Scientific Report – ESF Exchange Grant

Reference Number: 1464

Activity Title: Mediterranean Climate Variability and Predictability (MedCLIVAR)

Project Title: Regional Impact of Global Warming over Climate Extremes using Dynamical Downscaling and Regional Climate Models

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1. *Purpose of the visit*

Climatologists have been aware of the anthropogenic contribution to current global warming only over the last decades. According to Working Group I of the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), globally averaged net effect (warming minus cooling impacts) of human activities since 1750 have warmed Earth surface equivalently to a radiative forcing of 1.6 Wm^{-2}. As a consequence of that, 11 of the last 12 years (1995-2006) have been the warmest since instrumental record (IPCC, 2007).

In addition to these anthropogenic changes in mean temperatures (Katz and Brown, 2004), other climate anomalies are expected for the present century. Spatial and temporal changes in climate variability at shorter frequencies are expected to have larger negative impact over many vulnerable aspects of human health (Pan et al., 1995) and social organization (Kunkel et al., 1999). Therefore, increasing attention to climate extremes have been paid for the lasts years (Zhai et al., 1999; Kharin and Zwiers, 2000; Easterling et al., 2000).

According to projections for the 21st century using SRES (Special Report on Emissions Scenarios) scenarios, it is very likely (probability > 90%) that frequency of heat waves increases over most of land areas and it is virtually certain (probability > 99%) that warmer and more (less) frequent hot (cold) days and nights over most land areas happen in the future (IPCC, 2007). However, climate uncertainties linked to scenario emissions and to changes in dynamical processes are still too large.

All these IPCC climate change anomalies are estimated from global climate models. Therefore, the local-to-regional scale impact of climate extremes is poorly simulated. For example, although the unprecedented 2003 European heat wave (Schär et al., 2004; Levinson and Waple, 2004; Beniston and Diaz, 2004) was associated to a large scale dynamical process, high spatial resolution is essential in order to describe local impacts over the population. For example, good spatial resolution is necessary to confirm prerequisites for the heat wave (Stott et al., 2004) such as negative anomalies of soil moisture (Brabson et al., 2005) and air humidity (Black et al., 2004).

The main purpose of this work is the local-to-regional description of the expected climate change impact over regional extremes. As climate change projections from global models are still calculated at a relatively poor spatial resolution, regional models are still required for local-to-regional climate change estimations. Thus, climate change impact over surface temperature extremes at a regional scale is studied in the present work. Anomalies have been calculated from the last third of the 20th ("present time") and 21st ("future time") centuries. Expected values of gas emissions have been taken from two different scenarios (B2 and A2) from a dozen of regional climate models.

2. *Description of the work carried out during the visit*

2.1. Data

Model data from the PRUDENCE project (Kjellström et al., 2007) was used for the analysis. Several variables at the daily resolution were analysed from this dataset:

Maximum (TMAX), Mean (T2M) and Minimum (TMIN) Temperature, Sea Level Pressure (SLP), Soil Moisture (SM), Cloudiness (CLOUD), Precipitation (PREC) and Evaporation (EVAP). The ensemble of simulations from this dataset is made up of a dozen of regional climate models for the European region. Climate change anomalies were calculated from simulations for the control period (CTL, 1961/1990) and for two scenarios (B2 and A2, 2071/2100). High-resolution temperature observations from the ENSEMBLES project (Haylock et al., 2007) were used for the validation of heat waves and cold spells.

2.2. Methods

The present and future occurrence of warm and cold days is described in Section 3.1. In this part of the work, T2M was detrended for every simulation of each model. Several percentiles (from P_{50} to $P_{99.99}$ for warm days and from P_{50} to $P_{0.01}$ for cold days) were calculated for each grid point of the CTL simulation. For each grid point, warm (cold) tail days of CTL, B2 or A2 were then defined as days in which temperature from CTL, B2 or A2 reaches the CTL percentile. The intrannual variability of this occurrence was calculated for each grid point and this seasonal variability was averaged for each continental grid point in Central Europe and then for each model.

