CORDEX experiment design for dynamical downscaling of CMIP6

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The **COordinated Regional climate Downscaling EXperiment** (CORDEX) was implemented under the auspices of the World Climate Research Program (WCRP) in order to improve downscaling techniques and their use in the provision of robust regional climate information for application in vulnerability, impacts, and adaptation (VIA) studies. The first phase of CORDEX activities included a validation stream aimed at assessing and improving regional climate downscaling models and techniques, along with a regional projection stream based on the downscaling of global projections from the fifth phase of the Climate Model Intercomparison Project (CMIP5).

This experiment design document presents a simulation framework for the second phase of CORDEX; for the dynamical downscaling of global climate projections from the sixth phase of CMIP (CMIP6). The general aim is to downscale a subset of climate scenarios from the CMIP6 ensemble of projections generated in ScenarioMIP, and to make these downscaled regional scenarios publicly available (for more details see Gutowski et al. 2016 and the CORDEX White paper which is in preparation).

1. CORDEX domains

14 standard CORDEX domains have received an official CORDEX designation and include: *South America, Central America, North America, Europe, Mediterranean, Middle East North Africa, Africa, Central Asia, South Asia, East Asia, Southeast Asia, Australasia, Arctic and Antarctica*. The simulations have to follow the size specifications for the CORDEX domains (link to the CORDEX domain doc, to be provided), paying particular attention to the specified minimum domain sizes. Notably, **the CORDEX domain has to be fully inside your model domain and not include any of the boundary relaxation zones**. It is appreciated that domains will not be identical, as for various reasons groups may choose to modify their actual domains somewhat.

This experiment design addresses the 14 continental-scale CORDEX domains, which cover essentially all land areas of the globe. Currently, smaller domains may only be addressed within the Flagship Pilot Studies (FPS) programme.

If the regional CORDEX communities think that the configuration of their CORDEX domains is not optimal (e.g. too small, too large, etc.) they can provide a formal request to the International Project Office for CORDEX (IPOC) to update the current configuration. It is also possible to apply for a new CORDEX domain (see Criteria for Selecting and Updating CORDEX Domains). The request for updating a CORDEX

domain has to come from the Point-of-Contact (POC) of a CORDEX domain, after a common agreement has been reached, not from individual RCM groups.

Similar to the CORDEX experiment design for the dynamical downscaling of CMIP5, **the Africa domain** is a focus region. We would therefore like to remind you to prioritize the Africa domain when selecting regions for integration beyond your 'home domain'.

2. Resolution/Grid-spacing

In order to provide an advancement compared to the previous CORDEX simulations, and to resolve additional features of regional climate, the grid-spacing of the new CORDEX simulations ideally should be on the order of a few tens-of-kilometers. However, a flexible choice of grid-spacing between different domains is allowed, to accommodate the needs and capacities of different communities and groups.

The primary targets are grid-spacings of 25 km and 12.5k m. The CORDEX domains should decide which resolution they need and can afford, with a preference for higher resolutions when possible. The POCs for each domain should provide guidance on the preferred resolutions for their domain.

It is recommended that one common grid-spacing be used per domain to avoid a wide range of resolutions for the same domain. A resolution between **25 and 12.5 km** may also be used if both **25 and 12.5 km** are not optimal, and if there is a common agreement on an intermediate resolution within a domain. Resolutions higher than 12.5km may also be used upon agreement within a domain; however, it is recommended that corresponding, complementary simulations at the domain's primary, coarser resolution also be provided. Simulations have to be provided on native RCM grids first (no remapping). Then, a subset of variables interpolated to a common, regular grid may also be provided.

3. Model complexity

As with previous CORDEX simulations, dynamical downscaling for CMIP6 should be done, at a minimum, with regional atmosphere - land surface models. However, increased efforts towards regional earth system models (RESMs), which include additional model components to represent other processes (e.g. ocean, sea ice, snow, urban, vegetation/agriculture, land hydrology, glaciers, aerosols and chemistry), are encouraged. When possible, models should be run in the atmosphere - land only configuration first, and then with one, or more, additional component models, in order to document the impact of the additional processes on regional climate. As far as is practical, each domain should also strive for a subset of simulations that use multiple models representing the same component processes to provide a multi-model perspective on RESM simulations. Output and archiving of additional variables

from RESMs, beyond the standard CORDEX variables, should be coordinated by each regional domain in consultation with the CORDEX Science Advisory Team (SAT). Many RCM details are model specific (e.g., the number of vertical levels and top level), so it is up to the RCM groups to define an optimal configuration for their RCMs. Multiple nesting can be used if necessary.

