J1.7 SOIL MOISTURE – ATMOSPHERE INTERACTIONS DURING THE 2003 EUROPEAN SUMMER HEATWAVE

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1. INTRODUCTION

A record-breaking heatwave affected the European continent in summer 2003, causing between 22,000 and 35,000 deaths and large financial loss due to crop shortfall and forest fires (Schär et al. 2004, Luterbacher et al. 2004, Schär and Jendritzky 2004). The physical processes and the sequence of feedbacks during the formation of this extreme event involve substantial uncertainties.

2. MODEL AND DATA

Here we use the regional climate model CHRM (Climate High-Resolution Model) to identify key processes and feedbacks that contributed to the occurrence and persistence of this heatwave. In particular, we investigate the role of the synoptic-scale circulation, soil hydrology and its interaction as well as related feedback processes for this particular event. The CHRM (Vidale et al. 2003) is a state of the art regional climate model, using a regular latitude/longitude grid with a rotated pole and a hybrid sigma pressure coordinate with 20 vertical levels and three active soil layers (total depth 1.7m). The CHRM is the climate version of the former mesoscale weather forecasting model of the German and Swiss meteorological services known as the HRM (High-Resolution Model) or formerly EM (Europa-Modell). The model has been modified by Lüthi et al. (1996) for application as a regional climate model. The computational domain covers Europe and the North-eastern Atlantic with a horizontal resolution of 56km.

3. EXPERIMENTAL SETUP

A sensitivity experiment is performed by perturbing spring soil water in order to determine its influence on the formation of the heatwave. The experiment includes 11 simulations for summer 2003: One control simulation (hereafter CTL), which is initialised in January 2002, and 10 sensitivity simulations with perturbed soil water. In the sensitivity simulations the soil water is instantly increased or decreased by 10%, 15%, 20%, 25% or 50% in all 3 soil layers at every grid-box over the model domain on April 1, 2003. After this instantaneous, one-time perturbation the soil water evolves freely until the simulation end in December 2003.

All 11 simulations are driven by assimilated lateral boundary conditions and sea surface temperatures from the ECMWF operational analysis using relaxation boundary technique. As model climatology we use a multi-year regional climate simulation for 1970–2000 (hereinafter CLIM) driven with ERA-40 reanalysis data.

The simulated summer temperature anomalies for 2003 are validated with the NASA GISS Surface Temperature Analysis (GISTEMP) (Hansen et al. 1999 and Hansen et al. 2001). GISTEMP is a global analysis of surface temperature using observational station data as input data, collected by many national meteorological services around the world and provided by the Global Historical Climatology Network.