In Section 3.2, changes in regional heat waves (cold spells) are studied. Regional warm (cold) extreme days and regional heat waves (cold spells) were determined as follows. Firstly, TMAX (TMIN) was detrended and percentile P_{99} (P_1) was calculated for each grid point. A regional index of heat waves (cold spells) was then calculated:

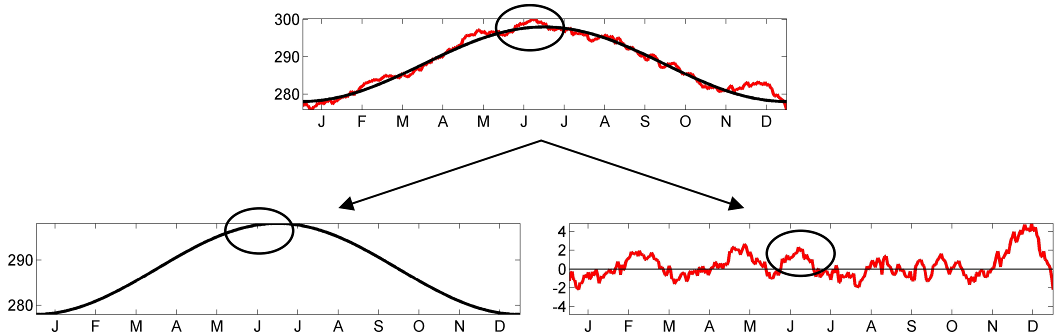
$$Heat\ Wave\,(t) = \sum_{(x,y)\in continent} max\left\{0, TMAX\,(x,y,t) - P_{99}^{TMAX}\,(x,y)\right\}\cdot latitude(y)$$

$$Cold\ Spell\,(t) = \sum_{(x,y)\in continent} max\left\{0, P_{1}^{TMIN}\,(x,y) - TMIN(x,y,t)\right\}\cdot latitude(y)$$

These regional indices integrate for every continental grid point in Central Europe (see the central small box in Figures 4 to 6) the magnitude of exceedance of Temperature above (below) the local P_{99} (P_1) percentile. Finally, percentile P_{99} of these regional indices was calculated in order to determine those days of each time period with local extreme conditions in most of the region. These days will be referred here as regional warm (cold) extreme days. Similarly, a regional heat wave (cold spell) was defined as a set of at least 5 consecutive regional warm (cold) extreme days.

Once regional extreme days and events were determined, original anomalies from all the variables were detrended and decomposed in two terms (Figure 1): the mean annual cycle and the interannual residual. Both terms were averaged for the set of regional extreme days found in the previous paragraph. On the one side, the average of the annual cycle for the extreme days indicates the "normal" summer conditions that occur during the summer (winter) peak, when heat waves (cold spells) usually take place. On the other side, the mean of the residual for the set of extreme days represents the mean anomaly above (below) the "usual" summer (winter) conditions of regional warm (cold) extreme days. From now on, the average of the first term for the set of regional extreme days will be referred as base summer (winter) conditions (AC), and the mean of the second term as extreme anomalies (EX).

$$f(x,y,t) = AC_f(x,y,day) + EX_f(x,y,t)$$



$$AC(x,y) = \frac{1}{n} \sum_{extreme\ days} AC_f(x,y,day) \qquad EX(x,y) = \frac{1}{n} \sum_{extreme\ days} EX_f(x,y,t)$$

Figure 1. Decomposition of detrended anomalies in two terms: (i) the base summer or winter conditions (AC) and (ii) extreme anomalies (EX).

3. *Description of the main results obtained*

3.1. Intrannual variability of tail day occurrence: validation and scenarios

The occurrence of warm and cold tail days was firstly validated for a set of 12 percentiles (Figure 2). As a general rule, the intrannual variability of warm tail days is better simulated than for cold tail days. On the one hand, for almost all the days of the year, the observed occurrence of warm tail days lies within the ensemble range defined by the dozen of models (not shown). However, models tend to generate too few (many) warm tail days in early (late) summer, which delays the simulated annual cycle of tail day occurrence with respect to observations. On the other hand, larger and more important problems are found for cold tail days. Large negative biases appear in the cold peak of the year, which implies that too few (many) cold days are simulated in January (early and late winter).

