SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	WeatHer rEgimes' REpresentation (WHERE)
Computer Project Account:	spitmavi
Start Year - End Year :	2018 - 2019
Principal Investigator(s)	Alessia Balanzino
Affiliation/Address:	Institute of Atmospheric Sciences and Climate, National Research Council (ISAC-CNR), Italy Corso Fiume 4, 10133, Torino, Italy
Other Researchers (Name/Affiliation):	Susanna Corti (CNR-ISAC) Paolo Davini (CNR-ISAC) Federico Fabiano (CNR-ISAC)

The following should cover the entire project duration.

Summary of project objectives

The WHERE special project intends to carry out a set of atmosphere-only (AMIP) ensemble historical (1950-2014) and future scenario (2015-2050) simulations with the EC-Earth global climate model in order to study the ability of the model to represent the Euro-Atlantic and Pacific North American atmospheric weather regimes (e.g. Straus et al. 2007, Cassou 2010) and the related prevailing teleconnection patterns. Several ensemble members are necessary to assess the relative contribution of the forced and the unforced variability to the frequency of weather regimes. Since all the ensemble members will be run using the same Sea Surface Temperatures (SSTs), the inter-ensemble variability provides an estimate of the internal variability, whereas the forced variability is represented by the variability of the ensemble mean. The activation of a stochastic physics parameterization scheme (Palmer et al. 2009) to represent subgrid-scale processes will be investigated by comparing with the baseline simulations.

Summary of problems encountered

We decided to deviate from our original plans of performing a 10-member ensemble of atmospheric only (AMIP) historical (1950-2014) experiments, performing instead two atmospheric only (AMIP) historical simulations at different horizontal resolutions, namely TL255 and TL511. The control integration has been performed with the EC-Earth-3P (Haarsma et al. 2020) at TL255, while the high-resolution (i.e. EC-Earth-3P-HR) was run at TL511. Our decision was motivated by the opportunity to compare our results with those from other models in conformity with the protocols of the HighResMIP (Haarsma et al. 2016) and Phase 6 of the Coupled Model Intercomparison Project (CMIP6). This report refers therefore to so-called “HighresSST- present” experiment, an atmosphere-only integration forced with observed SSTs, observed sea-ice concentrations, and external radiative forcings over the period 1950-2014.
Furthermore, recent works highlighted the negligible impact of stochastic physics parametrization in atmosphere-only integrations in the mid-latitude climate (e.g. Davini et al. 2017). Therefore, we also renounced original planned experiments with SPPT and SKEB schemes in favor of taking part to the CMIP6 effort, always keeping our focus on the weather regimes. Making use of EC-Earth3 an additional ensemble member (r4i1p1f1) for historical and SSP5-8.5 scenarios have been run and made available through an ESGF data node. Those integrations are analyzed in this report.

Experience with the Special Project framework

We have been very pleased with the support from ECMWF during the project

Summary of results

Over the last two decades, evidence has begun to accumulate suggesting that large scale circulation at mid-latitudes exhibits interesting local structure which manifests itself in the form of quasi-persistent weather regimes (e.g. Straus et al. 2007, Woollings et al. 2010, Franzke et al. 2011). In particular, such regimes have been identified in the winter season in the Euro-Atlantic region, and there is a growing recognition of their importance in modulating European weather (Ferranti et al. 2015, Matsueda et al. 2018) and, possibly, the regional response to anthropogenic forcing (Palmer 1999, Corti et al. 1999). Representing these regimes correctly is therefore an important goal for any general circulation model (GCM). Previous studies (Dawson et al. 2012) had suggested that high horizontal resolution may be an important factor in achieving this.

Computation of weather regimes – throughout this report – is based on daily fields of wintertime (December–February; DJF) geopotential height on the 500 hPa pressure level. A seasonal cycle is obtained by averaging the seasonal time series at each grid point over all years. This cycle is then smoothed using a 20-day running mean before being subtracted from the daily time series to produce an anomaly time series at each grid point. Data from both the reanalysis and model are interpolated onto a common 2.5x2.5 latitude longitude grid. Empirical orthogonal function (EOF) analysis is then used to reduce the dimensionality of the anomaly data set. The EOF analysis is performed on a European/Atlantic domain defined by the sector 30 –90 N, 80 W–40 E, and the four first principal components (PCs, which explain about the 55% of the variance) are retained (Fabiano et al, 2020). The k-means cluster analysis method Straus et al. (2007) is used to identify clusters in the reduced phase space using k=4. The clustering procedure aims to identify preferred regions of the phase space, which can be interpreted in the framework of regimes.

