Blocking-related extreme weather events in the LMDZ4 atmospheric model: Sensitivity to model resolution

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Background and aim

In the mid-latitudes, extreme weather events are often caused by persistent and quasi-stationary weather regimes, such as blocking. As a result, a realistic representation of this phenomenon in climate models is essential in order to provide credible projections of climate change scenarios. This study examines the ability of the AGCM LMDZ4 (IPSL,France) to simulate winter atmospheric blocking and its relationship with temperature and precipitation extremes in the Europe.

Model configuration

It consists of an interactive coupling (also referred to as two-way nesting) between a global climate model ("MASTER", 300 km) and a regional climate model ("SLAVE", 100 km over Europe), where both models run in parallel with an exchange of information (atmospheric temperature and circulation) every two hours. This information is then recorded every 6 hours, and used to force a higher resolution regional model ("REGIONAL", 20 km over France).

Data and method

- Atmospheric blocking within the European sector (15°W-30°E) is analysed using MASTER. A modified version of the Tibaldi and Molteni (1990) blocking index, which measures the strength of the average westerly flow in the mid-latitudes, is applied to daily 500 hPa geopotential height output. Model performance in reproducing the frequency, persistence and circulation signature, is analysed and compared with the re-analysis data ERA-40.
- SLAVE and REGIONAL are used to analyse blocking-related extreme weather events, and model results are compared with the gridded observation dataset E-OBS. This analysis considers the intensity, frequency and persistence of extremes, using a set of moderate to strong percentile-based threshold indices and statistical diagnostic tools (deescribed in the Figure' captions below).

