Reference Document on CORDEX-ESD Mid-term Plans

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Background
There is a growing demand for plausible, defensible and actionable region-specific information on potential future climate change. Such information might be obtained from various sources, including raw projections from global coupled atmosphere ocean general circulation models (in the following GCMs), dynamical downscaling of GCM projections (in the following RCMs) , and statistical downscaling (often called empirical statistical downscaling, ESD) including classical perfect prognosis approaches and the so-called bias correction of GCM and RCM projections.
All downscaling approaches suffer from a range of shortcomings and limitations. For statistical downscaling a variety of methods and sub-methods exist, each designed for different purposes and user problems, often without clearly formulating and testing the underlying assumptions. Regional projections of different approaches and methods often contradict each other, but little attention has been dedicated to understanding and resolving these differences. Physical interpretation, key to the understanding such differences, is often not pursued.
Even though evaluation studies of downscaling methods are fairly common, a rigorous evaluation and intercomparison of the applicability of a different methods in a range of contexts is often lacking. The situation is aggravated by the fundamental limitations of evaluating climate projections. All statistical and dynamical modelling approaches make some assumptions about the transferability of their specific implementation from present climate to a different future climate.
Finally, communication within the regional climate modelling community, and with users is often insufficient. First, global climate modellers, (dynamical and statistical) regional climate modellers, and impact modellers all contribute to the development of region-specific climate projections and their post-processing, but there is a lack of mutual awareness of the underlying assumptions and limitations of the respective modelling concepts. Second, users often receive insufficient communication of the problems discussed above, and are often not involved in the selection and tailoring of methods for a given application. As a result, the products delivered by the downscaling community often do not meet user needs.

Furthermore, ESD lacks global coordination. In contrast, the global climate modelling community has their model development, validation and scenario production well organised within the Coupled Model Intercomparison Project (CMIP). The RCM community is globally connected via the Coordinated Regional Downscaling Experiment (CORDEX), whose aim is to advance and coordinate the science and application of regional climate downscaling. The global framework for climate services (GFCS) is developing and incorporating science-based climate information into adaptation planning.

In CORDEX, originally no explicit preference was given to dynamical downscaling, but the scattered ESD community was not up to engaging with the streamlined production of regional projections, as well as with the CORDEX protocol. As a result, ESD, although widely used as a basis for adaptation planning, dropped out of the wider CORDEX activities, and played a decreasing role in major assessment reports. So far, ESD lacks an authoritative description of different methods, a common protocol for scenario generation as well as a common validation framework. Individual initiatives such as the EU COST Action VALUE or the downscaling metadata project of the National Climate Predictions and Projections (NCPP) initiative have attempted to close some of these gaps, but no global initiative with the authority of CORDEX existed until recently. Therefore, the CORDEX-ESD initiative was launched in 2013. To stimulate and coordinate initial discussions, and to develop a prototype experiment for validation, a series of three workshops with broad participation from the international statistical downscaling community was organised. The final workshop in Cape Town in June 2015 initiated a discussion on the midterm plans for CORDEX-ESD. This document is the outcome of this discussion.

Mission and Objectives

The mission of CORDEX-ESD is to guide and coordinate the development, validation and use of statistical downscaling methods, and also to contribute to the generation and interpretation of region-specific climate change projections. The specific objectives of CORDEX-ESD are

- to foster communication, collaboration and coordination within the ESD community,
- to improve collaboration with the RCM and GCM communities and with stakeholders;
- to produce an authoritative description of a technique family tree;
- to develop a framework for ESD studies;
- to develop a protocol for validation of regional climate projections and assessment of added value, with a focus on statistical downscaling and correction methods;
- to contribute to a framework for high-end regional climate change studies, including CORDEX Flagship Pilot Studies (FPS) and WGRC Frontiers of Climate Information (FOCI) projects;
- to contribute to the international archives of regional projections (e.g. Copernicus.eu);
- to provide cohesion across the ESD community towards major scientific questions, such as:
    - how to distill information out of multi-method downscaling?
    - how can ESD contribute to the integration of GCMs/RCMs/ESD for regional information?
    - what are the shortcomings of downscaling methods and what are major pathways for model improvement?
    - What are alternatives to provide optimal region-specific information? (thinking out of the box)
    - How will climate change manifest at the regional scale?

Positioning CORDEX-ESD in regional climate change research

ESD is a key ingredient of many region-specific climate change projections, and widely used as input for impact modelling and to inform adaptation planning.

Any downscaling crucially depends on the driving global climate model. Depending on the context, ESD can either be used as an alternative to dynamical downscaling (in the form of classical perfect prognosis statistical downscaling or bias correction), or as an additional post-processing of dynamical downscaling (e.g., in the form of bias correction). Statistical and dynamical approaches can in principle be joined into a multi-method ensemble, although it is currently unclear how multi-model ensembles of statistical methods should sensibly be designed.