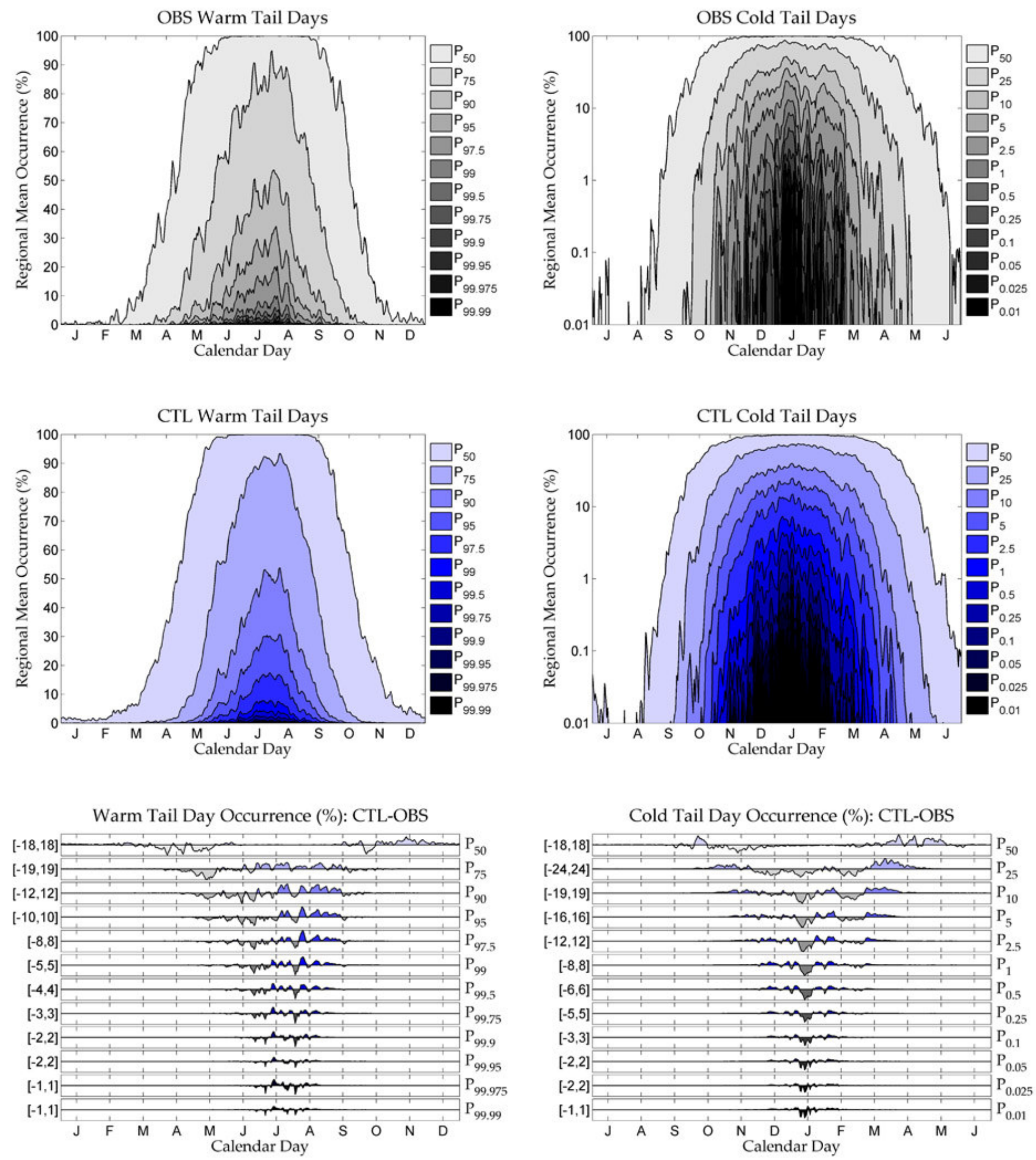


Figure 2. Intrannual variability of warm (left) and cold (right) tail day occurrence (%) as a function of the percentile used for its definition. From top to bottom, observations (OBS, in grey), the control simulation (CTL, in blue) and the model bias (CTL–OBS).