Blocking statistics

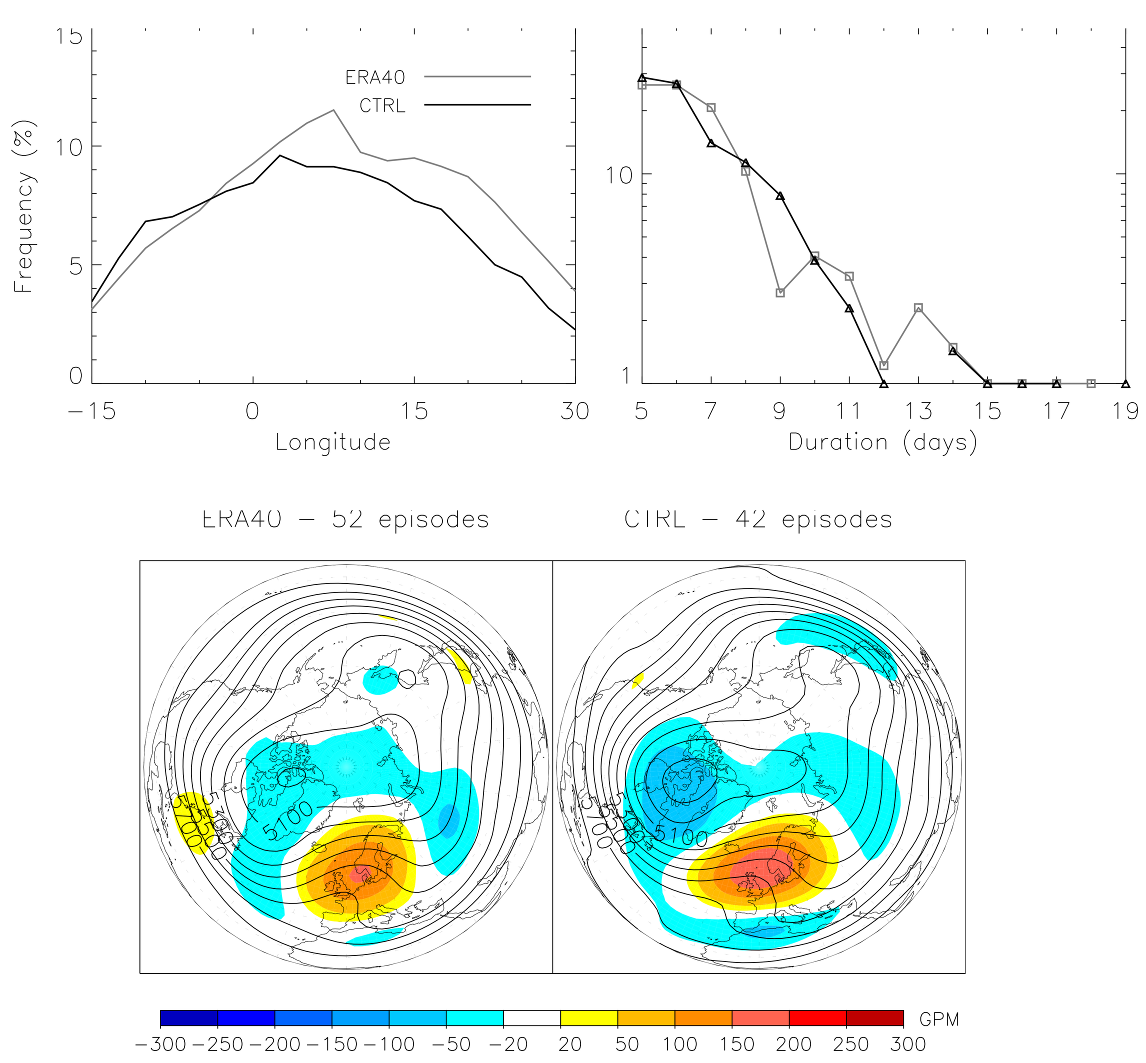
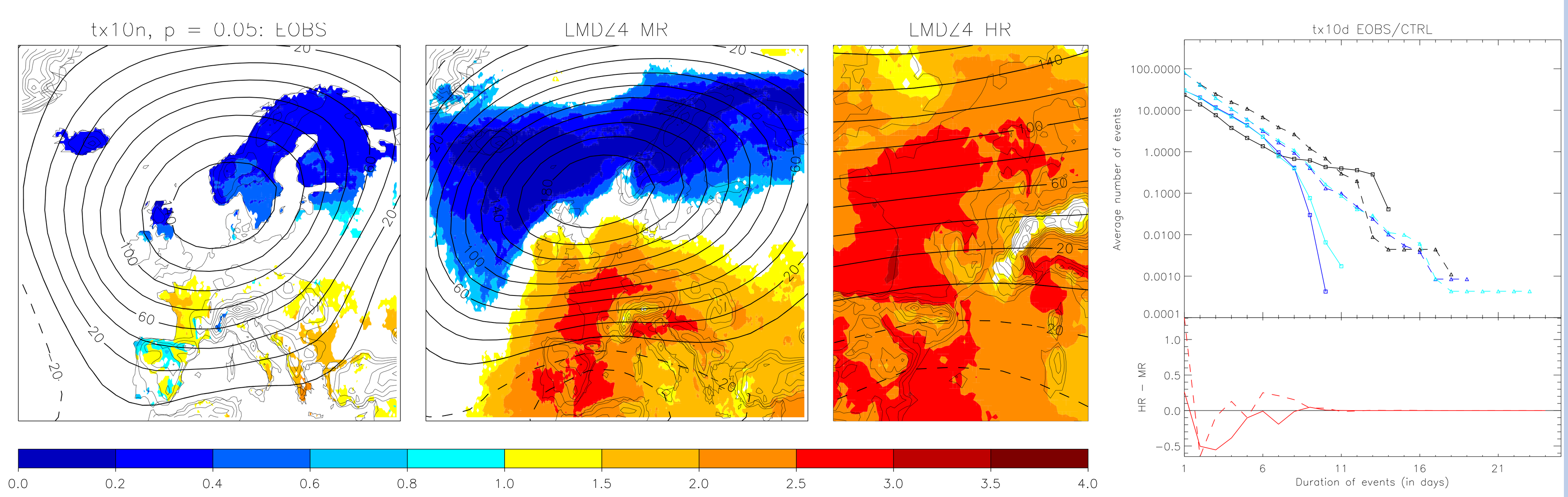