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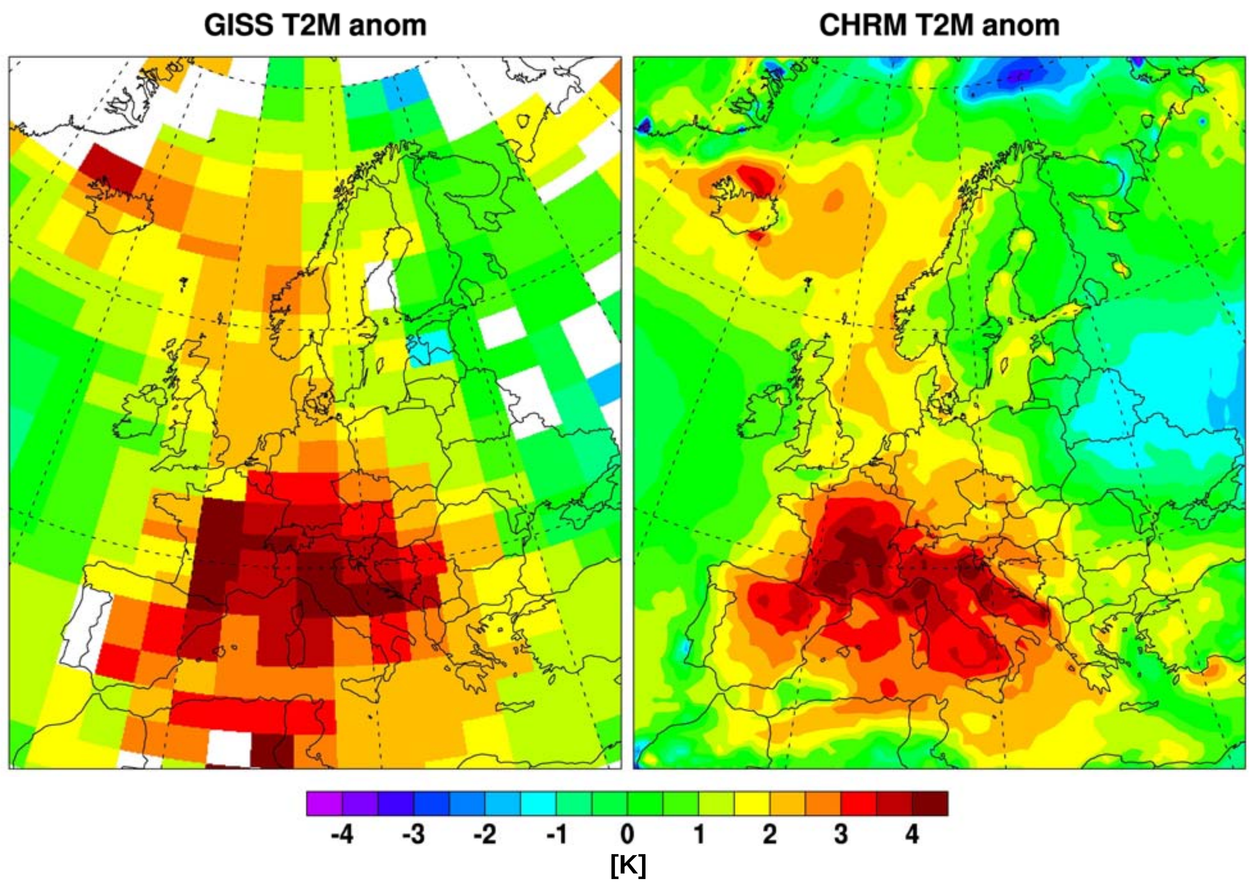

Figure 1: *Summer (JJA) 2003 temperature anomalies wrt 1970-2000 represented in observation-based NASA GISS surface temperature analysis (fig. 1, left panel) and simulated by the CHRM model (fig. 1, right panel).*

4. VALIDATION

Figure 1 displays the summer (JJA) temperature anomaly 2003 with respect to 1970–2000 represented by the GISTEMP (Fig. 1a) and simulated by the CHRM model (anomaly CTL-CLIM, Fig. 1b). The overall spatial patterns of temperature departures compare remarkably well. The amplitude of the warm anomalies is in reasonable agreement except for the maximum heat anomaly over Northern France, which is slightly underestimated by the model.

5. RESULTS

In order to determine the influence of soil water on surface temperature in summer 2003, the perturbed simulations are compared to the CTL simulation. Figure 2 shows the summer temperature anomaly resulting from a reduction (-25%, hereinafter DRY RUN) and an increase (+25%, hereinafter WET RUN) of the total soil water depth. The reduction of spring soil water by 25% is revealed to produce a strong summer (JJA) warm anomaly of around 2°C over a large zonal band covering land regions between the Mediterranean and the North Sea, and the Atlantic and the Black Sea. This anomaly, which results from the lack of soil water and the subsequent feedback processes, corresponds to about 30-50% of the observed Central European warm anomalies in 2003 (CTL-CLIM). The opposite signal is found in the simulation with increased spring soil water (WET-CTL) displayed in figure 1 (right panel). Over large areas, the soil water increase (+25%)

