ECMWF COPERNICUS REPORT

Copernicus Climate Change Service

# Experimental design for the GCM/RCM matrix

## D34b_Lot2.1.1.1

Issued by: SMHI/ Jon Stark

Date: 29/6/2018

Ref: C3S_ D34b_Lot2.1.1_201803_ Experimental design for GCM-RCM matrix_V1

# Contributors

**DMI**
Ole B. Christensen

**SMHI**
Grigory Nikulin
Erik Kjellström

**ETHZ**
Silje Sørland

**CNRS**
Robert Vautard

**MF**
Samuel Somot

**ICTP**
Erika Coppola

**MOHC**
Erasmo Buonomo

**HZG**
Claas Teichmann

**KNMI**
Erik van Meijgaard

## Table of Contents

# 1. Introduction

The main task of COPERNICUS C3S_D34b_Lot2 (PRINCIPLES) is to produce a very large amount of Regional Climate Model (RCM) simulations for the standard Euro-CORDEX EUR-11 area in 12km resolution (http://www.cordex.org). The RCMs are used for downscaling CMIP5 and possibly CMIP6 (Coupled Model Inter-comparison Project phases 5 and 6) GCMs (Global Climate Models) under different forcing scenarios. Simulations will also be done to cover some of the uncertainty range related to natural variability by downscaling different ensemble members of the same GCM under the same forcing scenario. This report documents how the experiment is designed in terms of which GCM-RCM-RCP combinations to run in the project. We present a table with a number of simulations existing now, plans for the current Service Contract 2, and tentatively our goals for the end of the project.

The existing (as of 2018-06-20) database of simulations consists of a total of 60 simulations[1] excluding those performed so far in PRINCIPLES. The budget of PRINCIPLES allows for roughly 75 simulations to be completed. The exact number depends on exactly how many simulations are done at the respective partner institutes, as the costs between them differ. At the time of writing, one simulation per participating institution in PRINCIPLES is already complete or close to completion as specified in Service Contract 1.

The number of GCM simulations where possible boundary data have been saved is quite high, of the order of 30 (e.g., McSweeney et al., 2014). In the evaluation of GCMs with saved boundary data in that paper, the models treated below were deemed satisfactory with respect to present-climate performance with the exception of MIROC5, downscaled in the German Reklies-DE (http://reklies.hlnug.de) project and included in Tab 2 and 3, whose simulation of European circulation in summer is implausible. Some concerns were raised about NCC-NorESM1-M, as its mean flow is too zonal but still adequate for Europe, and only a partial evaluation was possible for ICHEC-EC-EARTH as necessary data were not available to the authors at the time. Another important criterion of the GCM selection methodology described in McSweeney et al. (2014) is to choose a subset of models whose climate changes projections span as wide a range of responses in important variables or processes as possible given limitations of overall ensemble size. However, in this work we have emphasized existence of prior simulations rather than an optimal choice of an ensemble based on performance and agreement on climate change, though, as the results are assessed it will be important to put these in the broader context of the full ensemble of GCMs that we might have downscaled if a more systematic design had been chosen at the outset of Euro-CORDEX. This prioritization was chosen to maximize the possible final GCM-RCM-RCP matrix.

Some pragmatic considerations were also made: The NCC-NorESM1-M GCM simulation is one of 3, selected for variability of climate signal for an ongoing CORDEX “Climate Atlas” project, and it was therefore prioritized. Also, a few PRINCIPLES institutions had technical problems with specific GCM boundary conditions.

[1] In this report we will count one simulation including the period 1961-2100 according to some RCP emission scenario as one simulation.

## 2. Strategy

The combination matrix under discussion has 3 dimensions: global model (GCM) choice, regional model (RCM) choice, and forcing scenario (RCP) choice. There are 9 different RCMs participating in PRINCIPLES (Table 1); we are interested in 3 different RCPs. (RCP2.6, RCP4.5, and RCP8.5). In the original pre-PRINCIPLES Euro-CORDEX combination matrix, 6 different GCMs had been downscaled; 2 more have been downscaled in other projects since then, and also several ensemble members of each GCM-RCP combinations have become available constituting a fourth dimension.