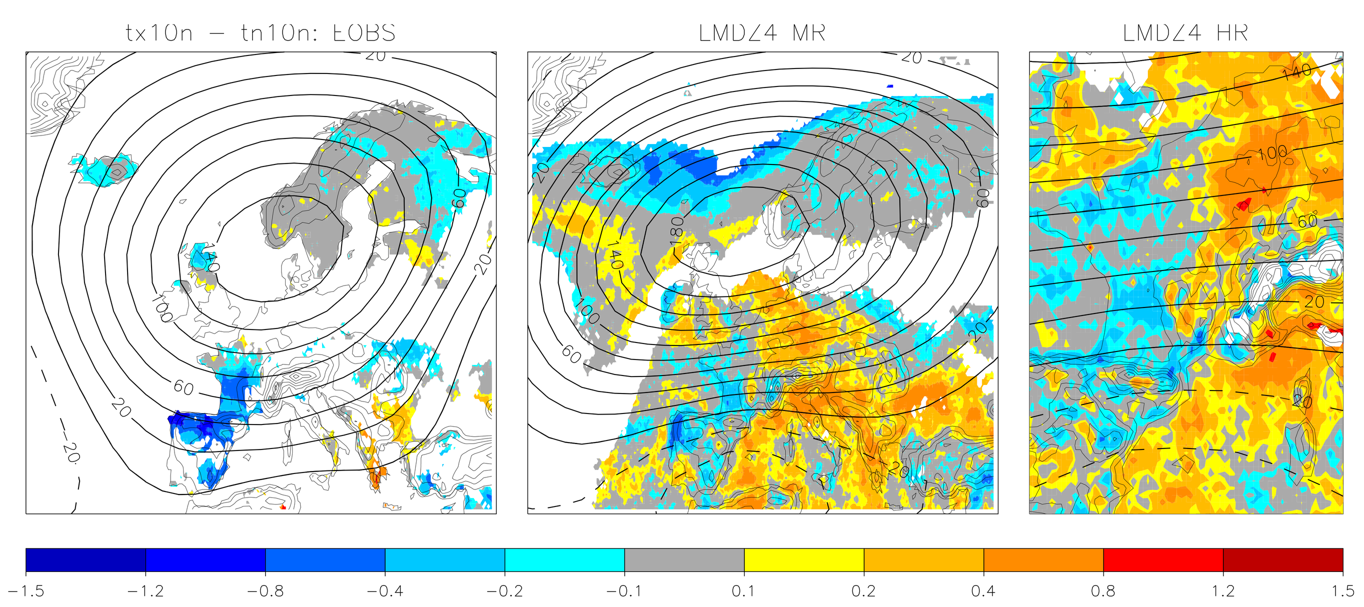
Figure: Frequency (top left), persistence (top right) and signature (bottom) of European blocking episodes.

Blocking frequency is relatively well simulated by the model, although slightly underestimated over the eastern part of the domain (20% on average). The average duration of blocking episodes is slightly underestimated (7.7 days for LMDZ vs 8 days for ERA-40), although the model tends to produce more long-lasting blocks than in the re-analysis.

The 2-way nesting over Europe improves considerably the frequency and persistence of blocking episodes over this region, mainly because of a more realistic stationary wave pattern. It is also responsible for an increase in the average geopotential height anomaly of the blocking high, and a westward extention of the signature.

