Understanding the 2003 and 2010 heat waves
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1. Introduction
Both 2003 and 2010 heat waves had dramatic consequences on the surrounding populations and none of those extreme events has been predicted in advance. Moreover, results of attribution studies seem to suggest that this kind of heat waves are more likely to occur in the future due to climate change. Thus, to be able to adapt and mitigate the effect of such heat waves, decision makers need a reliable and anticipated prediction of this kind of events.

In the present study, we demonstrate that those heat waves were predictable up to 4 months in advance. This allows us to investigate the mechanisms underlying the occurrence of the heat waves and especially the role of dry soil moisture initial conditions, which has been suggested to be a crucial factor for the occurrence of both heat waves.

2. Model and data
In order understand the role of soil moisture in initial condition in 2003 and 2010 heat waves we compare two sets of hindcasts:

<table>
<thead>
<tr>
<th>model</th>
<th>Period</th>
<th>Start dates</th>
<th>Land IC</th>
<th>Atm IC</th>
<th>Oce/Ice IC</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC-Earth 2.3 \textsuperscript{(T106-ORCA1)}</td>
<td>1981-2010</td>
<td>May, June, July, August</td>
<td>ERA-Land</td>
<td>ERA-interim</td>
<td>ORA-S4</td>
</tr>
</tbody>
</table>

We use ERA-interim to validate 2m-temperature (T2m) and soil moisture.

3. Were 2003 and 2010 heat waves predictable?

Observed Anomalies

- a) T2m: ERAInt
- b) T2m: CLIM
- c) T2m: INIT

Forecast Initialized in May

- (odds ratio)
- (top) French, 2003; middle and bottom: Russia, 2010. The stars show the observed anomalies and the number above: the quartile corresponding to this anomaly. The box-and-whisker plots show the distribution of the anomalies for the members of the 2 simulations (left of the star: CLIM, right of the star: INIT).

- The 2003 heat wave seems to be predictable 4 months in advance even without the realistic soil initialization.
- Cold Anomalies in Eastern Europe in 2003 are predicted only when the soil is initialized.
- The 2010 heat wave is predicted by the model 4 months in advance but only when the soil is properly initialized.

4. How does the predictability evolve with the start date?

- Detrended monthly anomalies of T2m (top and middle) and soil moisture averaged in the box represented on the previous figure (top: France, 2003; middle and bottom: Russia, 2010). The stars show the observed anomalies and the number above: the quartile corresponding to this anomaly. The box-and-whisker plots show the distribution of the anomalies for the members of the 2 simulations (left of the star: CLIM, right of the star: INIT).
- In black the simulations initialized in May, blue: June, red: July, green: August.
- Realistic soil moisture initialization improves the prediction of the 2010 heat wave, especially for simulation initialized in May and August.
- Simulations initialized in June and July generates dry soil moisture anomalies in July, probably because of successful prediction of the circulation in June and July.

5. Conclusion
Seasonal hindcasts produced with EC-Earth2.3 are able to predict the 2003 and 2010 heat waves up to four months in advance.

The 2003 heat wave seems to occur independently of the soil conditions.

For the 2010 heat wave, the dry condition of the soil at the beginning of August are necessary to reproduce the event.

\textsuperscript{1} For more on the SPECS project: http://www.specs.bsc.es
\textsuperscript{2} For more on the PREFACE project: protacc.bsc.es