The Danish Meteorological Institute

Emulating a Complete GCM-RCM Euro-CORDEX Matrix

Ole Bøssing Christensen[1] and Erik Kjellström[2]

[1]Danish Meteorological Institute, Copenhagen, Denmark (obc@dmi.dk)

[2]Swedish Meteorological and Hydrological Institute, Norrköping, Sweden

Background

The EURO-CORDEX model simulation ensemble is very large, with 8 GCMs being downscaled by 11 RCMs in the case of the RCP8.5 emission scenario for a total of 58 simulated GCM/RCM combinations at the time of this work. In this study only one downscaled GCM ensemble member has been used for GCM/RCM combinations where several GCM ensemble members have been downscaled.

We aim at emulating values of various fields for the GCM/RCM combinations, which have not actually been performed, in order to get a more "democratic" picture of ensemble means. In the following we will show results for a number of standard variables: Seasonal means of temperature, precipitation, and wind strength as well as some extremes.

The work has been described in Christensen and Kjellström (2020; 2022).

ANOVA

This analysis is done independently for each grid point, each field, and each season. We consider a field value Y_{ijk} to be a sum of contributions S_i from the scenario period i the choice G_j of GCM j and the choice R_k of RCM k. There are cross terms, and the remainder after the split is SGR. In symbols:

$$Y_{ijk} = M + S_i + G_j + R_k + SG_{ij} + SR_{ik} + GR_{jk} + SGR_{ijk}$$

All quantities sum to zero over each index, and they constitute a unique split of inter-simulation variance on the different terms.

The ANOVA technique as such is a text book technique, which only works for a filled matrix. All quantities can be determined in a unique way due to all the summation rules. For "well behaved" fields, we can learn something about, e.g., the role of GCM choice vs. RCM choice. For more noisy fields, e.g., extreme precipitation, most of the variability will lie in the "remainder" terms *GR* and *SGR*.

In order to find values for missing simulations (holes), we will set the remainder terms GR_{jk} and SGR_{ijk} to zero for all holes, and simply solve the resulting linear equations for the missing Y_{ijk}. This works for well distributed matrices down to a number of simulations of $N+M-1$, for a GCM-RCM matrix of NxM. For the actual RCP8.5 matrix there is plenty of simulations to fill the holes. See Christensen and Kjellström (2022).

Note that this set of linear equations only has to be solved once for any given configuration. After that, all missing values for points, seasons, and fields can be found by multiplying the same solution matrix with the respective fields.

The EURO-CORDEX RCP8.5 matrix

RCP8.5	RCA4	CCLM4-8-17	crCLIM	REMO 09.15	RACMO22E	HIRHAM5	WRF361H	WRF381P	ALADIN63	RegCM4.6.1	HadREM3-GA7.05	Total by GCM
MOHC-HadGEM2-ES	1	1	1	1	1	1	1	1	1	1	1	11
ICHEC-EC-EARTH	1	1	1	1	1	1	1	1		1	1	10
CNRM-CERFACS-CNRM-CM5			1	1	1	1		1	1		1	7
NCC-NorESM1-M	1		1	1	1	1		1	1	1	1	9
MPI-M-MPI-ESM-LR	1	1	1	1	1	1	1	1	1	1	1	11
IPSL-IPSL-CM5A-MR	1			1	1	1		1				5
CCCma-CanESM2		1		1								2
MIROC-MIROC5		1		1			1					3
Total by RCM	5	5	5	8	6	6	4	6	4	4	5	58

Calculation of averages

Ensemble averages are normally calculated as simple averages over the available ensemble members. This means that each GCM will be weighted with the number of downscaling simulations that happened to be performed. The same situation applies to the RCMs. We can try to remedy this asymmetry by first filling the holes with the present technique, and then taking an average over both existing and emulated field values. This way, all GCMs as well as all RCMs are weighted the same.

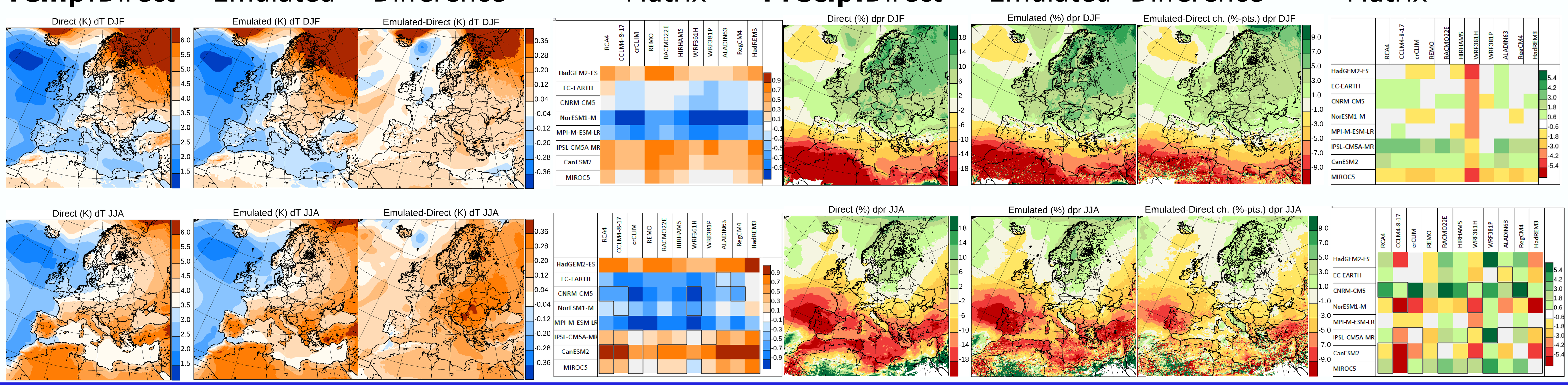
This can make a big difference for sparse matrices, but it is not expected to be of huge importance for this well-filled matrix.

Below we will compare the two methods of calculating averages, direct vs. emulated.

Comparison of averages

We compare the two methods of taking ensemble averages for climate change. Surface air temperature to the left (K), total precipitation to the right (%); winter (DJF) top row, summer (JJA) bottom row. Each set contains the direct average, the average including emulated values and the difference between the two methods. In order to analyse the origin of deviations we show a plot of average deviations from mean signal for each GCM/RCM combination. For the summer plots, the filled holes are framed.

Temp:Direct Emulated Difference Matrix **Precip:**Direct Emulated Difference Matrix



Conclusions

- The investigation indicates that the ensemble averages, which can be obtained from the existing simulations, would be extremely close to the values of a filled matrix for seasonal-average 2m temperature and precipitation (as well as 10m wind speed, not shown here). The new method gives very different winter temperatures in the north, where the effect of sea ice reduction on temperature is dependent on both GCM and RCM. Also, drying in Southern Europe is somewhat larger in the new ensemble average.
- With fewer simulations, down to the minimum requirement of $N+M-1 = 18$ simulations (see Christensen and Kjellström, 2022), the deviation of an emulated matrix from a filled matrix would be considerably larger and less trustworthy. This, e.g., applies to the sparser populated RCP2.6 and RCP4.5 matrices.
- The ANOVA-based technique gives improvements over direct averaging for all fields considered but these improvements are still small compared to the geographical variation of climate change and can be replaced by direct ensemble averages without large differences in results, due to the high degree of filling already present in the current matrix.

References

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Acknowledgements: This study has been partly funded by the Copernicus Climate Change Service through the PRINCIPLES project. ECMWF implements this Service on behalf of the European Commission. Part of the funding is by the Danish state through the National Centre for Climate Research (NCKF).