Using RCMs for case studies of European temperature extremes

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From PhD

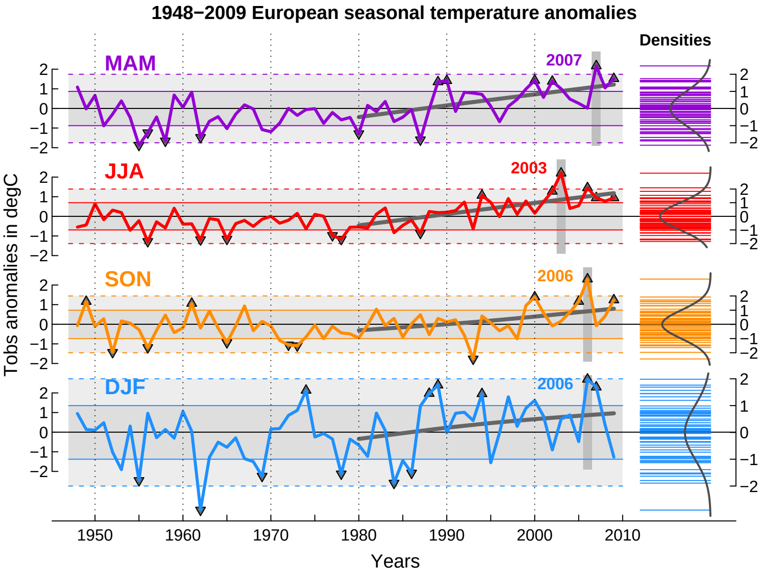
European temperature extremes: mechanisms & responses to climate change

Julien Cattiaux

PhD: LSCE (IPSL), with Robert Vautard & Pascal Yiou.
Jan 2011: CNRM/GMGEC/VDR (post-doc EUCLIPSE), with Hervé Douville.

March 28, 2011

European temperatures extremes?

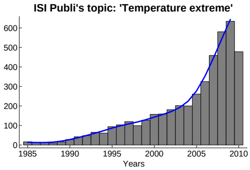


ECA&D stations

Summer 2003: the most popular case study

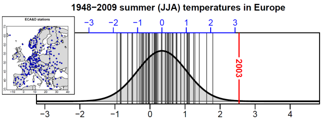
Summer 2003: public & scientific awareness.

- High impacts on societies & ecosystems.
- First *real* outlier: signature of climate change?



Understanding the summer 2003...

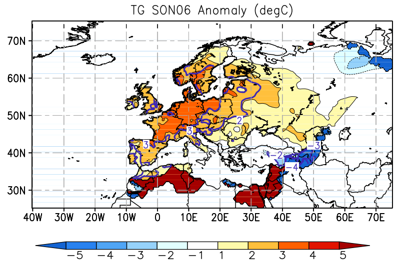
1. Statistical analysis:
   - How extreme? $+3.2\sigma$ (e.g., Beniston, 2004).
   - Associated features? Persistent anticyclonic blocking (e.g., Black et al., 2004).
   - Any idea why? Dry soils in early summer (e.g., Seneviratne et al., 2006)?
2. Model experiments: soil–atmosphere feedback (e.g., Vautard et al., 2007; Zampieri et al., 2009).
3. Future projections? amplification (e.g., Fischer and Schär, 2009).

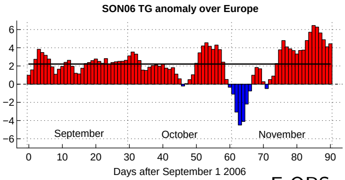


ECA&D stations

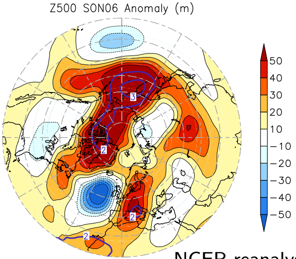
Autumn 2006

Autumn 2006: statistical analysis





E-OBS gridded



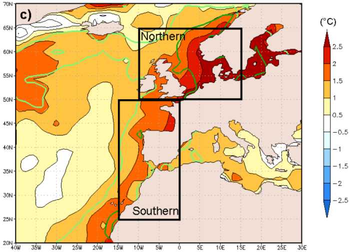
NCEP reanalysis

- $\Delta T \sim +2.3$°C $(+3.2\sigma)$ over Western Europe.
- $\Delta Z500$: persistent northerly flow (dipole L–H) $\Rightarrow \sim 50\%$ of the temperature anomaly.