1. *EC-Earth3P and EC-Earth3P-HR atmosphere-only runs*

The first part of the report focuses on the analysis of the results from the WHERE project involves the weather regimes features in the EC-Earth3P atmosphere-only runs at low (T255) and high resolution (T511), which are shown in Figure 1. From here a first property of the regimes can be investigated, indeed how similar the regime patterns of the model data are compared to those observed in re-analysis. It is possible to see that both the models have a reasonable representation of the regimes structure, although the LR configuration struggle more in the correct representation of the Atlantic Ridge and the Scandinavian Blocking. The frequencies of occupancy too are closer to observations in the high resolution configuration: in the low resolution the NAO+ regime is considerably underestimated.

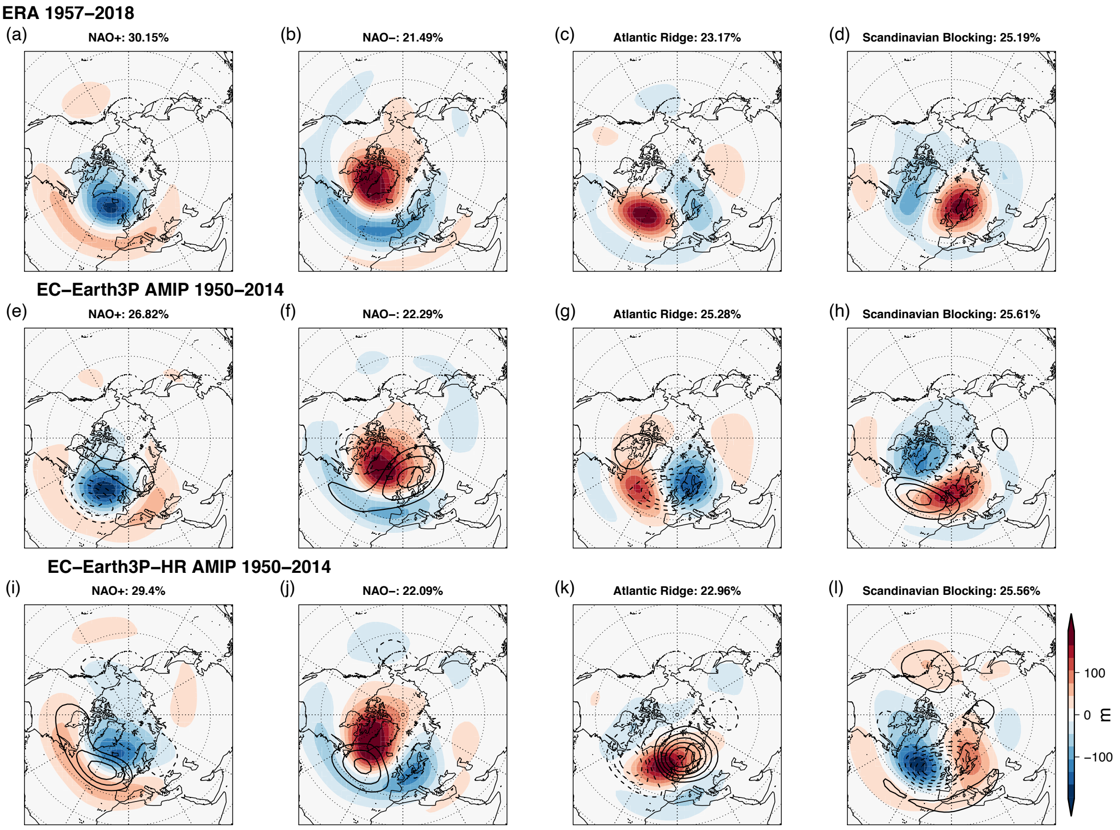

Figure 1. Weather regimes and their frequency of occupancy for the reference dataset, composed by ERA40 (1957-1978) and ERA Interim (1979-2018) (upper row), EC-Earth3P AMIP LR run (central row) and EC-Earth3P AMIP HR (bottom row). Contours show the difference against the ECMWF ERA-Interim Reanalysis

A further investigation can be carried out to go beyond the standard pattern comparison, i.e. checking how tightly clustered is the model data compared to re-analysis (i.e. how robust is the regime structure). The so-called "sharpness metric" gives a measure of how tightly clustered the dataset is relative to what is expected from random sampling variability (see Dawson et al. 2012 for details), and so measures the robustness of the model regimes. We found that in EC-Earth-3P significance increases with resolution (going from 70% at TL255 to 82% at TL511), even if this value is still lower to the one found for ERA-Interim (i.e. 98%, Strommen et al, 2019).