Variable resolution global climate models (VR-GCMs) that follow the CORDEX protocol for a given domain (e.g., resolution, etc.) may also contribute to that domain. In this case, the use of atmospheric nudging to incorporate information from the driving GCMs' atmosphere is encouraged; thus, making the VR-GCMs more comparable to the limited area RCMs. The inclusion of VR-GCMs adds to the overall diversity of the CORDEX ensembles, which provides some advantages, but the methodological differences when compared to limited area RCMs should be considered when combining the VR-GCMs and RCMs in an ensemble.

4. Evaluation experiment

All groups must first carry out an evaluation simulation driven by the **ERA5** reanalysis for each domain they simulate. The **ERA5** reanalysis covers 1979-2019 (2019 = last full year, as of February 2021), and the evaluation experiment must cover the entire 1979-2019 period, or a longer period depending on the availability of the **ERA5** forcing. Model level or pressure level data may be used to drive RCMs. A one year spin-up (1979) is reccomended for atmosphere-land models, but a longer spin-up (or an offline spin-up) may be required for models that include additional climate system components.

The ERA5 reanalysis has a pronounced cold bias in lower stratospheric temperatures for the years from 2000 to 2006. In order to fix this problem, a new set of the ERA5 reanalysis, termed ERA5.1, has been produced for 2000-2006. The impact of the cold bias on downscaling is not clear but it may potentially affect RCM simulations. It is recommended that the corrected version, ERA5.1, be used for 2000-2006.

Additional evaluation experiments (e.g. at different resolutions and/or driven by other reanalyses) may also be carried out to complement the **ERA5**-driven experiment. It is up to the regional CORDEX communities to set up their own experiment design for such additional reanalysis-driven simulations, depending on their own resources and scientific questions.

It is recommended that prescribed sea surface temperature and sea ice fraction also be obtained from the driving reanalyses. The driving reanalyses should be used at their native resolution.

GHG forcing

Through 2014, RCM groups should use the same historical atmospheric greenhouse gas (**GHG**) forcing as in CMIP6. For periods starting from 2015 onwards (e.g 2015-

2019) it is recommended that the scenario GHG forcing for the SSP2-4.5 as the mid-range scenario be used. The global and annual-mean time series of GHG concentrations for both the historical and scenario periods are available from the input4MIPs database (see for more details Meinshausen et al. 2017 and Meinshausen et al. 2019).

Land use/Land cover

As the first step, it is recommended that the static land cover and land use maps that are a regional models default be used. Recommendations for the implementation of transient land use change (e.g., datasets, translation to RCMs, etc.) will be provided later. When the recommendations become available, simulations with the static land cover and land use may be complemented by a number of new simulations with the transient land use change.

Aerosol

A static aerosol dataset (e.g. a regional model default climatology) is considered as a minimum requirement. It is strongly encouraged that for the evaluation experiment, RCM groups apply up-to-date regional or global aerosol datasets with realistic variability in time (monthly variation and trend) and space. For example, the state-of-the-art monthly mean MERRA-2 aerosol dataset can be used. Implementation of aerosol forcing in RCMs is model-dependent and general recommendations and more details are provided through a dedicated document which will be regularly updated. Comments and questions can be directly posted in a living document or sent to the IPOC.

Spectral nudging

It is up to RCM groups to decide on whether to apply large-scale spectral nudging for the reanalysis driven experiment or not. Specific details of the spectral nudging (e.g. strength, scales, variables, and levels) can be strongly region-dependent (e.g. the midlatitudes or tropics), so it is also up to RCM groups to decide on parameters for the nudging, based on their regional expertise. When possible, it is recommended that RCM groups provide two **reanalysis-driven evaluation simulations** - with and without nudging.

5. Historical experiment

Boundary conditions from the CMIP6 historical experiment, requested by CORDEX, are available for 1950-2014 (a link to a list with GCMs that have provided boundary conditions for RCM, when available). In addition to the moving 30-yr reference period (1991-2020 for the 2021-2030 decade) the World Meteorological Organisation (WMO) has also recommended that 1961-1990 be used as a standard static reference period for long-term climate change assessments. The CORDEX historical simulations have to cover at least **1960-2014** or preferably the entire **1950-2014** period. A one-year spin-up (1950 or 1960) is reccomended for atmosphere-land models but a

longer spin-up (or, e.g., an offline spin-up) may be required for models that include additional climate system components.

GHG forcing

RCM groups should use the same historical GHG forcing as in the driving CMIP6 models (see for more details Meinshausen et al. 2017).

Land use/Land cover

As the first step, it is recommended that the static land cover and land use maps that are a regional models default be used. Recommendations for the implementation of a transient land use change (e.g., datasets, translation to RCMs, etc.) will be provided later. When the recommendations become available, simulations with the static land cover and land use may be complemented by a number of new simulations with the transient land use change.