At each vertex in the 8x9x3 GCM-RCM-RCP matrix several single-model ensemble members may sit. The number of possible combinations makes it impossible to fill the matrix completely with non-zero elements. This shortcoming of resources is further accentuated if even more GCMs or ensemble members are considered within this project. Already in M1.1 it was therefore decided that PRINCIPLES would not do a homogeneous non-complete filling of the entire matrix, but would rather fill up selected matrix slices as completely as possible.

**Table 1.** PRINCIPLES institutes and regional models.

| Number | Partner institute | Regional Climate Model |
|---|---|---|
| 1 | SMHI | RCA4 |
| 2 | ETHZ | COSMO-crCLM |
| 3 | HZG | REMO2009 and REMO2015 |
| 4 | KNMI | RACMO22E |
| 5 | DMI | HIRHAM5 |
| 6 | CNRS-IPSL | WRF381P |
| 7 | Météo-France | ALADIN63 |
| 8 | OGS/ICTP | RegCM4.6.1 |
| 9 | MOHC | HadGEM3-RA |

In order to fill up matrix slices as efficiently as possible we will build and expand on the already existing ensemble. The existing simulations as well as plans for PRINCIPLES simulations are depicted in Table 2, where values indicate the number of existing ensemble members for each combination. Some simulations from the German Reklies-DE (http://reklies.hlnug.de) project with the CCLM, REMO and WRF models have been added to the table in the appropriate places even if the institution performing the simulations is different from the corresponding PRINCIPLES partner.

After discussion at the PRINCIPLES meeting in Hamburg 23-24/5/2018 it was decided to treat existing simulations with earlier versions of WRF (WRF361H) and CCLM (CCLM4-8-17) as different RCM models from the currently used ones, but to treat REMO2009 and REMO2015 as the same, due to the limited amount of difference between those two versions.

In Table 2 we show only simulations with the RCM model versions, which are being used for simulations in PRINCIPLES. For information and to provide an overview we show the larger table of all existing Euro-CORDEX simulations in Table 3.

Also, we have included the 3 datasets, which have been uploaded for the rapid evaluation in D34b_Lot2.4.3.1 but are not yet in the ESGF, and also the remaining SC1 simulations (M34b_Lot2.2.2.1), marked by an asterisk.

According to a draft number of SC2 simulations based on the maximum number and price per simulation for each institute (see M34b_Lot2.0.3.1), the table contains suggestions about which simulations might be carried out until the end of February 2019, indicated with "#".

Tables 2 and 3 also indicate current plans for the strategy of model combinations for the rest of PRINCIPLES. The tables are structured as follows: For each forcing scenario we depict a GCM-RCM matrix with numbers for the number of existing and published simulations of the particular GCM-RCM-RCP combination. The sum of existing and SC1 simulations ("Current status") are shown in the right column for each GCM and in the first bottom row for each RCM. The suggested final matrix is indicated by grey background colour; light grey for one simulation in the corresponding field, and dark grey for (at least) 3. With one or two pound sign(s) (#) we indicate suggestions for simulations, which would be part of the recently started SC2.

The row of simulations "Remaining" indicates the simulations planned to be done in PRINCIPLES after the completion of SC1. In the bottom of the table we sum up the already existing simulations including SC1; the SC1 and SC2 simulations specifically; the number of PRINCIPLES simulations in total and finally the grand total of PRINCIPLES and non-PRINCIPLES simulations expected at the end of the project for the EUR-11 Euro-CORDEX area. Other projects and initiatives not accounted for here may augment this total considerably. Note that each forcing scenario simulation counts as one, no matter whether the historical period is common to several emission scenario simulations or not. Note also that different versions of an RCM are counted together here.

The plan for the collective PRINCIPLES simulations is to distribute the allocated effort between three main goals:

- To enable studies of variability by performing several ensemble member downscaling simulations with the same GCM-RCM-RCP combination.
- To fill as large a sub-matrix as possible for the RCP8.5 emission scenario.
- To add a significant amount of simulations to the weak RCP2.6 scenario, where noise is relatively more important compared to the climate change signal.

These different goals can be prioritized in various ways. In PRINCIPLES the current prioritization is described below.