Results from WHERE project have been part also of multi-model comparison in the framework of the HighResMIP initiative. Overall we found that, while for some models and regimes increasing the resolution improves the pattern similarity with re-analysis, in many cases this is degraded. Indeed, on average across all models analyzed the impact of increased resolution is a small degradation of the pattern correlation. Figure 2 shows a Taylor diagram summarizing the impact on the spatial patterns of the regimes found in different model data (EC-Earth3P and EC-Earth3P-HR are shown by the light green dots). In conclusion increased resolution appears to improve the geometric robustness of North Atlantic regimes, but no other aspects of the regimes are systematically improved, suggesting a strong model dependency. A more complete discussion on the multi-model framework of the HighResMIP can be found in Fabiano et al. (2020) where coupled versions of the model here presented are investigated.

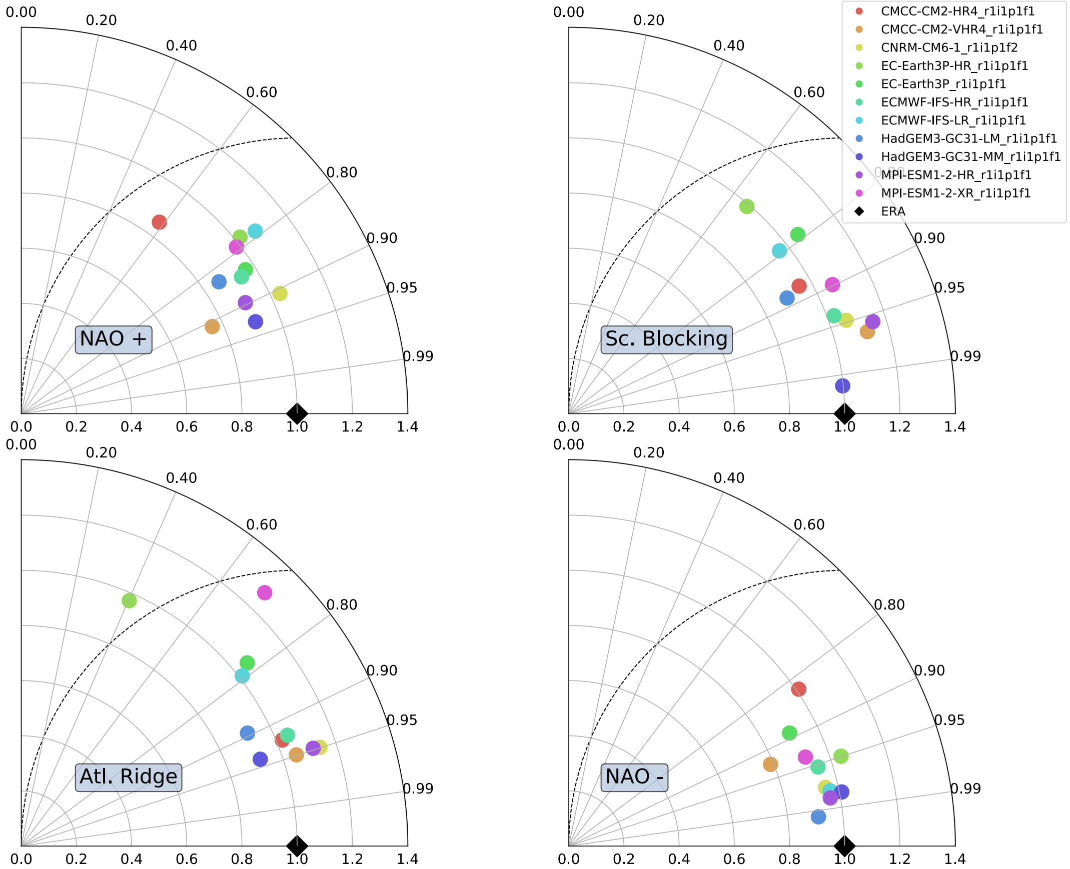

Figure 2: Taylor diagram representation of the visual similarity between the model weather regimes from model partners in HighResMIP (1950-2014), and those of the reference dataset, composed by ERA40 (1957-1978) and ERA Interim (1979-2018). Pattern correlation with ERA-Interim (black diamond) is denoted by the outer arc, the axes represent the standard deviation of the patterns, and the RMS error to ERA-Interim is denoted by the distance from ERA to the model point.