Projections of multi-model-multi-method ensembles typically span a broad range of possible changes, often contradictory even in sign. In this context, two issues are essential for the provision of plausible and defensible region-specific climate projections: first, understanding the ensemble spread and ultimately resolving potential contradictions. And second, understanding whether the simulated model spread is representative of our real underlying uncertainties, or whether essential deep uncertainties remain unquantified. Addressing these issues is a key exercise for distilling climate information from the ensemble of simulated changes. An important aim of CORDEX-ESD is therefore to contribute to climate information distillation. This also requires improving the communication of ESD researchers with global climate modelers, dynamical downscalers, impact modellers and decision makers.

ESD and dynamical downscaling can be used complementary in many ways. Apart from the use in scenario-generation as discussed above, both approaches can be used to mutually validate each other. RCMs, in particular convection permitting simulations of summertime extreme precipitation, can serve as pseudo-realities to test whether ESD methods correctly capture climate change signals. Conversely, ESD methods can be used for process-oriented validation of dynamical downscaling: statistical models linking large-scale circulation variables to local-scale surface variables can be calibrated to observational data as well as RCM simulations, to test whether RCMs correctly capture such scale relationships. Similar statistical downscaling models can be conceived for emulating small scale processes such as local convection, that would need expensive high resolution simulations. Such analyses and modelling studies also improve our physical understanding of regional climate change. CORDEX-ESD aims to explore these possibilities jointly with the RCM community.

CORDEX-ESD acknowledges the advanced coordination and production of generic gridded scenarios within the RCM community, in particular the development of a common protocol. But at the same time, we highlight that users often need tailored local projections, which could be delivered by ESD. In fact, the key strength of modern statistical downscaling approaches is not to provide generic high-resolution projections for large domains, but rather user-tailored regional products. Therefore, CORDEX-ESD aims to extend the CORDEX protocol to better accommodate user needs, and to integrate results from both dynamical and statistical downscaling. Synergies are expected with the ongoing development of protocols for high-resolution convection permitting simulations.

Ideal means to stimulate and streamline these interdisciplinary activities are the recently started (and planned) CORDEX Flagship Pilot Studies. These projects address key issues of high-end regional climate modelling; a collaboration between ESD and dynamical downscaling is sought. Frontiers of Climate Information projects are intended to foster interdisciplinary collaboration between RCMs and ESD, with other relevant groups such as the GCM communities, GEWEX, GCOS and the Impacts Adaptation and Vulnerability community to address the climate distillation problem for selected case study regions.

Organisation of CORDEX-ESD

CORDEX-ESD is currently organised as an ad-hoc global community, coordinated by an executive committee. Having a well organised global community is essential for fulfilling the objectives listed above, in particular harmonising activities such as developing common frameworks and evaluation standards, an authoritative description of methods, and a unified language. A short-term aim is therefore a formal approval of the CORDEX-ESD executive committee by the CORDEX Science Advisory Team (SAT) to continue its work as a CORDEX task force, predicated on the momentum it has already achieved. CORDEX-ESD would keep the SAT updated on developments.
A further regional organisation might, however, be necessary to achieve its region-focussed aims. Stakeholder engagement as well as the implementation of specific Flagship Pilot Studies are inherently regional and call for regional branches of CORDEX-ESD. Therefore, one aim of CORDEX-ESD is to additionally integrate into the regional CORDEX branches. One possible example is given by the recently established ESD-working group of EURO-CORDEX, which essentially comprises the statistical downscalers from VALUE. Another is the SAT-approved FPS in South America.

Planned Activities

Method development and validation

The results of the EU COST action VALUE as well as the discussions at the CORDEX-ESD workshop series highlight the need for improving downscaling methods, improving the conceptual basis of downscaling applications, and for improving the evaluation of regional climate projections. CORDEX-ESD aims to stimulate and coordinate substantial improvements of ESD and related methods, in particular with respect to the representation of

- spatial dependence across multiple sites;
- dependence of multiple variables;
- processes at sub-daily time scales;
- extreme events;
- representation of local (sub-grid) variability, e.g., by combining bias correction and ESD approaches;
- local long-term trends, in particular in the presence of local feedbacks, by means of statistical emulators.

In parallel to the development of methods, a framework for the validation of region-specific climate projections needs to be developed. Such a framework comprises both the design of suitable experiments as well as the choice of suitable diagnostics.

The validation framework should acknowledge both the complex nature of regional climates as well as specific use cases and thus also address complex phenomena such as drought or the timing of phenomena such as the onset of the rain season. The framework should further be designed in a way to inform users about the appropriateness of specific methods (the general approach, the transfer function, the choice of predictors) in a specific user context.

Although no validation will give a definite answer whether a projection is correct, a validation has to be as rigorous as possible. This does not only include the validation of downscaling methods in present-day climate, but also the validation of ESD methods in future pseudo-realities, and the validation of the full GCM-downscaling chain in present day climate. To increase the credibility of future projections, process-oriented diagnostics need to be developed that link the downscaled outcome to user relevant weather phenomena.

