SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2020
Project Title:	REsolved orography impact on the mid-latitude FlOw with ECEarth (REFOrgE)
Computer Project Account:	spitdav2
Principal Investigator(s):	Paolo Davini
Affiliation:	Istituto di Scienza dell'Atmosfera e del Clima, Consiglio Nazionale delle Ricerche (CNR-ISAC)
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Dr. Irina Sandu (ECMWF)
Start date of the project:	01/01/2019
Expected end date:	31/12/2021

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	29.5 millions	28 millions	30 millions	12 millions
Data storage capacity	(Gbytes)	40,000	40,000	55,000	50,000

Summary of project objectives (10 lines max)

Within REFORGE we aim at exploring the impact that resolved and sub-grid orography has on the flow using the EC-Earth global climate model. Making use of a set of atmosphere-only integrations at three different horizontal resolutions (~80 km, ~40 km and ~25 km) we will 1) explore the effect of resolved orography on the mid-latitude climate – with a special regard to recurrent weather pattern as atmospheric blocking –2) assess to what extent the current parametrizations of sub-grid orographic effects (which are unresolved at a standard climate model resolution, i.e. ~80 km) are able to reproduce the effects of the resolved orography, 3) explore ways of improving the simulation of circulation patterns in climate simulations improving the representation of the unresolved orography.

Summary of problems encountered (10 lines max)

In May 2020, a serious bug in EC-Earth has been encountered. This unfortunately occurred after the most of the CORE simulations has been run. The EC-Earth Global Climate Model is reading SST/SIC via a tool named “amip-reader”, and they are then interpolated to the required grid and temporal frame. However, as described on the EC-Earth development portal at Issue #817, the “amip-reader” was bugged when both the “fixed year” condition was active and the IFS restart frequency was shorter than one year. In this case, the SST/SIC drops to zero from the 15th to the 31st of December, every year. This configuration – uncommon for CMIP6 experiments – is the cornerstone of the REFORGE sensitivity simulations: indeed, the bug was discovered during the REFORGE project. The bug is now fixed and changes have been included in EC-Earth code in mid-June, but this had serious consequences on a large set of experiments already run. A large part of the TL511 and TL799 simulations are likely to be re-run.

Summary of plans for the continuation of the project (10 lines max)

Following the discovery of the bug a complete re-planning of the simulations need to be carried out: making use of a more conservative setup than originally expected, a few millions of SBUs have been saved. Using those hours, TL511 simulations will be re-run with the bug fixed version of the model making using of an extremely conservative setup. Then, those experiments will be compared with experiments already run and we will investigate to what extent older experiments are still usable for the goals of REFORGE. In the next year we will try to pursuit the original goal of REFORGE operating extra simulations in the low resolution configuration (TL255) playing with sub-grid orography aiming at improving the properties of the mid-latitude climate.

List of publications/reports from the project with complete references

None – The experiments are still under production

Summary of results

In the last 12 months of the project (from June 2019 up to June 2020) the most of the work has been technical, running the model in different configurations. Eight experiments have been run so far: the EC-Earth default configuration (*rfgr-ctrl-param*) plus the configuration where the sub-grid orography parametrizations are suppressed (*rfrg-ctrl-noparam*) at three different resolution (TL255, TL511, TL799). Then, other two experiments at TL511 and TL799 with the orography of TL255 have been performed (*rfrg-orog255-noparam*). In such way it is possible to distinguish among the effect of increase in “pure” resolution (for example, what is done by better resolved transient eddies), the effect of better resolved orography and the effect of orographic parametrizations.
Each simulation has been run for 31 years, and the last 30 years have been taken in consideration for analysis. Furthermore, other two ensemble members starting from different initial conditions have been initially run at TL255 for the *rfrg-ctrl-noparam* in order to assess whether or not the chosen 30-year window is long enough to detect changes in the variability at the mid-latitudes.
Since one of the most interesting feature to look at in this framework is the impact of resolution and orography on atmospheric blocking, we decided to take into account the blocking indices developed

by Davini et al. (2012) which is a 2-D extension of the original Tibaldi and Molteni (1990) index. This is based on the reversal of the daily geopotential height gradient at 500hPa.

