Europe-wide reduction in primary productivity caused by the heat and drought in 2003

Ph. Ciais, M. Reichstein, N. Viovy
Linking the 2003 European heatwave with carbon observations
Will the greening trends continue with more frequent climate extremes?

Can positive carbon-climate feedbacks come from temperate regions?

Secular increase in primary productivity from satellite NDVI over the past 20 years

Nemani et al., Science 2003
Europe-wide climate
Spell: heat & drought

Historical temperature records in Switzerland

Shär et al., Nature 2003

Precipitation history in Bavaria

Summer temperature reconstruction from harvest dates in Burgundy

Chuine et al., Nature, 2003
The eddy covariance sites on a MODIS landcover classification map

Sites used in this study include:
- Deciduous broadleaf forests: Soroe, Hainich, Hesse
- Evergreen needle leaf forests: Hyytiala, Tharandt, Bray
- Mediterranean needle-leaf and broad-leaf forests and macchia: Puéchabon, San Rossore, Pianosa, Roccares-pampani, El Saler, Castelporziano
Temperate and Mediterranean forests show reduced GPP, TER, NEE.
modelling system

Tower fluxes
- Measured NEE, ET
- Derived GPP, NPP
  - Model ET
  - Model NPP

Tower Climate
- Hourly 2003-2003

Global Climate
- Hourly 1900-2003
  - 30 - 100 km

ORCHIDEE model
- Model LAI
- Model FAPAR

EOS-MODIS
- FAPAR Spatial average

Crop Yield
- Country Average / species
  - Spatial average
  - Grid point
Climate, and carbon fluxes in summer 2002 vs. summer 2003
Abnormal Climate and Modelled Productivity in 2003

EOS-MODIS FAPAR anomaly
How abnormal is 2003?
Verification against crops yield national data
Interannual variations in CO$_2$ growth rate

Contour plot showing the temporal and spatial variations in the atmospheric increases of carbon dioxide. The cooler colors (green, blue, violet) represent periods of lower than average growth rates and the warmer colors (yellow, orange, red) represent high growth rate periods. The plot is derived from measurements of thousands of samples collected at the CMDL cooperative air sampling network sites. The variations in the growth rate of this climatically important gas are due to interannual variations in the imbalance between sources and sinks, and also to variations in atmospheric transport. Principal investigator: Thomas Conway, NOAA CMDL Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-6681 (thomas.j.conway@noaa.gov, http://www.cmdl.noaa.gov/ccgg).
Atmosphere-based inversion estimate

70 sites
Grid based inversion
(3.5 x 2.5°)

LMDZ model

Interannual winds

Spatial correlations

Anomalies vs. mean 97-03

See Peylin et al. Poster also Patra, Roedenbeck…
Fig. 2. Ratio $T$/PET calculated from sap flow measurements in an oak stand as a function of relative extractable water (REW) calculated from neutron probe measurements (from Bréda and Granier, 1996). Two data sets are reported: LAI = 6 m$^2$ m$^{-2}$ (black circles) and LAI = 4.5 m$^2$ m$^{-2}$ (open triangles). The dotted line shows the critical REW ($REW_c$).

Processes

Soil water content variation model and observations indicate large water stress at all sites in 2003 with Root Extractable Water $REW < 0$.

Breda et al. 2004
Small Changes in water use efficiency
Effects of high ozone exposure

Map showing the exceedance of the 180 μg/m³ ozone threshold interpolated 100 km around rural stations. Reference period: summer 2002 (April-August).

Carbon crashes in the recent past
Conclusions (1)

- Uniquely dense eddy covariance network to understand climate-carbon-water interactions at the sub-continental level
- Severe drop of transpiration and GPP
- Respiration tailed off with GPP drop rather than increased with warming
- Forests became net CO$_2$ sources to the atmosphere in July-Aug!
- Anomalous source of 0.5 PgC y$^{-1}$, undoing years of mean sink, enough to explain 50% of the global CO$_2$ growth rate anomaly during 2003
Conclusions (2)

• In the future, adverse impacts of climate extremes may cancel out the benefits of moderate climate change.

• Forest productivity may be durably reduced if extremes become more frequent.

• In the long run, conifer forest may be more adapted to future climate conditions in Europe.

• And so large uncertainties!
Implications for the future

Summer temperatures
Observed & Modelled by IPSL GCM

très chaud
moyen
très froid

1860 1900 1950 2000 2050 2100

2003
FPAR anomalies & recent droughts

2003

2005
Fig. 1: Temporal development of the spatial pattern of the fAPAR anomaly during 2003