(see also Beniston, 2007; Cattiaux et al., 2009; Luterbacher et al., 2007; Shongwe et al., 2009; van Oldenborgh, 2007; Yiou et al., 2007).

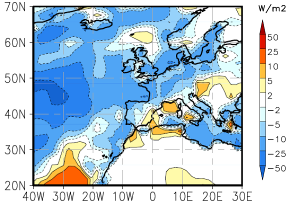
SST contribution to autumn 2006? Some stats

SON06 SST anomaly (NCEP)

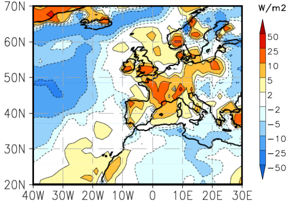


(Cattiaux et al., 2009)

SON06 LHd anomaly (NCEP)



SON06 SHd anomaly (NCEP)



Mechanism

1. Exceptionally warm North-Atlantic SST.
2. Increased LH & SH fluxes from ocean
   ⇒ warmer and wetter upper-air masses advected over the continent.

See also: M.E. Shongwe et al. (2009), Energy budget of the extreme Autumn 2006 in Europe, *Climate Dynamics*, pp. 1–12. DOI: 10.1007/s00382-009-0689-2

SST contribution to autumn 2006? RCM experiments

Model details (same as Vautard et al. (2007) and Zampieri et al. (2009))

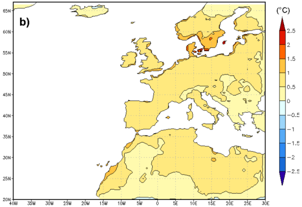
- MM5! ...RCM from NCAR/PSU, *aka* WRF's big brother.
- Non-hydrostatic, σ vertical coordinates, 32 vertical levels.
- Microphysics: Reisner 2, Cumulus: Grell, Boundary Layer: MRF, Radiation: RRTM (Mlawer), LSM: Noah (4 layers).
- Boundary conditions & nudging (when applied): ECMWF 4$\times$daily re-analyses.

Experimental set-up (Cattiaux et al., 2009)

- Runs over September – October – November 2006.
- Twin simulations, CTL & WNC, only differing from SST forcing (autumn 2006 vs climatological).
- Domain: Europe + North-Eastern Atlantic, Resolution: Mercator 0.5° ($\sim$51 to 21km).
- Large-scale dynamics nudged, not thermodynamical fields.

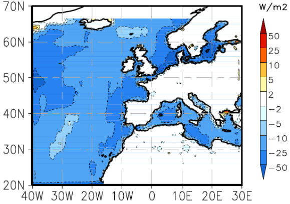
SST contribution to autumn 2006? RCM results

CTL−WNC T2m SON06

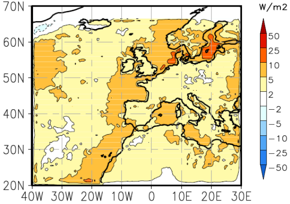


(Cattiaux et al., 2009)

CTL−WNC LHd SON06



CTL−WNC LWd SON06



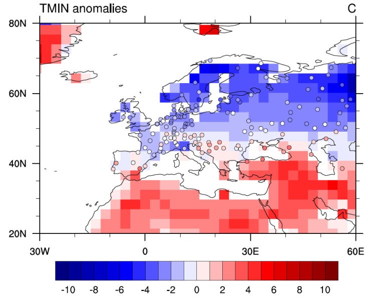
- ΔT2m response = 0.8°C ($\sim$ 30%), consistent with statistical estimate.
- Advected water vapor enhances local greenhouse effect, consistent with Shongwe et al. (2009).

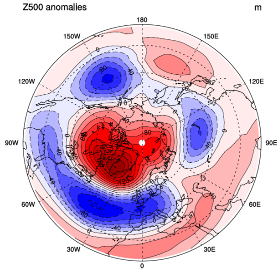
Limit

Difficulty to interpret sea–air fluxes in SST-forced experiments (Barsugli and Battisti, 1998).

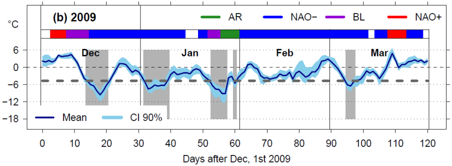
Winter 2009/10

Winter 2009/10: statistical analysis





ERA-Interim + ECA&D



Ouzeau et al., subm. GRL

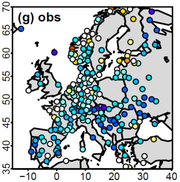
- $\Delta T \sim -1.3$°C (-0.9σ) over Western Europe.
- $\Delta Z500$: extremely persistent NAO−.