2. *EC-Earth3 coupled runs*

In the second part of the report we focus on the coupled runs: these are based on EC-Earth3, the CMIP6 configuration of the EC-Earth Earth System Model (Doescher et al. 2020), i.e. using IFS cy36r4 TL255L91 atmospheric configuration and NEMO 3.6.1 ORCA1L75 oceanic configuration. Two runs have been performed, one covering the historical period (1850-2014) and the other one covering the future period (2015-2100). Both runs are completely following the CMIP6 forcing for greenhouse gases and aerosols (Eyring et al, 2016, O'Neill et al. 2016), so that they have been cmorized and published on an ESGF data node hosted by CINECA (esgf-cnr.hpc.cineca.it). Several ensemble members have been produced by the EC-Earth consortium, covering a wide range of possible emission scenarios, as can be seen in Figure 3. The ensemble member here discussed is making use of SSP5-8.5 emission scenario for the future time window.

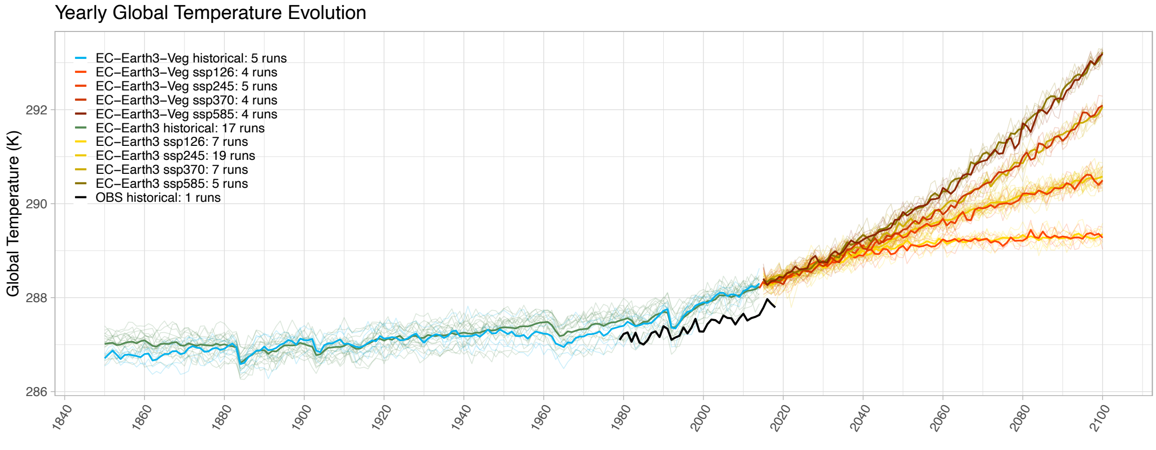

Figure 3. Yearly averaged global surface air temperature for the EC-Earth3 ensemble taking part to CMIP6.

Weather regimes for the above-mentioned runs are reported in Figure 4. Here, it is possible to compare ERA-Interim reanalysis, the CMIP6 EC-Earth3 historical and SSP5-8.5 scenarios. The model has a reasonable representation of the four regimes also at low resolution, since it is able to reproduce four spatial patterns that resemble the observed ones. However, the patterns are slightly different but most importantly the frequency of occupancy is often biased. Indeed, the NAO+/NAO- regimes is way less/more frequent in EC-Earth3 than in the reanalysis. Conversely, Atlantic Ridge and Scandinavian blocking are quite reasonably simulated. This is extremely interesting considering the common bias that climate models show in atmospheric blocking over the European sector (Davini and D'Andrea 2016): indeed, this may imply or 1) a very good representation of blocking or 2) more likely, a large bias in the mean state (i.e. removing the mean improves the representation of the variability). Indeed, it should be noticed that weather regimes computation does not take into consideration the effect of the mean flow bias since the computation is performed on the anomalies from the seasonal cycle, while atmospheric blocking computation often involves the full fields.

