SCIENCE INSIGHTS

CORDEX: Assessing its Progress, Roles, and Challenges

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The downscaling project has galvanized research into local and regional climate change impacts, but it is a mistake to use CORDEX data in isolation for robust, global physical risk analysis.

Abstract

This report summarizes the goals behind the CORDEX initiative, the progress it has made, and the challenges it faces. It also discusses the reasons why its data and models are not currently the best choice as the foundational data set for reliable and robust physical risk analysis of the kind used for global risk management and resilience decision-making.

CORDEX research has been extremely useful for learning and comparison. It has enabled a large scientific community to address the topic of climate change impacts at both the regional and national levels. Its growing body of research benefits the development of novel downscaling approaches and applications that have been built for decision-makers. This report urges that the scientific community continue to watch, evaluate, and support CORDEX efforts.

We caution that CORDEX is not designed to provide the consistent risk analysis necessary to make global financial and policy decisions and to do so would be a mistake. More importantly, depending on CORDEX to be a sufficient set of data for analysis is extremely limiting. We detail nine shortcomings that render it currently unsuitable for robust global climate risk assessment. Instead, a toolbox spanning available downscaling methods suitable for parameter, time and space scale, and use case should be deployed in globally consistent ways to meet sustainable business requirements.

Background and goals of the CORDEX program

The **CO**ordinated **R**egional **D**ownscaling **E**xperiment (**CORDEX**) is an initiative of the World Climate Research Programme (**WCRP**) born from the need identified within the scientific community to study climate change impacts at a national level (Giorgi et al., 2009).

This was a necessary, and so far productive, step to augment the work of the Intergovernmental Panel on Climate Change (**IPCC**) contributors focused on global climate change and the general circulation modeling that supports it. As a coordinated but distributed effort, the vast majority of financial support for CORDEX comes from national-level funding agencies, or world funding agencies that support nations with smaller research budgets. The community recognizes that scientific endeavors can be more impactful and focused when an organization such as the WCRP supports a framework for information and idea exchange and also develops protocols for contributing organizations. CORDEX can be distinguished from other high-profile downscaling experiments by its focus on direct dynamical downscaling, which embeds a regional model directly in a global circulation model (**GCM**). The first attempts within any early body of research often lead to more questions than answers, and CORDEX is no exception.

Further coordination and scoping under the WCRP framework have led to current and future CORDEX activities aimed at downscaling the most recent global model projections (Gutowski Jr. et al., 2016). While those CORDEX contributions have yet to mature (and, in most cases, appear), the goals of the activities are clearly stated in that paper:

1. To better understand relevant regional/local climate phenomena, and their variability and changes, through downscaling
2. To evaluate and improve Regional Climate Downscaling (**RCD**) models and techniques
3. To produce coordinated sets of regional downscaled projections worldwide, and
4. To foster communication and knowledge exchange desired to support the development of regional research programs.

National and organizational interests drive specific modeling details, and by construction, the collection of CORDEX simulations is not meant to present a unified or consistent view. In its role, the WCRP serves the essential role of coordinating various organic activities across the globe. It provides the framework for model intercomparison when national efforts make that convenient. Those intercomparisons can be a valuable part of evaluating the models and lead to improvements; for them, details such as time ranges and climate scenarios (RCPs or SSPs) are chosen as specific simulation goals.

Clarifying the role of CORDEX

CORDEX has served—and will continue to serve—a valuable scientific purpose by enabling a large scientific community to participate in inquiry addressing the broad topic of climate change impacts at the regional and national level. But it is important to remember the role of CORDEX. A recent paper by Fiedler et al. (2021) points out the dangers of using climate models and derived data without a clear understanding of their limitations. Like any other source of data, data resulting from CORDEX has some important limitations for application to financial use cases, even if the science is solid.

CORDEX is a proven enabler for the scientific community that is interested in exploring the regional effects of climate change. A quick Google Scholar search indicates over 1,000 publications and presentations on the web (not just peer-reviewed) with the acronym CORDEX in the title, and over 13,000 in which CORDEX appears anywhere in the text. WCRP activities provide credibility to national-level organizations that seek funding for regional downscaling experimentation. The science born from these distributed-yet-coordinated efforts has in turn advanced knowledge of both the strengths and weaknesses of dynamic downscaling approaches. As a result, the quality of dynamical downscaling has improved over the last 20 years.

The challenges that CORDEX must meet

Major challenges remain, as discussed by Gutowski Jr. et al. (2016), which form the primary goals of the ongoing CORDEX campaigns that are still in their early days. To quote:

1. ... The use of [Regional Climate Downscaling] RCD[1] techniques does not always result in more valuable information for scientific analysis and [vulnerability, impacts, and adaptation] VIA applications.