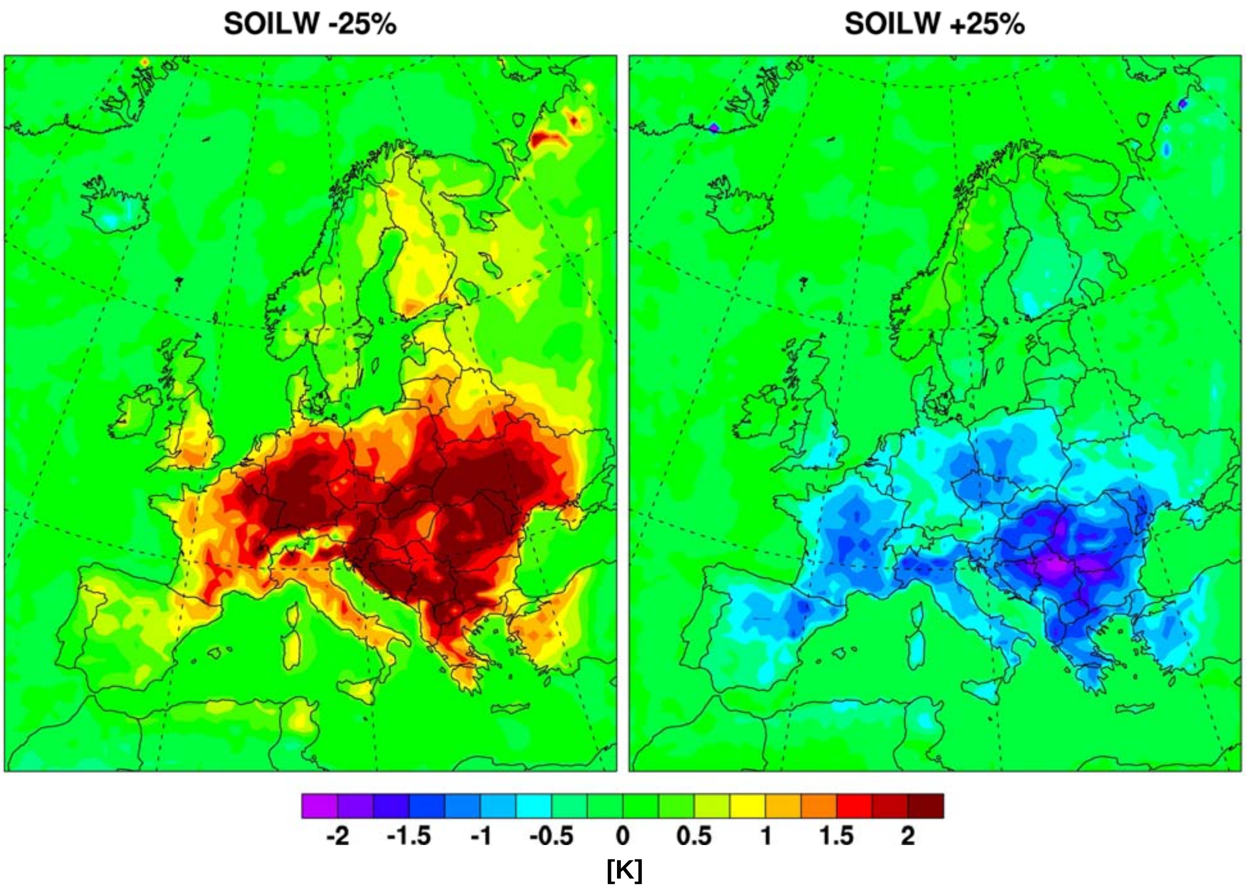

Figure 2: *Temperature anomaly due to soil water perturbation represented by the simulated difference dry run wrt control run (fig. 2 left panel) and wet run wrt control run (fig. 2 right panel).*

accounts for negative temperature departures with respect to the CTL simulation of around -1.5°C. This finding suggests that the temperature in summer 2003 would have been substantially cooler given the same lateral boundary conditions but wetter soils. Soil water affects the surface temperature mainly through anomalous latent heat flux (not shown) and a circulation feedback.