In this context it is essential for ESD to assess (1) the perfect prognosis assumption, i.e., the assumption that the predictors are bias free in present climate and credible in future climate, and (2) the informativeness assumption, i.e., that the predictors carry all relevant information about the predictand variability from short time scales to climate change. Here, comprehensive studies are required that assess the representation of long-term trends. A key challenge for a validation framework is to sensibly test the performance of bias correction methods, and their applicability for climate change projections. Here it needs to be assessed whether (1) the predictors are realistic in present climate and credible in future climate, and (2) are representative of the local conditions and their climate change signal. For both approaches, the validity of the model structure (i.e., the way how predictors are mapped onto the predictands) needs to be evaluated.

A framework for validation should also tackle uncertainties/errors in reanalysis and observations and better understand their consequences. This issue comprises understanding the relevance for different use cases, how to quantify the resulting errors in model calibration and ultimately downscaled climate projections, and how to potentially mitigate these effects by using multiple reference data.

Framework and protocol for ESD-based climate projections

A framework for ESD-based climate projections must ensure transparent and reproducible results that are as robust as possible, easily comparable and accessible for users. Thus, a protocol should ensure the following points:

- Best practice in model development and (region specific) predictor selection;
- different sources of uncertainty should be sufficiently sampled; approaches to combine multiple statistical methods into ensembles need to be developed;
- common data standards that are easy to use by both downscalers and users have to be defined (either gridded in CMOR standard, station standard to be defined);
- experiment standards have to be defined including the definition of time periods and the handling of stochastic simulations;
- a set of meta data has to be compiled to define methods applied in a specific experiment as completely as reasonably possible, including information on the predictors;
- meta data in turn require a controlled vocabulary.

Contribution to international archives, including flagship and frontier projects

CORDEX-ESD will contribute to the international climate model data archives. A key strength of ESD is the provision of user-tailored, but spatially limited projections (typically ranging from a few sites to a region or country). A framework needs to be defined to include such data sets in an efficient, transparent and rigorous way that meets the high quality standard of CORDEX. The character of ESD data sets (similarly with convection permitting simulations) will be different from the standard CORDEX simulations, as smaller regions, potentially station data, and often only one ESD method will be considered. Because of the availability of a wide range of different methods, with different underlying assumptions and often poorly understood limitations, such a framework arguably has to include results of a common validation. For this reason, results and methods may benefit from case studies, examples, and best practices (perhaps also explanations why poor choices do not work).

Gridded data will follow the CMOR standard and directly extend the CORDEX RCM simulations. For station data, a new protocol has to be defined. The main data channel will be the ESGF, in Europe also Copernicus. For individual regions also platforms such as IS-ENES will be employed.

Distillation problem

Generating plausible, defensible and actionable information from multi-method region-specific climate projections is a key challenge for regional climate research. It includes a series of scientific questions:

- how to establish plausibility/credibility? This involves understanding the assumptions underlying different approaches, and requires a detailed physical understanding of the climate of interest, including climate change. Storyline approaches arguably are particularly suited for producing plausible information.
- what are the sources of uncertainty? This involves more than the analysis of model (and method) spread, but also a separation of error sources, sensitivity studies, tracking the influence of large scale GCM biases on local-scale variables, a better understanding of internal climate variability, and assessing the uncertainties resulting from imperfect observational data sets. Additionally, it requires developing an understanding of deep uncertainties, which are not sampled by standard models used operationally. The latter argument holds in particular for small-scale extreme events.
- what are the limitations of downscaling? Which gaps between downscaling and user needs cannot be closed? And what could be alternatives to downscaling?

CORDEX FPS and WCRP FOCI projects are ideal vehicles to address these issues in focussed and concerted actions. These projects will be ideal testbeds to develop improved ESD methods, to explore how ESD and RCMs can be combined to understand regional climate, to develop rigorous validation procedures, and to produce user-tailored information, possibly including storylines.

Exploration of alternative usages of ESD and statistical modelling

ESD, and more generally statistical modelling, is a powerful approach that can be used in a variety of climate research contexts. For instance, ESD has been successfully used to evaluate the ability of dynamical climate models to simulate the empirical links between large and small scales, i.e., ESD can be applied for process based evaluation.

Next steps

- Definition of a CORDEX-ESD-Protocol/Framework
  - Finalizing an experiment design (downscaling in present day, applicability in the future, ...)
  - Definition of a common naming system and the Data-Reference-Syntax
    - including definition of a file-design for gridded and station based ESD-results
  - Definition and development of validation standards + procedures
- Future research tasks:
  - Development of methods for
    - multi-site + multi variable
    - sub daily and extremes
    - downscaled multi-model ensemble projections
  - scientific understanding of
    - predictor stationarity; more specifically, stationary means that (1) the statistical model includes the right predictors to represent climate change, and (2) that the model structure is suitable for extrapolating to the climate state we are interested in;
    - dependence on training data sets (both predictor and observations)
    - idealised experiments (check with Chris)
    - what are the weaknesses of bias correction?

Action points

1. ”trend checks” in first experiment (is this feasible? Can we trust trends in reanalysis predictors?)
2. GCM experiment
3. develop physical validation diagnostics
4. development of data format for station data
5. pseudo-reality experiment
6. development of experimental framework (scenarios, historical, hindcasts; account for stochastic approaches)