Aerosol

A static aerosol dataset (e.g., a regional model's default climatology) is considered as a minimum requirement. It is strongly encouraged that for the historical experiment RCM groups apply aerosol forcing which is either directly consistent with the driving CMIP6 GCMs or more broadly consistent with the CMIP6 aerosol forcing. The first priority is given to aerosol optical properties (e.g., total aerosol optical depth or aerosol optical depth per species) provided by most CMIP6 GCMs. General recommendations and more details are provided through a dedicated document which will be regularly updated. Comments and questions can be directly posted in a living document or sent to the IPOC.

Spectral nudging

It is up to RCM groups to decide on whether to apply large-scale spectral nudging for the CMIP6 driven simulations or not.

6. Scenario experiment

Boundary conditions from the CMIP6 ScenarioMIP, requested by CORDEX, are available for 2015-2100. The main focus in the CORDEX Request to CMIP6 (2016) was on the Tier 1 **SSP5-8.5** and **SSP1-2.6** scenarios. However, currently, there is a stronger focus on the **SSP3-7.0** as a high impact scenario instead of the **SSP5-8.5**. Thus, the **SSP3-7.0** and **SSP1-2.6** scenarios have to be downscaled first for one ensemble member for the entire 2015-2100 period. It is also recommended that additional downscaling using the **SSP2-4.5** scenario and then the **SSP5-8.5** scenario, with that order of priority, be completed after downscaling the **SSP3-7.0** and **SSP1-2.6** scenarios, if computational resources allow for additional scenarios.

If the CORDEX modeling groups have sufficient resources, additional complementary simulations for other ensemble members and scenarios of the same GCM are also welcome. It is up to the regional CORDEX communities to define a set of additional

scenario simulations depending on resources and scientific questions. It is strongly recommended that individual CORDEX RCM groups should coordinate their simulations with CORDEX POCs for respective domains in order to avoid uncoordinated efforts leading to sparse and unbalanced RCM-GCM matrices.

GHG forcing

RCM groups should use the same scenario GHG forcing as in the driving CMIP6 models (see for more details Meinshausen et al. 2019).

Land use/Land cover

As the first step, it is recommended that the static land cover and land use maps that are a regional models default be used. Recommendations for the implementation of a transient land use change (e.g., datasets, translation to RCMs, etc.) will be provided later. When the recommendations become available, simulations with the static land cover and land use can be complemented by a number of new simulations with the transient land use change.

Aerosol

A static aerosol dataset (e.g. a regional model's default climatology) is considered as a minimum requirement. It is recommended that for the scenario experiment RCM groups apply aerosol forcing which is either directly consistent with the driving CMIP6 GCMs or more broadly consistent with the CMIP6 aerosol forcing. The first priority is given to aerosol optical properties (e.g., total aerosol optical depth or aerosol optical depth per species) provided by most CMIP6 GCMs. General recommendations and more details are provided through a dedicated document which will be regularly updated. Comments and questions can be directly posted in a living document or sent to the IPOC.

Spectral nudging

It is up to RCM groups to decide on whether to apply large-scale spectral nudging for the CMIP6 scenario driven simulations or not.

7. RCM Documentation

Climate model documentation, providing all necessary details on model configurations, experiments, etc., is an integral part of climate modeling activities. The Earth System Documentation (ES-DOC) is an international effort to develop tools to describe Earth system models from the CMIP5 and CMIP6 activities. This kind of coordinated effort is still missing in CORDEX and currently there is no common system for collecting and providing RCM details, although work in this direction is ongoing. Nonetheless, when possible, it is strongly recommended to create RCM documentation and errata if necessary that details all aspects of the experiments and make it publicly available.

8. Selection of GCMs

There are a number of approaches but no commonly accepted methodology on how to select a subset of GCMs for downscaling. Additionally, a subset of GCMs selected for one CORDEX domain is not necessarily an optimal choice for other domains. It is up to the regional CORDEX communities to decide which CMIP6 models should be downscaled over a specific domain, considering, for example: i) the availability of forcing data, ii) the ability of the CMIP6 models to simulate important aspects of regional and global climate, and iii) a range of plausible future climates simulated (e.g. climate sensitivity). It is also up to the regional CORDEX communities to decide on a minimum number of simulations and the design of RCM-GCM matrices for a specific domain, depending on resources available.

9. Output variables

The CORDEX Data Request (DR) details variables and frequencies to be saved and their priorities for delivery are found here (link to CORDEX DR, to be provided).

10. Archiving and publishing specifications

CORDEX output shall be published on the Earth System Grid Federation (ESGF) in order to be consistent with the CMIP6 archive and to make the output available to as many users as possible. All CORDEX simulations have to be formatted (cmorised) according to the CORDEX archive specifications that provide technical aspects of CORDEX data format and guidance for publishing CORDEX data on ESGF (link to CORDEX archive specs, to be provided).

References

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