Soil water anomalies not only influence surface temperature but also pressure near the surface and in the mid-troposphere. Figure 3 depicts the geopotential height anomalies on 1000hPa (left) and 500hPa (right) resulting from a spring soil water reduction of 25% (DRY-CTL). Decreased soil water content is found to reduce 1000hPa height by up to 12m. The shape of this surface heat low exactly corresponds to the associated temperature anomaly depicted in figure 2. The same effect, but opposite in sign, is found in the simulation with increased soil water (not shown). Figure 3 (right panel) shows that soil water not only affects pressure near the surface but equally in the mid-troposphere on 500hPa level. There the effect is reverse but of similar amplitude. The surface heat depression is associated with a positive 500hPa height anomaly aloft, covering roughly the same region. This positive anticyclonic height anomaly (DRY-CTL) reaches its maximum over the same region as the anomaly CTL-CLIM (not shown) observed in JJA 2003. Although the amplitude of the departure DRY-CTL corresponds to only 10-15% of CTL-CLIM, these findings suggest that a soil water reduction may enhance a positive height anomaly and possibly make it more persistent. Through this effect a dry soil anomaly might force a slight northward shift of the stormtracks. A similar effect has previously been observed in soil water experiments over North America by Oglesby and Erickson III (1989) and Pal and Eltahir (2003).

6. DISCUSSION AND CONCLUSION

The exceptionally high temperatures of the summer 2003 in Europe were initiated by anticyclonic atmospheric circulations that enabled a dominance of the local heat balance over the continent. Strong positive radiative anomalies and a large precipitation deficit in the months preceding the extreme summer event (Black et al. 2004) contributed to a rapid loss of soil water, which exceeded the multi-year average by far. The lack of moisture resulted in strongly reduced evapotranspiration and latent cooling during the 2003 heatwave (Ferranti and Viterbo 2005). The evaluation of the experiments with perturbed spring soil water shows that this quantity is an important parameter for the evolution of the European summer climate. Simulations indicate that moderate spring soil water anomalies may account for more than 2°C surface temperature differences during summer 2003. Moreover, negative soil water anomalies are revealed to influence the tropospheric circulation by forcing a surface heat low and strengthening the positive height anomaly in the mid-troposphere, pointing towards a positive feedback mechanism between surface conditions and atmospheric circulation.