Concerning climate change, large anomalies are forecasted for the end of the 21st century, especially for the most extreme percentiles. For example, 36% (47%) of future July and August days will be warmer than percentile P_{99} in the CTL simulation, which is the threshold normally used for the definition of extreme days or events. Relative changes are even larger for the most extreme percentiles. For example, 8% (16%) of future July and August days will be warmer than percentile $P_{99.99}$ in the CTL simulation. Notice that in a 30 year simulation there are around 10000 days, so $P_{99.99}$ represents the warmest day in the control simulation.

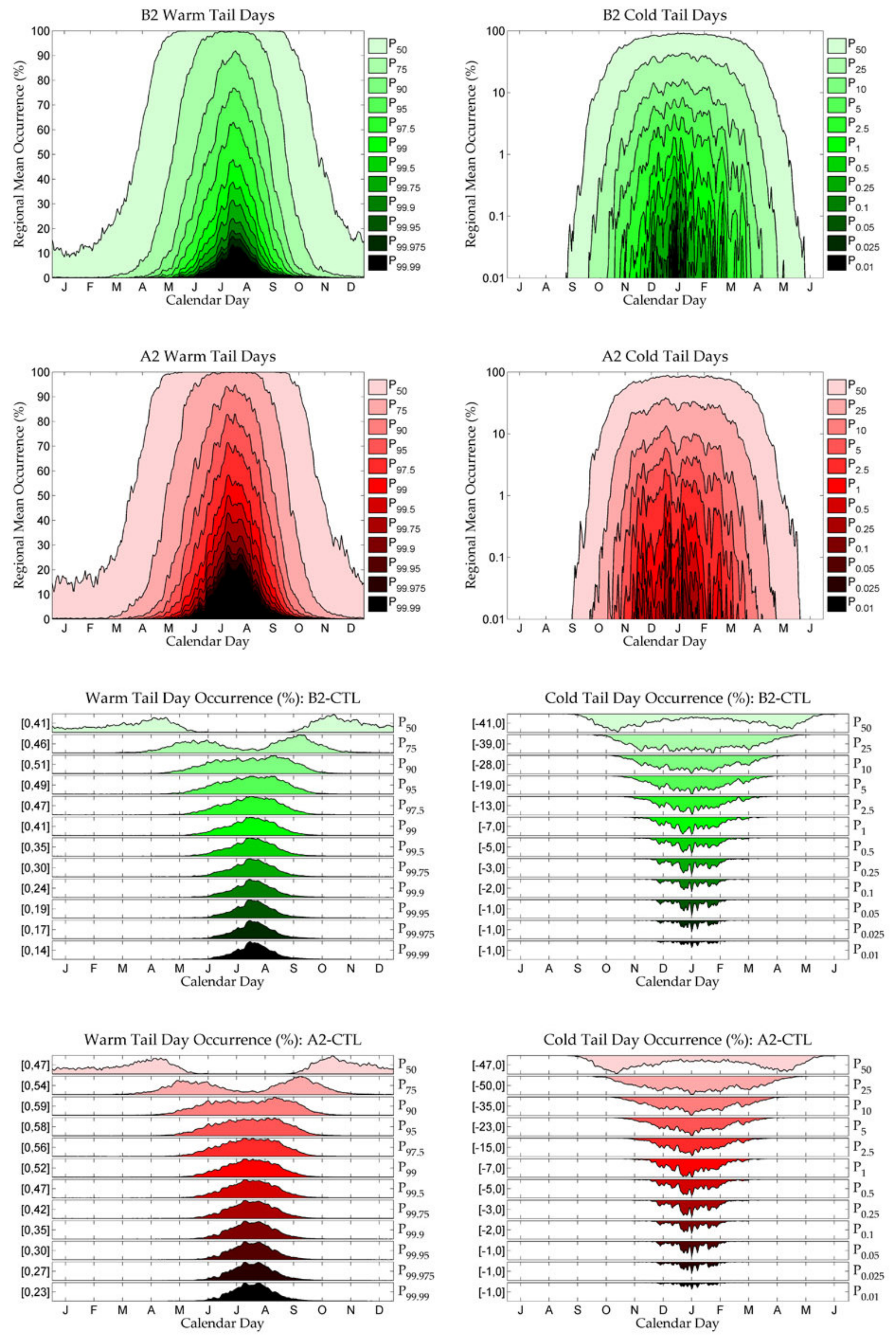


Figure 3. Intrannual variability of warm (left) and cold (right) tail day occurrence (%) as a function of the percentile used for its definition. From top to bottom, forecasts for B2 (in green) and A2 (in red) and climate anomalies (Scenario–CTL) for B2 (in green) and A2 (in red).

On the other hand, cold tail days will almost disappear. Plots in Figure 2 were displayed in a semi-logarithmic scale in order to highlight the lower values in the future climatology. Large reductions are expected for all the percentiles, but decreases relative to the current climatology are larger for the largest percentiles. Indeed, the most extreme percentiles will definitely disappear. Percentile normally used for the definition of extremes (P_1) will not completely disappear, but it will only occur once every 2 (4.5) years in the B2 (A2) scenario.