Regarding the climate change scenarios, EC-Earth suggest a significant zonalization of the flow, having a more frequent NAO+ and less frequent Scandinavian Blocking. This is usually observed in several climate models (e.g. Anstey et al, 2013). Surprisingly, the patterns in the SSP585 scenarios are more similar to the observed patterns.

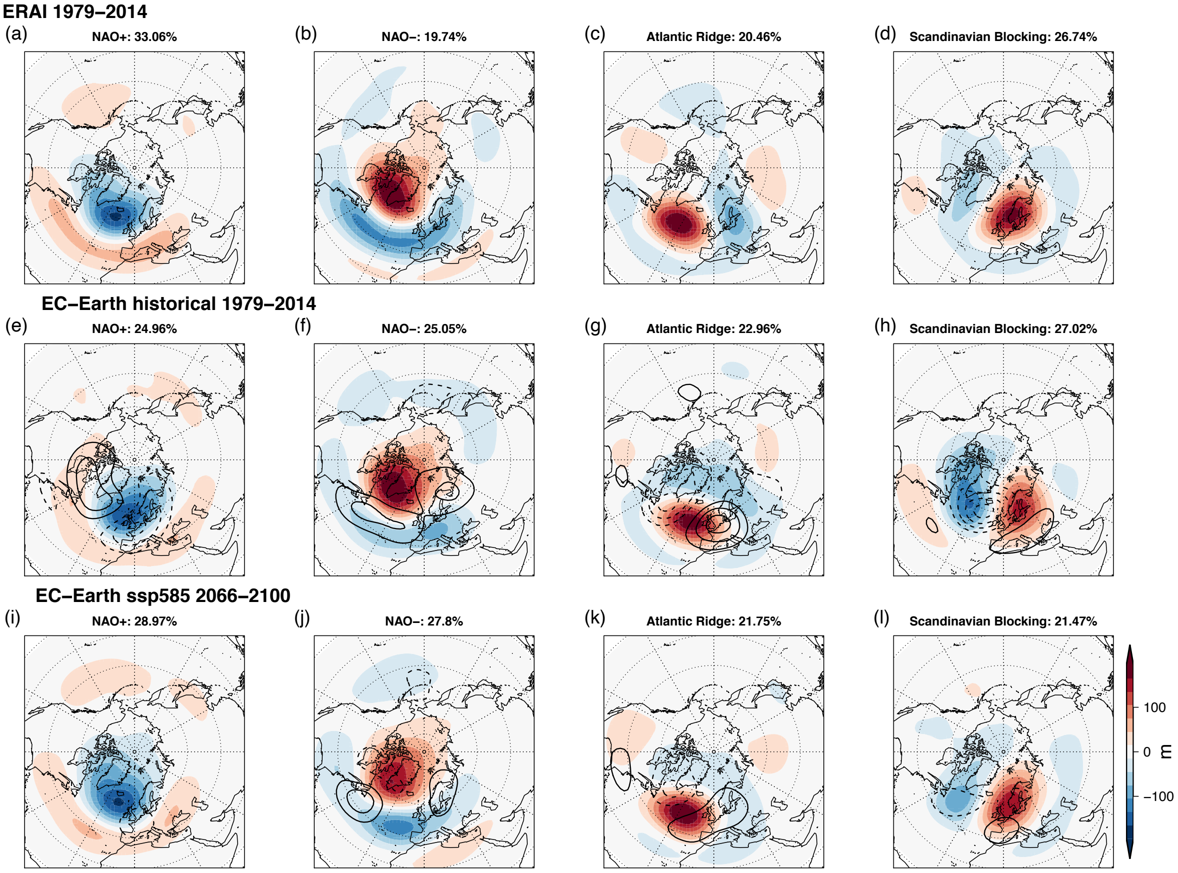

Figure 4: Weather Regimes and their frequency of occupancy for ERA-Interim (upper row), EC-Earth3 r4i1p1f1 historical run (central row) and EC-Earth3 r4i1p1f1 future scenario (bottom row). Contours show the difference against the ECMWF ERA-Interim Reanalysis

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List of publications/reports from the project with complete references

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- Fabiano, F., Corti S. et al. 2020, A regime view of future circulation changes in mid-latitudes in CMIP6 models, in preparation

Future plans

No further integrations are planned at the moment.