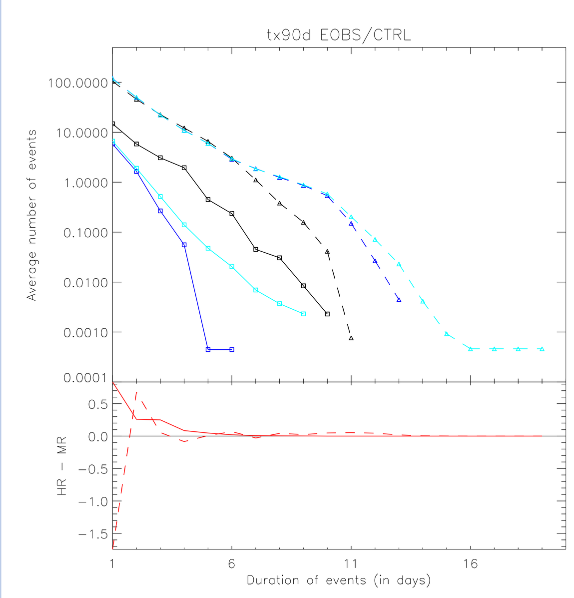
Cold days & nights

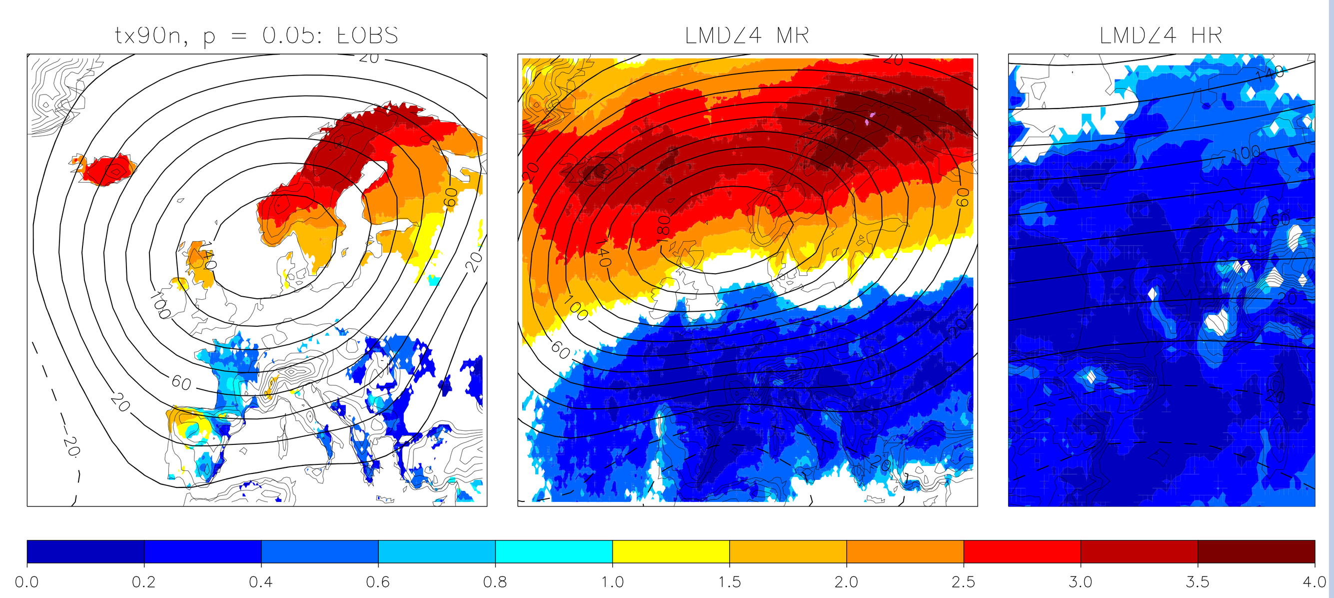




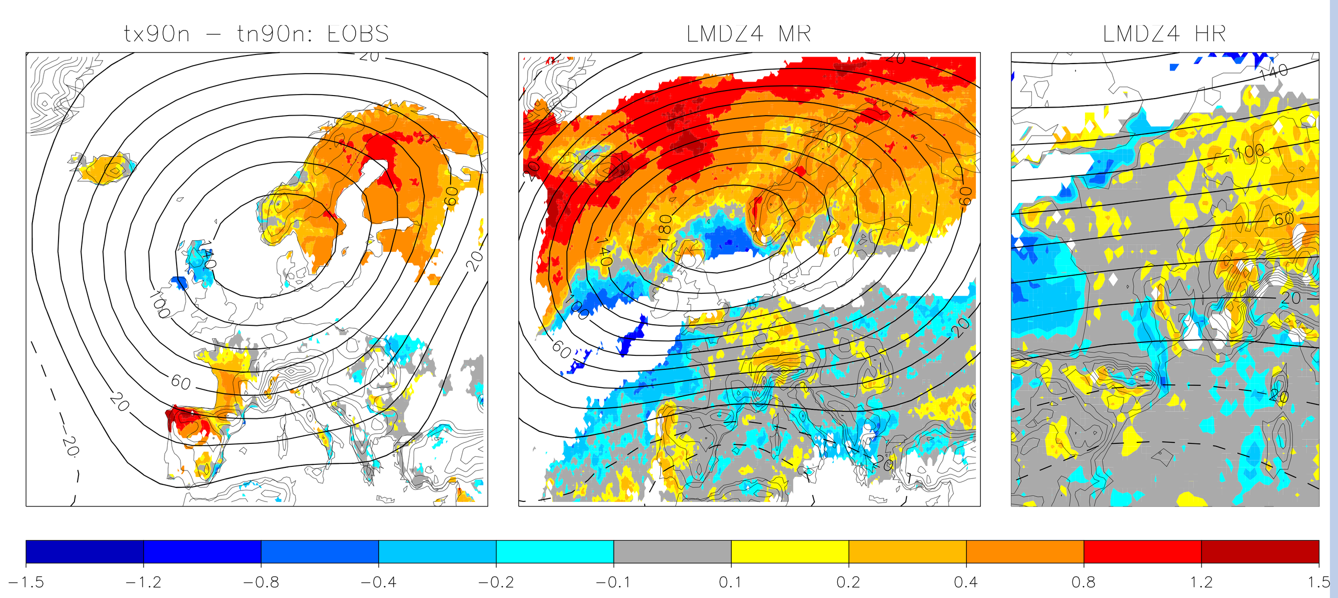
Map Figures: EOBS (left), SLAVE (MR, middle), REGIONAL (HR, right). **Top:** Relative contribution of blocking to extreme frequencies with respect to average conditions (R): If $R > 1$ ($R < 1$), the contribution of blocking to extremes is greater (lower) than average. **Bottom:** Difference between day and night.