Regarding internal variability the idea is to augment single-model ensembles already being constructed, and supplement with a few simulations where the same GCM-single-model-ensemble is downscaled with different RCMs. As a consequence there are 16 RCP8.5 runs specifically devoted to targeted studies on internal variability as depicted in the dark grey areas of Table 1, supplemented by already existing simulations. Several ensemble members exist for the ICHEC-EC-

EARTH and MPI-M-MPI-ESM-LR models where the necessary data for regional downscaling have been saved (model level fields of temperature, wind components and moisture with a temporal frequency of at least 6 hours). For ICHEC-EC-EARTH boundary conditions are available from the realizations r1i1p1, r3i1p1, and r12i1p1. In addition, KNMI has produced 16 extra members with ICHEC-EC-EARTH (Aalbers et al., 2017), and archived the boundary conditions from each of them, such that the ensemble size of combinations with this GCM would have the possibility to be increased even further in the future.

This leaves 35 PRINCIPLES simulations for completely filling up an RCP8.5 matrix. Note that Reklies-DE has added 2 GCMs, which were not part of Euro-CORDEX proper. We have kept those out of the set of GCMs to be further downscaled in PRINCIPLES due to the limitations of the number of simulations we are able to do.

**Table 2** Simulation overview for PRINCIPLES models. SC1 simulations, are marked with *; if they are complete at the time of writing, also with a number. # indicates simulations, which could be set for SC2 (201803-201902). Grey areas indicate the target matrix. The totals in the right column refer to the situation immediately after SC1. The same applies to the "Remaining" rows. The "Grand total" is the sum of currently existing simulations and all currently planned PRINCIPLES simulations.

| **RCP8.5** | SMHI | ETHZ | HZG | KNMI | DMI | CNRS | MF | ICTP | MOHC | Total now |
|---|---|---|---|---|---|---|---|---|---|---|
| MOHC-HadGEM2-ES | 1 | | 1 | 1 | 1* | # | # | * | * | 6 |
| ICHEC-EC-EARTH | 1## | | 1 | 2# | 1## | | | | # | 6 |
| CNRM-CERFACS-CNRM-CM5 | 1 | | 1 | 1* | # | | * | | | 4 |
| NCC-NorESM1-M | 1* | * | * | # | 1 | # | | # | | 4 |
| MPI-M-MPI-ESM-LR | 1 | 1## | 2# | | | | | # | | 3 |
| IPSL-IPSL-CM5A-MR | 1 | | | | | 1* | | | | 2 |
| CCCma-CanESM2 | | | 1 | | | | | | | 1 |
| MIROC-MIROC5 | | | 1 | | | | | | | 1 |
| Current status | 6 | 2 | 8 | 4 | 3 | 1 | 1 | 1 | 1 | 27 |
| Remaining | 4 | 8 | 2 | 6 | 5 | 5 | 4 | 4 | 4 | 42 |

| **RCP4.5** | SMHI | ETHZ | HZG | KNMI | DMI | CNRS | MF | ICTP | MOHC | Total now |
|---|---|---|---|---|---|---|---|---|---|---|
| MOHC-HadGEM2-ES | 1 | | | 1 | | | | | | 2 |
| ICHEC-EC-EARTH | 1 | | | 2 | 1 | | | | | 4 |
| CNRM-CERFACS-CNRM-CM5 | 1 | | | | | | | | | 1 |
| NCC-NorESM1-M | | | | | 1 | | | | | 1 |
| MPI-M-MPI-ESM-LR | 1 | | 2 | | | | | | | 3 |
| IPSL-IPSL-CM5A-MR | 1 | | | | | | | | | 1 |
| Current status | 5 | 0 | 2 | 3 | 2 | 0 | 0 | 0 | 0 | 12 |
| Remaining | 1 | 0 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 6 |