2. High-resolution models are especially useful tools to study the effects of human activities on regional and local climates. Typical examples of these effects are those induced by land-use change and urban development (in particular the growth and spread of coastal megacities) or by aerosols of anthropogenic origin.

3. ... greater integration and coordination across regional settings [would be beneficial].

4. ... CORDEX can provide an optimal framework to improve the robustness in the projection of change in regional hydroclimatic regimes.

5. The CORDEX initiative can provide an essential contribution in ... research [addressing high resolution and extreme winds].

Unsuitability for global financial or policy decision-making

Despite its clear utility in advancing scientific discovery and improving modeling focused on regional and national impacts, CORDEX was never envisioned as a basis for global financial or policy decisions regarding impacts, adaptation, and resilience. Neither of the two guiding documents suggests that as a goal (Giorgi et al., 2009; Gutowski Jr. et al., 2016). The organizational structure underlying CORDEX and the research born from the coordinated effort demonstrate clearly why it would be irresponsible to use CORDEX output as a foundational data source for these use cases.

CORDEX activities are extremely useful for learning and comparison, but they do not add value to current approaches that are more scalable and globally consistent that render downscaled climate data to inform impacts, adaptability, and resilience. There are nine key reasons why:

1 RCD here refers to the use of Regional Climate Models in dynamical downscaling experiments.

1. CORDEX makes no attempt to normalize the overall methodology or models used. The lack of consistency in methods is problematic for global quantitative interpretation.

2. Most of the continents are covered at 20-50 km grid spacing. Some regions have closer to 12 km grid spacing for a single regional climate model (**RCM**). Overall, these resolutions are insufficient to simulate the dynamics needed to capture extreme hydrometeorological and wind events. A resolution of 4 km or less is needed to capture convective rainfall dynamics and avoid parameterization (see item 3). A similar resolution is usually needed to capture the effects of complex terrain on the wind, as well as land-sea and urban-rural contrasts that strongly influence temperature.

3. The CORDEX simulations, even when embedded within the same GCM, can show different climate trends (e.g., drying versus more rainfall). This is a result of inconsistencies in how rain-producing convection is parameterized. In addition to different RCMs not agreeing with first-order trends, the largest scales in a CORDEX RCM do not always agree with the same scale in the forcing GCM, revealing inconsistencies between the RCM and the GCM. Parameterization is required at the resolution of CORDEX simulations. These conflicting trends make interpretation extremely difficult.

4. CORDEX contributions are not required to be based on simulations embedded within any particular GCM, further complicating the interpretation.

5. It will be years before CORDEX can reflect CMIP6/AR6. All contributions are currently based on CMIP5.

6. With few exceptions, CORDEX reflects only RCP 4.5 and 8.5, which limits analysis of the possible range of global outcomes. Addressing this is an explicit goal for future CORDEX work.

7. A lack of ensembles inhibits robust extreme value calculations. Addressing this also is an explicit goal for future CORDEX work.

8. CORDEX lacks information to assess risks associated with tropical cyclones.

9. Relying on an organic, distributed funding network for continued maintenance and development of CORDEX puts enterprise decision-making at risk.

The basis of our opinion

Precipitation (items 2 and 3 above) is a key driver of the flood, heat, drought, and wildfire perils, and is of course essential to any water resource conversation. It thus deserves further scrutiny. The process of deep convection within an organized complex, or embedded within larger-scale frontal systems, is responsible for several weather impacts that are changing with the climate; these impacts result from extreme precipitation that drives local and regional inland flooding, damaging winds, and hail. Deep convection also supplies the majority of water for agriculture in non-irrigated farming regions. Deep convection occurs on the scale of meters to tens of kilometers in the atmosphere; modeling the organized complexes characterizing the large end of that range requires accounting for processes from the size of ice crystals to the width of the convective plumes that comprise the larger complexes.

The dynamics of deep convection are far from resolved in GCMs; that fact is a primary driver for the entire downscaling enterprise. Deep convection is most often entirely parameterized in numerical models operating at grid scales greater than approximately 8 km. The parameterizations primarily remove water in its various forms from the atmosphere as precipitation, vertically redistribute heat resulting from rapid phase changes (heat produced by water vapor turning to water droplets and ice crystals), and vertically redistribute the various forms of water. Models with grid scales below 3 or 4 km, termed Convection Allowing Models (**CAMs**), explicitly redistribute the heat and water (vertically and horizontally), while parameterizing the phase changes and other details at the scale of the water droplets, ice crystals, raindrops, hail, snow, etc. At 4-8 km grid spacing, only the very largest scales of organized deep convection begin to be resolved, creating a conflict with the parameterized convection intended to be well below grid scale.[2]