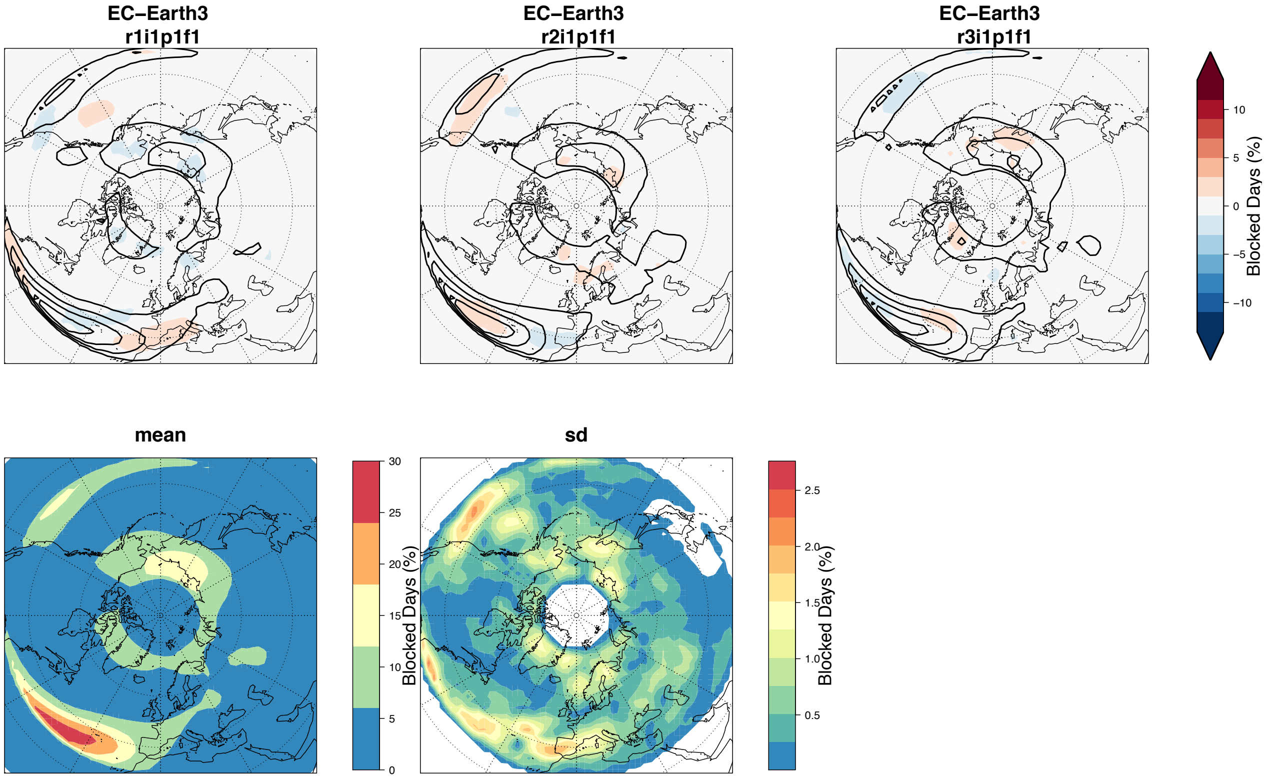

Figure 1. EC-Earth (TL255) DJFM 2000-2029 atmospheric blocking frequency anomalies from the ensemble mean (upper row), ensemble mean (bottom left) and standard deviation (bottom center).

From Figure 1 is possible to see that even making use of a highly non-linear diagnostic as atmospheric blocking the differences among different ensemble members for the same experiment are very small, around 1% of blocked days. The standard deviation of this small ensemble is rarely exceeding the 2%, suggesting that even a 30-year window is enough to investigate the effect of changes in orography parametrization on the variability of the winter mid-latitude climate.

The complete comparison among different experiments is presented in Figure 2, where again blocking frequency over the winter period (DJFM) is analyzed. Here blocking is expressed as an anomaly from the TL255 *rfrg-ctrl-noparam* configuration, which represent a sort of control run for the EC-Earth3 model within REFORGE. Please note that while TL511 and TL799 have their names highlighted in the legend, the TL255 is always referred simply as EC-Earth3 since this is exactly the same configuration as the one used for CMIP6.
Similarly, Figure 3 present a more common diagnostic which is the winter climatological zonal wind at 850hPa, again in winter.