(see also Cattiaux et al., 2010; D'Arrigo et al., 2011; Seager et al., 2010; Wang et al., 2010).

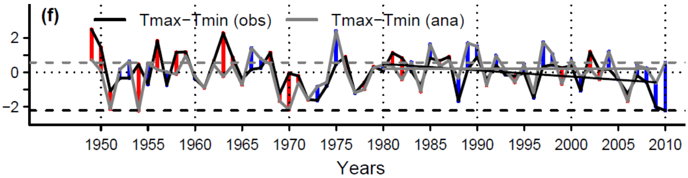
Snow contribution to winter 2009/10? Some stats

Not a temperature extreme... But! Record-breaking reduced diurnal range.

DJF Tx−Tn (ECA&D)

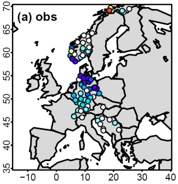


1949–2010 DJF Tmax−Tmin (Cattiaux et al., 2010)

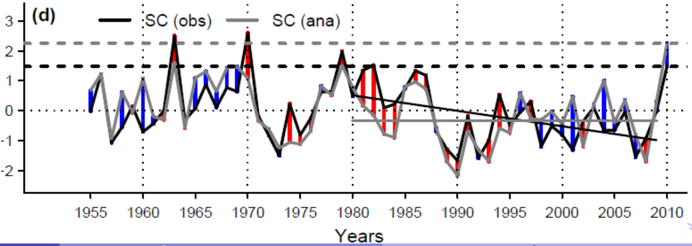


Associated with a positive anomaly of snow cover (only few stations...).

DJF Snow C (ECA&D)



1949–2010 DJF Tmax−Tmin



Snow contribution to winter 2009/10? RCM experiments

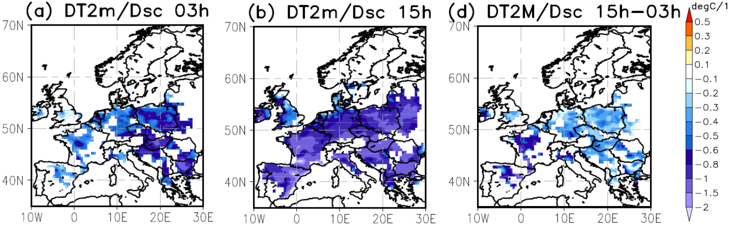
Model details (still the same. . .)

- MM5! . . . RCM from NCAR/PSU, *aka* WRF's big brother.
- Non-hydrostatic, σ vertical coordinates, 32 vertical levels.
- Microphysics: Reisner 2, Cumulus: Grell, Boundary Layer: MRF, Radiation: RRTM (Mlawer), LSM: Noah (4 layers).
- Boundary conditions & nudging (when applied): NCEP 4$\times$daily re-analyses.

Experimental set-up

- Runs from January 4 to January 28 of 2008, 2009 and 2010 (75 days).
- Twin simulations, CTL & TRS, only differing from ground-snow albedo (normal vs transparent).
- Domain: Western Europe, Resolution: Mercator 0.5° ($\sim$40 to 20km).
- Large-scale dynamics nudged, not thermodynamical fields.

Snow contribution to winter 2009/10? RCM results



Averaged linear fit:

$$\Delta\left(T2^{15h} - T2^{3h}\right) = \Delta T2^{15h} - \Delta T2^{3h} \sim -0.5\ SC^{CTL}$$

$\Rightarrow$ Extra snow cover contribution to the winter 2010 reduced diurnal temperature range: $\sim 10\%$.

Some limits (among others...)

- Only the albedo effect is taken into account.
- Poor observational dataset.

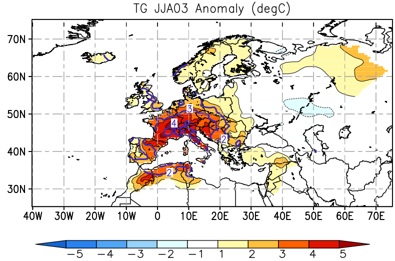
Concluding remarks

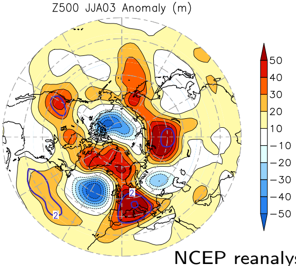
- Summer heatwaves: Northern propagation of soil moisture deficits in early summer.
- Autumn 2006: Advection of heat and water vapor from the anomalously warm North Atlantic ocean.
- Winter 2009/10: Minor contribution of extra snow cover to the unprecedented reduced temperature range.