Warm days & nights

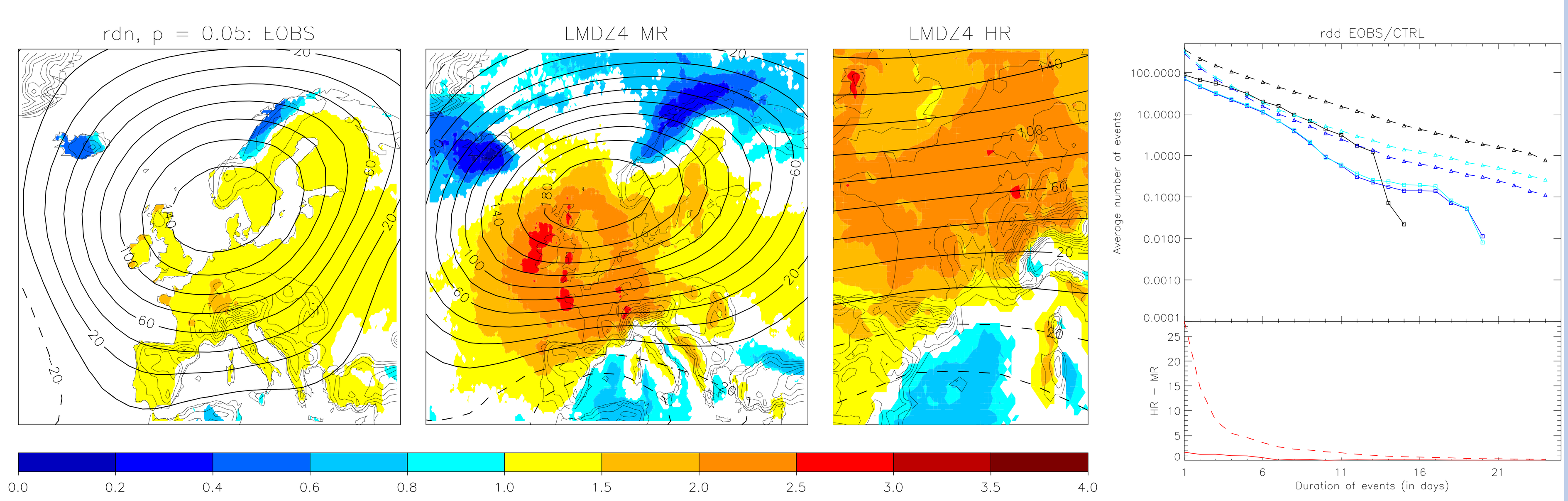




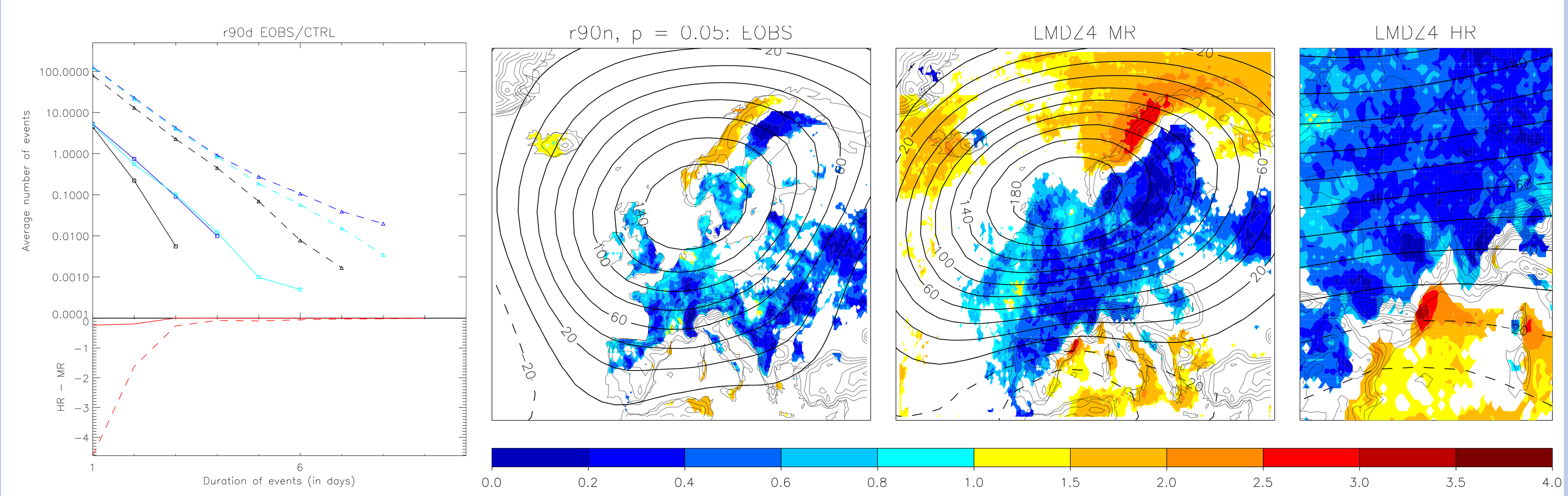
Line plot Figures: EOBS (black), SLAVE (MR, blue), REGIONAL (HR, cyan): Averaged number of extreme events as a function of spell duration over France, for blocked (solid lines) and non-blocked (dashed lines) situations independently. The red curves in the lower panels are the differences (HR - MR) for blocked and non-blocked regimes.



Dry days



Wet days



Conclusion

- **Observed blocking impact on extremes**

  During European blocking, northern Europe (above 55°N) experiences more warm and wet (less cold and dry) extreme weather conditions, due to the anomalous advection of air from southern Atlantic ocean over Scandinavia. On the other hand, anomalously cold and dry continental air from northern countries is advected, and brings more cold and dry (less warm and wet) extremes over southern parts of Europe (below 55°N).
  The likelihood of extremes during blocked situations seems to increase with extreme intensity and persistence.
  The contribution of blocking on cold (warm) extremes tends to be greater during the night (day). This is due to larger anomalies in outgoing than incoming radiation over most of Europe.
  Blocking-related extreme weather events seem to be primarily caused by anomalies in temperature and moisture advection. The latter being also responsible for anomalies in the radiative budget (advection of clouds), modify the diurnal temperature range.

- **Simulated blocking impact on extremes**

