (wheat) had nearly terminated their growth by the time of the heatwave and so suffered less NPP reduction than summer crops (corn) undergoing maximum development in July-August.

We used a spatially explicit terrestrial biosphere carbon model, called ORCHIDEE, to upscale pointwise eddy covariance observations, and assess continental-scale changes in primary productivity during 2003. The model calculates fluxes each half hour, allocation and carbon pools dynamics, mortality and respiration processes. We also used the model in order to estimate the consequences of the heatwave for the net carbon balance of Europe. We simulated a 30 per cent reduction in gross primary productivity over Europe (an area of 5 Millions km^2). The simulations were evaluated against independent observations of satellite fraction of absorbed solar radiation from SeaWiffs and EOS-Terra-MODIS sensors. The crash in productivity of 2003 over Europe resulted in turn into a strong anomalous net source of carbon dioxide (0.5 PgC y^{-1}) to the atmosphere, reversing the effect of four years of net ecosystem carbon sequestration. The effects of the heatwave ‘rebound’ in 2004 and 2005 are now under investigation and preliminary results will be shown.

Overall, our model results, now confirmed with other independent simulations, suggest that the NPP drop in Eastern and Western Europe can be explained by soil water deficits, caused by initial rainfall deficit and likely amplified by extreme summer heat enhancing plant transpiration. We also calculated the contribution of exceptionally high tropospheric ozone levels on NPP during 2004, using as an input of our biosphere model the Ozone analysis at ground level from a regional air quality model. Elevated ozone was estimated to contribute up to 10% locally, and 3% across the continent to the drop of productivity in 2003. The model simulations, corroborated by historical records of crop yields, suggest that such a reduction in Europe's primary productivity is unprecedented during the last century. An increase in future drought events could turn temperate ecosystems into carbon sources, contributing to positive carbon-climate feedbacks already anticipated in the tropics and at high latitudes. To test this effect, we will show how simple assumptions regarding plant mortality in response to increasing extremes may propagate into a future decline of productivity and diminish the sink capacity of terrestrial ecosystems