Parameterized convection serves a critical role in GCMs and regional modeling employing grid scales greater than 8 km, but it cannot simulate precipitation characterizing extreme events. It is a key reason for the diverging impacts found in CORDEX simulations for the same region. The redistribution of heat and water has a profound and far-reaching effect on the simulation well beyond precipitation; it can impact every prognostic and diagnostic variable in the model (velocity, temperature, pressure, etc.). Parameterization by its nature is based on empiricism rather than first principles. Though the many schemes can be grouped broadly by their functional structure, the details of each means that the effect on model simulations can vary widely. More fundamentally, the climate of different models employing parameterized convection can diverge, because the variability in schemes can introduce problematic inconsistencies between regional embedded models that parameterize deep convection and the GCMs in which they are embedded.

Conversely, solutions to the equations of motion that govern resolved convection are far more consistent and settled. The peer-reviewed literature is unambiguous about the benefits of CAMs in simulating the dynamics governing extreme precipitation, and the additional simulation benefits that result; while gains are easy to measure when stepping from 12 or 9 km to 4 or 3 km (for example), and further benefits from even higher resolution exist, they are less clear and more variable.

The theory is clear, and the goals of the weather prediction community have been built on this foundation for the last 20 years. Regional CAMs have been operational for over a decade, and organizations with the greatest supercomputing capability are on the brink of useful global CAM predictions. Because of parameterization of other processes that still require it, CAMs can diverge in weather prediction settings, but this divergence is far less severe and is at the detail level. More importantly, we can expect the climate of regional CAMs to be more consistent from model to model. Additionally, though regional CAMs are often embedded within global weather models, the primary inconsistencies associated with that can be addressed by successively stepping down in scale. The CAM for weather forecasting is ultimately embedded within a regional model that has a far greater affinity with it, thus minimizing inconsistencies.

2 The dynamics of deep convection require simulations on the order of meters to tens of meters to be fully distinct from parameterized convection, but that is impractical here and meaningful discussion is around benefits of km-scale simulations versus larger.

The benefits of CAMs are easy to argue, but, in practice, coordinated efforts toward CAM deployment in the scientific climate downscaling community will remain elusive for years to come. A jump from 12 km to 4 km requires an order of magnitude greater computational capability than current-generation CORDEX activities require, which could immediately alienate most of the CORDEX community from participation. This coordination is thus not likely to happen as a WCRP-coordinated activity anytime soon.

The inconsistencies and lack of fidelity to hydrodynamic extremes have motivated the most recent downscaling experiments, which have employed regional CAMs (e.g., Leutwyler et al., 2017; Liu et al., 2017). Because of the massive computational capacity required to deliver regional CAMs, they simulate only historical, mid-century, and end-of-century conditions. By construction, they cannot capture decadal time-scale oscillations in the atmosphere and ocean, for example, or the path to the middle and end of the century. These recent and current efforts at downscaling with CAMs avoid the pitfalls of the direct dynamical downscaling of future GCM output that characterizes CORDEX. Instead, approximations are made so that historical conditions, scaled for future climates, with the availability of more suitable boundary condition information, drive the CAMs. That provides a sound basis for modeling, while the limitations of the approximations can be explained and considered in interpretation of any results.

Decisions about global asset portfolios can benefit from consistent methodologies drawn from (and built upon) a wide range of peer-reviewed downscaling techniques. They require a different approach to dynamical downscaling than those designed to answer broad scientific inquiries. Neither dynamical nor empirical downscaling is the best choice for all parameters and use cases. Innovative systems that leverage the breadth of possible approaches are already in use in leading private sector organizations. Drawing from the peer-reviewed literature, including the CORDEX literature, they focus on extreme events rather than long simulation periods, leverage the scalability of cloud computing, embed regional high-resolution models in ways that mitigate the inconsistencies associated with parameterized deep convection, and combine dynamical downscaling with consistent empirical downscaling approaches (also widely used). The result is enterprise-grade, flexible, scalable, consistent, and defensible downscaled impacts that are suited to individual and compound hazards.

The mobilization of the global scientific community under CORDEX should be applauded; its lessons and capacity go far; CORDEX data can certainly be useful in limited downscaling use cases, but to base global financial and policy decisions on CORDEX output is a mistake. We should continue to watch, evaluate—and indeed support—CORDEX efforts. The outcomes of the growing wealth of CORDEX research will continue to inform systems built by those at the forefront of applications aimed at decision-makers. Simultaneously, the case for global CAMs (Palmer & Stevens, 2019) provides the roadmap for the revolutionary change in climate modeling we can all support.

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