- RCMs useful for investigating physical processes.
- Main limit of sensitivity tests: physics must be broken somewhere.
- Multi-model experiments needed for estimating uncertainties.
- Plausability of mechanisms assessed from observations.

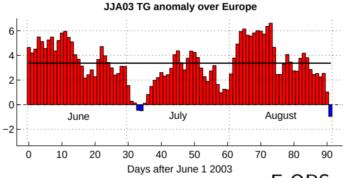
Thanks for your attention. Questions?

Summer 2003: statistical analysis





NCEP reanalysis

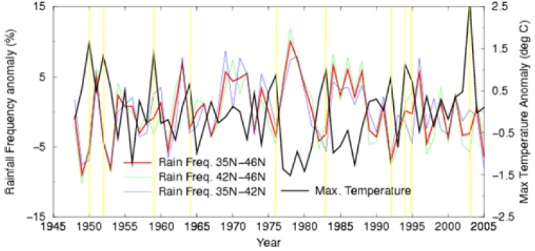


E-OBS gridded

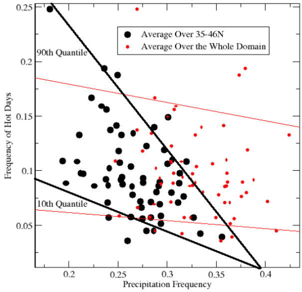
- $\Delta T \sim +3.4°C$ ($+3.6\sigma$) over Western Europe.
- $\Delta Z500$: persistent blocking.

(see also Beniston, 2004; Black et al., 2004; Cassou et al., 2005; Ferranti and Viterbo, 2006; Fischer et al., 2007; Stott et al., 2004; Trigo et al., 2005; Vautard et al., 2007, among others. . .).

Summer heatwaves need dry soils? Some stats



Vautard et al. (2007)



Vautard et al., pers. comm.

- Summer heatwaves preceeded by rainfall deficits (overall $r \sim 0.55$).
- Wet $\Rightarrow$ few hot days / Dry $\Rightarrow$ surprise!

(see also Black et al., 2004; Ferranti and Viterbo, 2006; Fischer et al., 2007; Hirschi et al., 2010; Zampieri et al., 2009, among others. . .).

Summer heatwaves need dry soils? RCM experiments

Model details

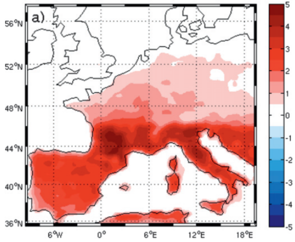
- MM5! ...RCM from NCAR/PSU, *aka* WRF's big brother.
- Non-hydrostatic, σ vertical coordinates, 32 vertical levels.
- Microphysics: Reisner 2, Cumulus: Grell, Boundary Layer: MRF, Radiation: RRTM (Mlawer), LSM: Noah (4 layers).
- Boundary conditions & nudging (when applied): ECMWF or NCEP 4×daily re-analyses.

Experimental set-up (Vautard et al., 2007; Zampieri et al., 2009)

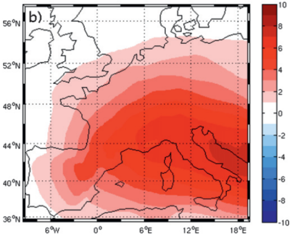
- Selection of the 10 hottest summers over 1948–2003 (Vautard et al., 2007).
- Runs initialized at June 1, ending at August 7 of each hot summer.
- Twin simulations, WET & DRY, initialized with climatological $\pm 1\sigma$ soil moisture south of 46°N.
- Domain: Western Europe, Resolution: Lambert 36km.
- No nudging applied.

Summer heatwaves need dry soils? RCM results

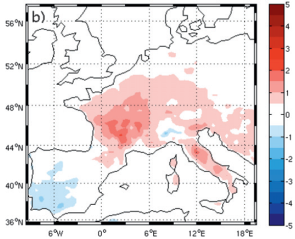
DRY−WET T2m June/July



DRY−WET Z500 June/July



DRY−WET T2m July−June



(Zampieri et al., 2009)

Mechanism

1. Higher SH fluxes ⇒ local warming.
2. Limited LH fluxes ⇒ drier air (less clouds).
3. Lesser convection ⇒ upper-air anticyclonic circulation.

(see also Ferranti and Viterbo, 2006; Vautard et al., 2007, among others).