| **RCP2.6** | SMHI | ETHZ | HZG | KNMI | DMI | CNRS | MF | ICTP | MOHC | Total now |
|---|---|---|---|---|---|---|---|---|---|---|
| MOHC-HadGEM2-ES | 1 | | 1 | 1 | | | | | | 3 |
| ICHEC-EC-EARTH | 1 | | 1 | 1 | 1 | | | | | 4 |
| CNRM-CERFACS-CNRM-CM5 | | | | | | | | | | 0 |
| NCC-NorESM1-M | # | | | | | | | | | 0 |
| MPI-M-MPI-ESM-LR | 1 | | 2 | | | | | | | 3 |
| IPSL-IPSL-CM5A-MR | | | | | | | | | | 0 |
| Current status | 3 | 0 | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 10 |
| Remaining | 2 | 0 | 2 | 2 | 3 | 1 | 3 | 2 | 3 | 18 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Total outside PRINCIPLES | 13 | 1 | 13 | 8 | 5 | 0 | 0 | 0 | 0 | 40 |
| Remaining all RCPs | 7 | 8 | 8 | 7 | 9 | 6 | 7 | 6 | 7 | 66 |
| SC1 already counted | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9 |
| SC2 commitment | 3 | 2 | 2 | 2 | 3 | 2 | 1 | 2 | 1 | 18 |
| PRINCIPLES total | 8 | 9 | 9 | 9 | 10 | 7 | 8 | 7 | 8 | 75 |
| Grand total | 21 | 10 | 22 | 17 | 15 | 7 | 8 | 7 | 8 | 115 |

**Table 3** Simulation overview for all models. SC1 simulations, are marked with *; if they are complete at the time of writing, also with a number. # indicates simulations, which could be set for SC2 (201803-201902). Grey areas indicate the target matrix. The totals in the right column refer to the situation immediately after SC1. The same applies to the "Remaining" rows. The "Grand total" is the sum of currently existing simulations and all currently planned PRINCIPLES simulations.

| RCP8.5 | RCA4 | CCLM4-8-17 | CcrCLM | REMO 09,15 | RACMO22E | HIRHAM5 | WRF361H | WRF381P | ALADIN53 | ALADIN63 | RegCM4.6.1 | HadGEM3-RA | | Total now |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MOHC-HadGEM2-ES | 1 | 1 | | 1 | 1 | 1* | 1 | # | | # | * | * | | 8 |
| ICHEC-EC-EARTH | 1## | 1 | | 1 | 2# | 1## | 1 | | | | | # | | 7 |
| CNRM-CERFACS-CNRM-CM5 | 1 | 1 | | 1 | 1* | # | | | 1 | * | | | | 6 |
| NCC-NorESM1-M | 1* | | * | * | # | 1 | | # | | | # | | | 4 |
| MPI-M-MPI-ESM-LR | 1 | 1 | 1## | 2# | | | 1 | | | | # | | | 5 |
| IPSL-IPSL-CM5A-MR | 1 | | | | | | | 1* | | | | | | 2 |
| CCCma-CanESM2 | | 1 | | 1 | | | | | | | | | | 2 |
| MIROC-MIROC5 | | 1 | | 1 | | | | | | | | | | 2 |
| Current status | 6 | 6 | 2 | 8 | 4 | 3 | 3 | 1 | 1 | 1 | 1 | 1 | | 37 |
| Remaining | 4 | | 8 | 2 | 6 | 5 | | 5 | | 4 | 4 | 4 | | 42 |
| **RCP4.5** | | | | | | | | | | | | | | |
| MOHC-HadGEM2-ES | 1 | 1 | | | 1 | | | | | | | | | 3 |
| ICHEC-EC-EARTH | 1 | 1 | | | 2 | 1 | | | | | | | | 5 |
| CNRM-CERFACS-CNRM-CM5 | 1 | 1 | | | | | | | 1 | | | | | 3 |
| NCC-NorESM1-M | | | | | | 1 | | | | | | | | 1 |
| MPI-M-MPI-ESM-LR | 1 | 1 | | 2 | | | | | | | | | | 4 |
| IPSL-IPSL-CM5A-MR | 1 | | | | | | 1 | | | | | | | 2 |
| Current status | 5 | 4 | 0 | 2 | 3 | 2 | 1 | 0 | 1 | 0 | 0 | 0 | | 18 |
| Remaining | 1 | | 0 | 4 | 0 | 1 | | 0 | | 0 | 0 | 0 | | 6 |
| **RCP2.6** | | | | | | | | | | | | | | |
| MOHC-HadGEM2-ES | 1 | | | 1 | 1 | | | | | | | | | 3 |
| ICHEC-EC-EARTH | 1 | 1 | | 1 | 1 | 1 | | | | | | | | 5 |
| CNRM-CERFACS-CNRM-CM5 | | | | | | | | | 1 | | | | | 1 |
| NCC-NorESM1-M | # | | | | | | | | | | | | | 0 |
| MPI-M-MPI-ESM-LR | 1 | 1 | | 2 | | | 1 | | | | | | | 5 |
| IPSL-IPSL-CM5A-MR | | | | | | | | | | | | | | 0 |
| Current status | 3 | 2 | 0 | 4 | 2 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | | 14 |
| Remaining | 2 | | 0 | 2 | 2 | 3 | | 1 | | 3 | 2 | 3 | | 18 |
| Total outside PRINCIPLES | 13 | 12 | 1 | 13 | 8 | 5 | 5 | 0 | 3 | 0 | 0 | 0 | | 60 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Remaining all RCPs | 7 | | 8 | 8 | 8 | 9 | | 6 | | 7 | 6 | 7 | 66 |
| SC1 already counted | 1 | | 1 | 1 | 1 | 1 | | 1 | | 1 | 1 | 1 | 9 |
| SC2 commitment | 3 | | 2 | 2 | 2 | 3 | | 2 | | 1 | 2 | 1 | 18 |
| PRINCIPLES total | 8 | | 9 | 9 | 9 | 10 | | 7 | | 8 | 7 | 8 | 75 |
| Grand total | 21 | 12 | 10 | 22 | 17 | 15 | 5 | 7 | 3 | 8 | 7 | 8 | 135 |