3.2. Regional Extremes

As in the previous section, simulations were firstly validated (Figure 4). In general terms, most of the main properties of heat waves and cold spells are correctly simulated: size, shape and intensity. However, heat waves (cold spells) are slightly shifted to the southeast (east) in the simulation. Although this shift generates moderate bipolar biases, they cannot be attributed to an overestimation or underestimation of these events.

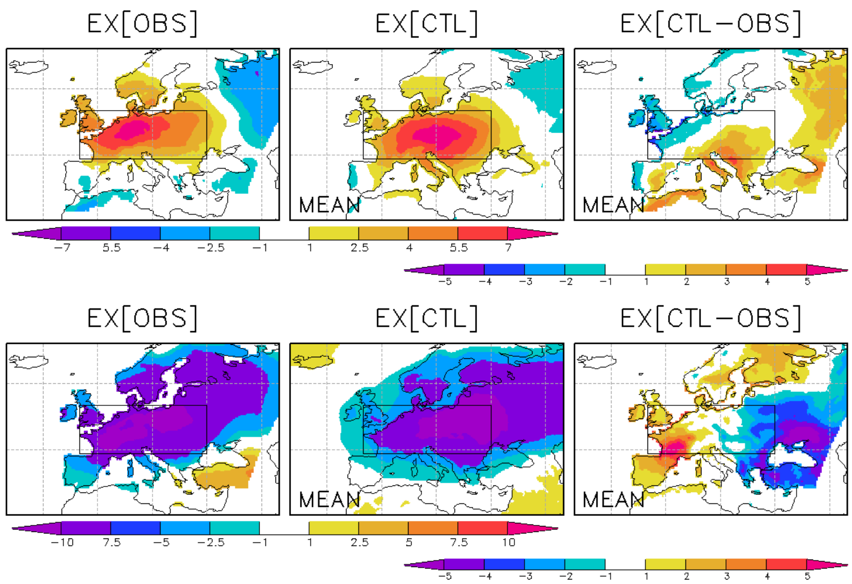


Figure 4. Validation of extreme anomalies (EX, in K) for regional TMAX heat waves (top) and TMIN cold spells (bottom). From left to right, observations (OBS), the control simulation (CTL) and the model bias (CTL–OBS).

Forecasted changes in heat waves and cold spells for Central Europe are shown in Figures 5 and 6. When only extreme anomalies (EX) are analysed, small positive changes or even negative anomalies are found in Central Europe. This implies that interannual anomalies linked to regional extreme days will not largely change. When base summer conditions (AC) are added to extreme anomalies (EX), only positive anomalies can be observed. Therefore, the increase of heat wave intensity must be mainly attributed to warmer summer temperatures and not to changes in dynamics of extremes.