From Figure 2 and Figure 3 is possible to see how large is the impact of the orographic parametrizations on the flow, especially over the Euro-Atlantic sector: over Central Europe the blocking diagnostic is always increased by about 5%, which represent almost a doubling of the blocking frequency in this region. For the same reason, the Atlantic eddy-driven jet is slowed down by a several m/s, retracting its path from Eastern Europe to Central Atlantic. The relevance of sub-grid orography parametrizations was expected given the results of Pithan et al (2016), but in EC-Earth3 is much more evident.
As long as we increase the resolution, the blocking and the zonal wind simulation in *rfgr-ctrl-param* experiments remains quite similar, showing the best results at TL511. However, when we are looking at the *rfrg-ctrl-noparam* experiments we can see that a bit of the improvement is also

coming from increase in resolution. This suggests that the effect of the parametrizations may be smaller at higher resolution.

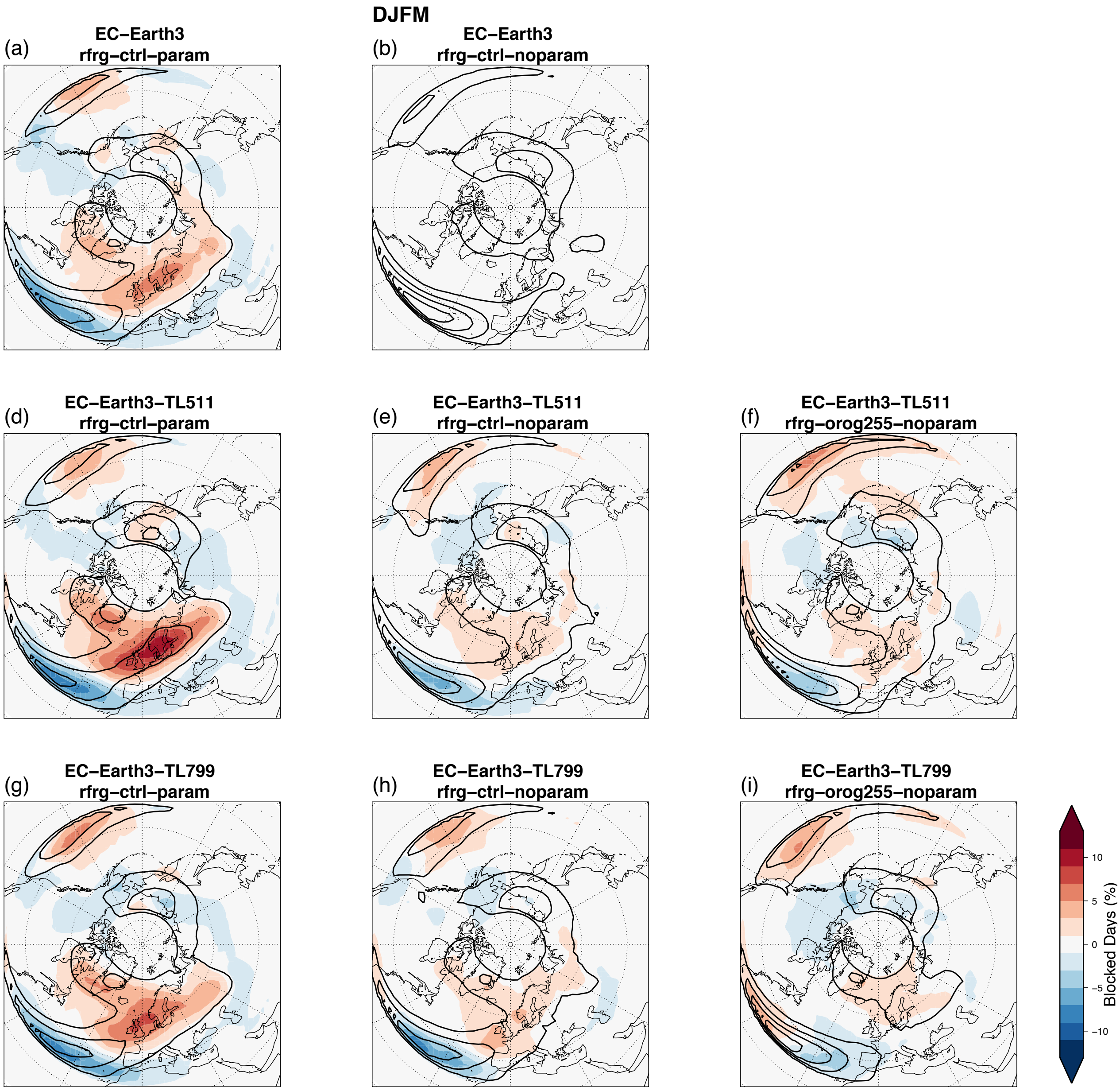

Figure 2. EC-Earth DJFM 2000-2029 atmospheric blocking frequency (contours) and their anomalies from the EC-Earth3 rfrg-ctrl-noparam (shading).