Due to the specific interest from ECMWF in RCP2.6, the already quite populated RCP4.5 matrix will not be increasing a lot in this project. The 6 PRINCIPLES RCP4.5 simulations have been placed to make the RCP4.5 matrix resemble the future RCP2.6 matrix as much as possible. For RCP2.6 the PRINCIPLES budget leaves room for 18 simulations to supplement the already existing multi-model ensemble.

SMHI and HZG, and to a lesser extent KNMI and DMI, will be the institutions concentrating on both GCM and scenario diversity. The RCP8.5 emission scenario will obtain quite large GCMxRCM matrices of 5x9 as well as 6x6. It will not be possible to completely fill a considerable 3-dimensional matrix for all 3 emission scenarios, however, comparatively few additional RCP4.5 simulations would be needed to reach a 4x4 matrix covering all 3 scenarios.

This distribution of simulations means that we are not looking outside the set of GCMs already downscaled within the EURO-CORDEX community. This limitation is instigated by the fact that the ECMWF prefers completely filled sub-matrices for the purpose of building the Climate Data Store instead of a not-quite-filled but more homogeneously populated and consequently larger matrix. This will have implications for the relevance of the results for use in comprehensive climate change risk assessments (McSweeney et al., 2014) which will be investigated as part of the analysis underpinning guidance material provided with these simulations.

A final word here relates to the work in Work Package 3 related to the possible consideration of CMIP6 GCMs for downscaling in PRINCIPLES. The current document and plan for simulations in Table 2 does not take into account possible CMIP6-based downscaling simulations. In case it is deemed possible and worthwhile to downscale also CMIP6 GCMs, this plan will have to be revised.

## 3. References

Aalbers, E.E., Lenderink, G., van Meijgaard, E., and van den Hurk, B. J. J. M. (2017) Local-scale changes in mean and heavy precipitation in Western Europe, climate change or internal variability? Clim Dyn. https://doi.org/10.1007/s00382-017-3901-9.

McSweeney, C. F., Jones, R. G., Lee, R. W., Rowell, D. P. (2015) Selecting CMIP5 GCMs for downscaling over multiple regions. Clim. Dyn. DOI10.1007/s00382-014-2418-8.

Copernicus Climate Change Service

ECMWF - Shinfield Park, Reading RG2 9AX, UK

Contact: info@copernicus-climate.eu

climate.copernicus.eu copernicus.eu ecmwf.int