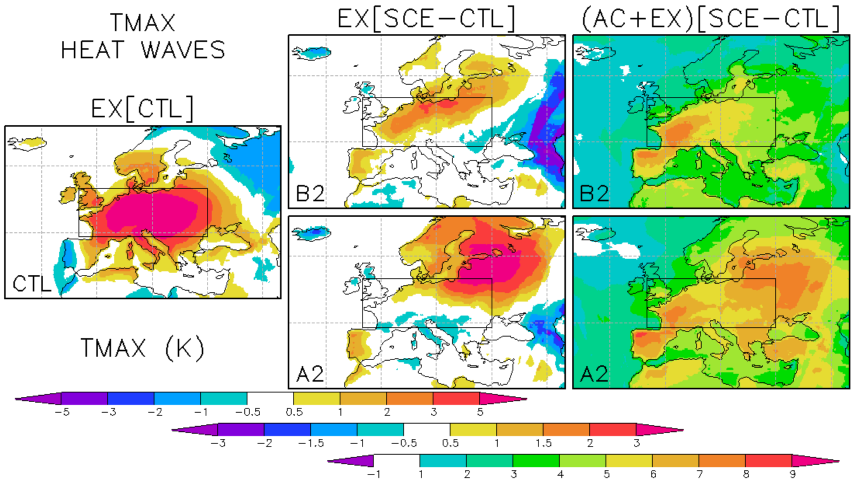


Figure 5. (Left) Extreme anomalies (EX, in K) in the control simulation (CTL). (Centre) Changes in extreme anomalies (EX, in K) for scenarios B2 (top) and A2 (bottom) relative to the control simulation.
(Right) Changes in base summer conditions (AC, in K) plus extreme anomalies (EX, in K) for scenarios B2 (top) and A2 (bottom) relative to the control simulation.

Conclusions for cold spells are different. Changes in extreme anomalies (EX) for Central Europe are larger for cold spells than for heat waves. However, changes in base winter conditions (AC) of cold spells are of the same order of magnitude than changes in extreme anomalies (EX). Therefore, the weakening of Central Europe cold spells as a consequence of climate change may be approximately attributed to the same degree to changes in winter base conditions and to changes in dynamics of extremes.

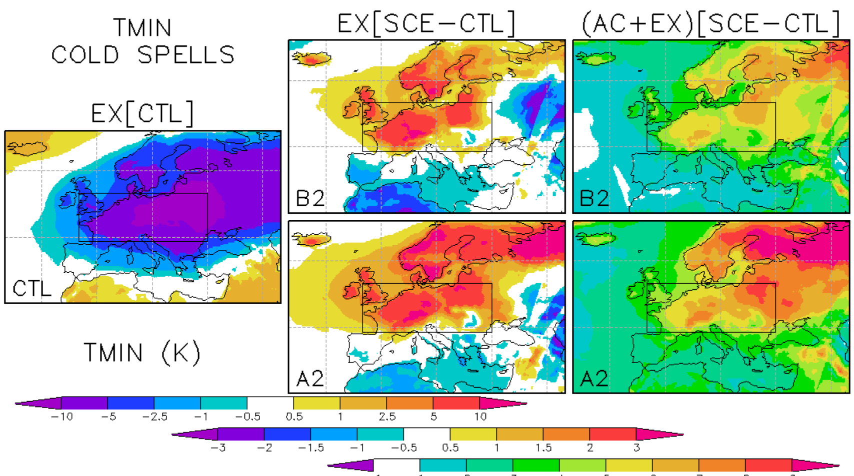


Figure 6. Same as Figure 5, but for TMIN cold spells.

4. *Projected publications/articles resulting or to result from your grant*

A paper to a major peer-reviewed journal is currently written, including these and other results.

5. *Other comments*

Model data have been provided through the PRUDENCE data archive, funded by the EU through contract EVK2-CT2001-00132. I also acknowledge the observed climate dataset from the EU-FP6 project ENSEMBLES.

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