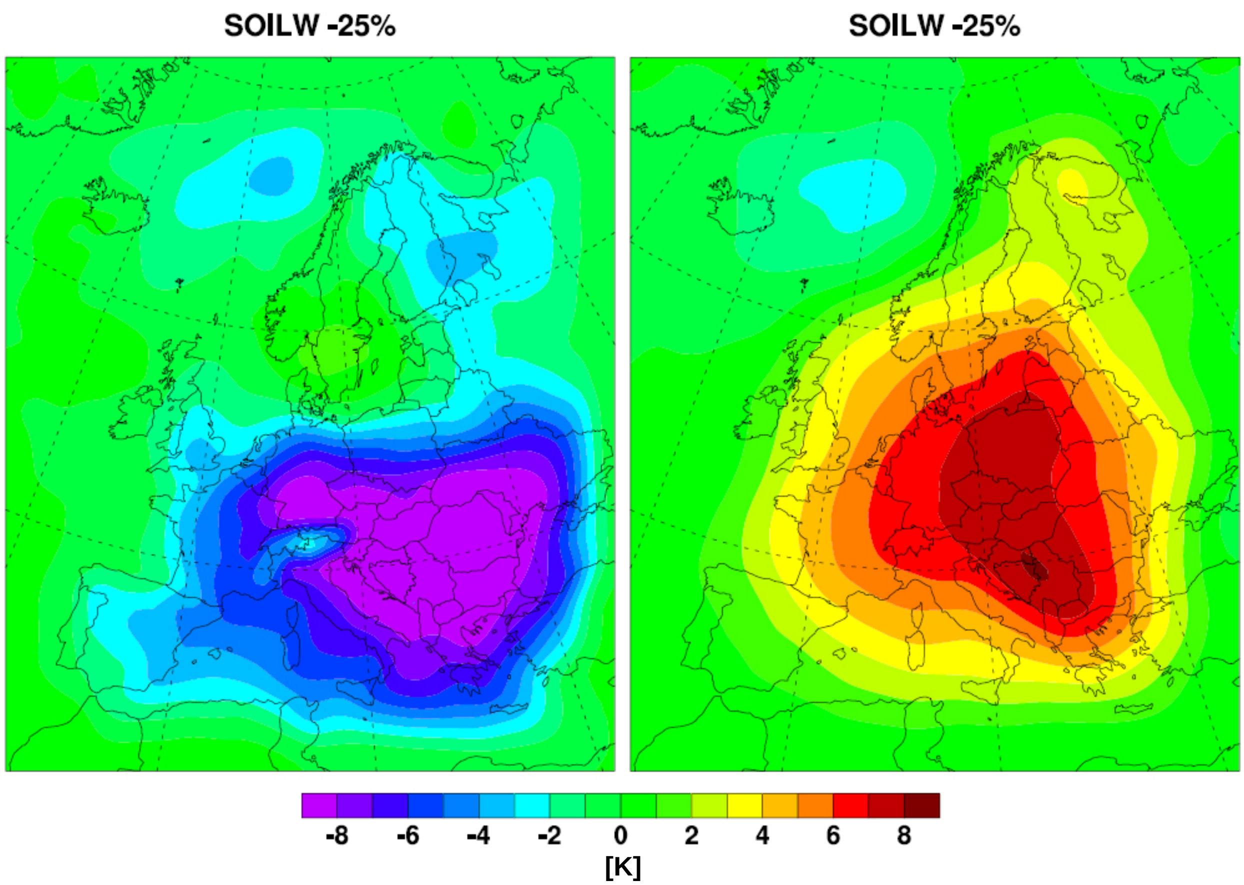

Figure 3: *Geopotential height anomaly due to soil water reduction represented by the simulated difference dry run wrt control run of the 1000hPa (fig. 3 left panel) and 500hPa lievel (fig. 3 right panel).*

7. REFERENCES

Schär, C., P. L. Vidale, D. Lüthi, C. Frei, C. Häberli, M.A. Liniger, C. Appenzeller, 2004: The role of increasing temperature variability in European summer heatwaves. *Nature*, **427**, 332 .

Luterbacher, J., D. Dietrich, E. Xoplaki, M. Grosjean, H. Wanner, 2004: European Seasonal and Annual Temperature Variability, Trends, and Extremes Since 1500. *Science,* **303**, 1499.

Schär, C. and G. Jendritzky, 2004: Hot news from summer 2003. *Nature,* **432**, 559–560.

Lüthi, D., A. Cress, H. C. Davies, C. Frei, C. Schär, 1996: Interannual Variability and Regional Climate Simulations. *Theor. Appl. Climatol.*, **53**, 185.

Vidale, P.L., D. Lüthi, C. Frei, S. I. Seneviratne, C. Schär, 2003: Predictability and uncertainty in a regional climate model. *J. Geophys. Res.,* **108**(D18), 4586.

Hansen, J., R. Ruedy, J. Glascoe, and M. Sato, 1999: GISS analysis of surface temperature change. *J. Geophys. Res.,* **104**, 30997–31022.

Hansen, J., R. Ruedy, M. Sato, M. Imhoff, W. Lawrence, D. Easterling, T. Peterson, and T. Karl, 2001: A closer look at United States and global surface temperature change. *J. Geophys. Res,.* **106**, 23947–23963.

Oglesby, R.J. and D.J. Erickson III, 1989: Soil moisture and the persistence of North American drought as simulated by the NCAR Community Climate Model 1. *J. Climate,* **2**, 1362?–1380.

Pal, J.S. and E.A.B. Eltahir, 2003: A Feedback Mechanism Between Soil Moisture Distribution and Storm Tracks. *Q. J. Roy. Meteor. Soc.*, **129** (592), 2279–2297.

Black, E., M. Blackburn, G. Harrison, and J. Methven (2004). Factors contributing to the Summer 2003 European heatwave. *Weather*, **59**, 217–223.

Ferranti, L. and P. Viterbo, 2005: The European summer of 2003: sensitivity to soil water initial conditions. *J. Climate*, submitted.

Fischer, E., S.I. Seneviratne, P.L. Vidale, D. Lüthi, M. Hirschi, and C. Schär, 2005: The 2003 summer heatwave and its sensitivity to soil water perturbations. In preparation.