  For all extremes, the contribution of blocking to extremes with respect to average conditions (whether it is positive or not) is overestimated, and increases with the intensity of extremes. Systematic errors ($LMDZ - EOBS$) increase with the intensity of extremes, particularly where the impact is positive (more extremes). Two possible reasons for this overestimated impact:
  - Blocking episodes are more intense and persistent (advective winds are stronger and more persistent)
  - The average gradient between where the anomalous advection of air originate and the region experiencing the anomalous weather condition is overestimated (the advection term - $\nabla\Psi$ - is overestimated).

  Anomalies in daily temperature range seem to be underestimated, particularly over southern parts of Europe. This is due to underestimated anomalies in outgoing radiation (problem with clouds at high and medium levels).

- **Impact of model resolution**

  The model performance is slightly better at higher resolution, due to higher spatial and temporal small-scale variability in the latter (more surface inhomogeneities, sharper topography perhaps cause better resolved mixing and turbulences in the boundary layer). Differences between the high and low resolution simulations are greater during non-blocked than blocked situations for both temperature and precipitation extremes. This suggests that, the difference in model resolution is less important, due to the persistent quasi-stationary feature of blocking, during which small-scale variability processes are less prominent. However, the performance of the model in simulating blocking-related extreme weather events is highly related to its performance in simulating blocking (frequency, persistence, intensity, location), and also depends on the parameterized physics of the model (e.g. clouds).

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