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The role of extreme events and hydrological interactions in the carbon-cycle-climate feedback: effects of the 2003 European heatwave on the terrestrial carbon cycle

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Climate-carbon-cycle feedbacks have most often been discussed in the context of gradual changes of temperature ('global warming'). Recent flux tower, remote sensing and modelled data over Europe from the past years have however stressed the potential role of extreme events and of interactions with the hydrological cycle for the terrestrial carbon cycle. Here we present a comprehensive analysis of the terrestrial carbon cycle's reaction to such climate anomalies over Europe in 2003, taking advantage of the European CARBOEUROPE/FLUXNET monitoring sites, spatial remote sensing observations via the EOS-MODIS sensor and ecosystem modeling, that provide independent and complementary views on the effect of the 2003 heatwave on the European biosphere's productivity and carbon balance. In our analysis these data streams consistently demonstrate a strong negative anomaly of the primary productivity during the summer of 2003. FLUXNET eddy-covariance data indicate that the drop in productivity was not primarily caused by high temperatures ('heat stress') but rather by limitation of water (drought stress) and that, contrary to the classical expectation about a heat wave, not only gross primary productivity but also ecosystem respiration declined by up to more than to 80 gC m^{-2} $month^{-1}$. Anomalies of carbon and water fluxes were strongly correlated. While there are large between-site differences in water-use efficiency (1-6 kgC/kgH_2O) here defined as gross carbon uptake divided by evapotranspiration (WUE=GPP/ET), the year-to-year changes in WUE were small (<1g/kg) and quite similar for most sites, i.e. WUE decreased during the year of the

heatwave. Remote sensing data from MODIS and AVHRR both indicate a strong negative anomaly of the fraction of absorbed photosynthetically active radiation (fAPAR) in summer 2003, at more than 5 standard deviations of the previous years. The spatial differentiation of this anomaly follows climatic and land-use patterns: Largest anomalies occur in the centre of the meteorological anomaly (central Western Europe) and in areas dominated by crops or grassland. In conjunction with diagnostic and prognostic ecosystem modeling we come to the conclusion that terrestrial European ecosystems acted as a net anomalous source of 0.1-0.5 PgC CO_2-C in 2003 thus exhibiting a positive feedback in the carbon cycle climate system. Preliminary analysis of the terrestrial biosphere's response to the 2005 climate anomaly indicates a similar reaction but quite complementary spatial patterns, where in particular the Iberian Peninsula and Eastern Europe is heavily affected.