Extremely interesting are also the experiments at high resolution where the TL255 orography has been used in absence of any parametrizations, i.e. the *rfrg-orog255-noparam*. A small difference with their counterparts *rfgr-ctrl-noparam* is found, especially evident in Figure 3, suggesting that at least the half of the benefit of increasing resolution is associated with resolved orography. A curious feature in these experiments is that the both blocking and wind are displaced over Northern Europe when compared to *rfgr-ctrl-noparam*.

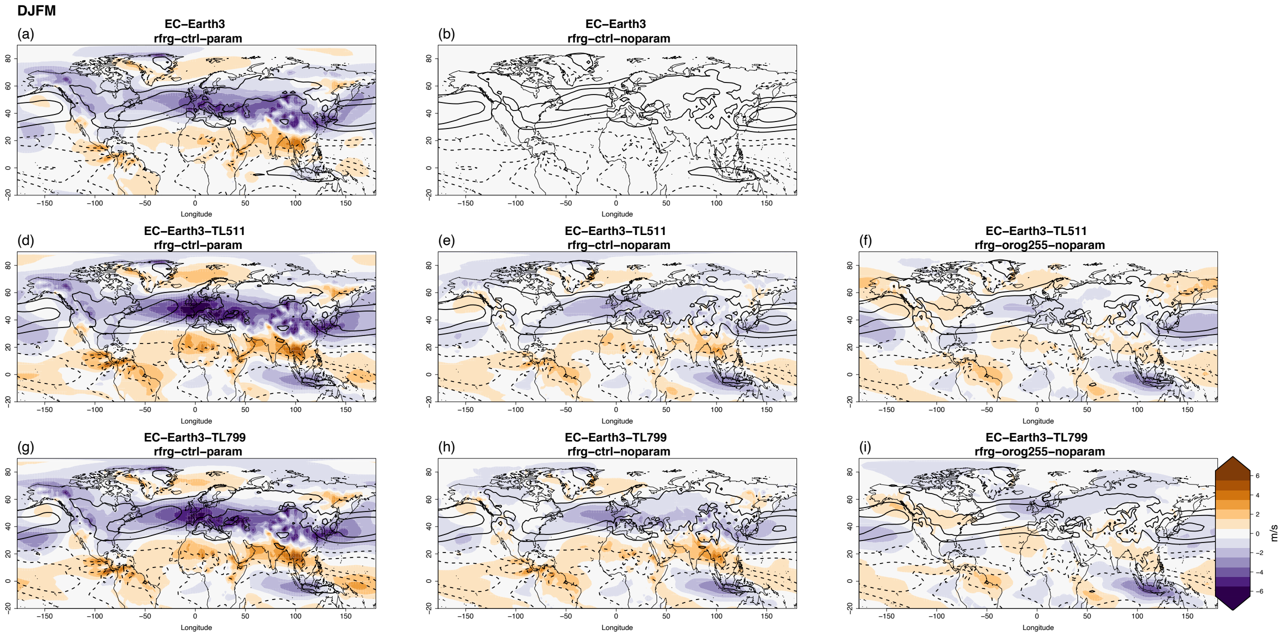

Figure 3. EC-Earth DJFM 2000-2029 zonal wind at 850hPa (contours) and their anomalies from the EC-Earth3 rfrg-ctrl-noparam (shading).

Of course, the presence of the bug discussed in the first part of this report probably significantly affects the results presented so far, since late December and early January data need to be discarded. Therefore, a note of caution on the interpretation of these findings must be expressed in this sense. Much more detailed analysis and results will be provided once the experiments with the bug fix at TL511 will be run.

References

1. Davini, P., Cagnazzo, C., Gualdi, S., & Navarra, A. (2012). Bidimensional diagnostics, variability and trends of Northern hemisphere blocking. Journal of Climate, 25(19), 6996–6509.
2. Pithan, F., Shepherd, T. G., Zappa, G., & Sandu, I. (2016). Climate model biases in jet streams, blocking and storm tracks resulting from missing orographic drag. Geophysical Research Letters, 43, 7231–7240. https://doi.org/10.1002/2016GL06955
3. Tibaldi, S., & Molteni, F. (1990). On the operational predictability of blocking. Tellus, Series A, 42, 343–365