WCRP REPORT

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REPORT

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Executive summary and key outcomes

More than 400 scientists, all interested in regional climate, came together in Brussels, Belgium, in early November 2013 for the 2nd International Conference on CORDEX (Coordinated Regional Climate Downscaling Experiment). This conference was embedded in a wider event on Regional Climate Change jointly organized by the World Climate Research Programme (WCRP), the European Commission (EC) and the Intergovernmental Panel on Climate Change (IPCC). The first day of this important gathering featured a High Level Session with the participation of the EC Commissioners for Research & Innovation and for Climate Action, where the IPCC presented key findings from the Working Group I Contribution to the Fifth Assessment Report *Climate Change 2013: The Physical Science Basis*. This was followed by a Stakeholder Dialogue session focusing on how regional climate information can best serve the needs of policy and decision-makers. This segment was intended to provide the socio-economic and policy contexts within which WCRP regional climate research activities and programmes operate.

During the following three days dedicated to regional climate science, the oral and poster presentations highlighted the achievements of the first phase of the project (CORDEX-I). CORDEX–I has been a successful framework in which scientists around the world adopted a common protocol to guide the development of high-resolution Regional Climate Model (RCM) and empirical statistical downscaling (ESD) projections, and the intercomparison of these projections, on each continent. The conference provided evidence that much of the work underway is relevant to the climate change vulnerability, impacts and adaptation (VIA) studies and that CORDEX must address several key challenges in order to better serve these communities. Indeed the scientists recognized:

1. the need to establish a two-way dialogue with the end users of regional climate information so as to ensure an appropriate tailoring of the CORDEX outputs to the decision makers' needs;
2. the demand for training activities that build capacity for interaction among practitioners, policymakers, scientists and other societal decision making groups;
3. the importance of high-resolution observational data sets, and availability and accessibility of model products in support of the evaluation of regional climate simulations;
4. the need to develop mechanisms to communicate the scientific uncertainty generated by regional climate modeling and the implications that post-processing techniques such as bias corrections and those uncertainties can have on VIA studies.

These issues revolved around a recurrent theme of "added value" of the regional dynamical and statistical downscaling methods especially as currently challenged by the advent of high-resolution global models. As a result there was consensus on the need to rigorously demonstrate the reliability and usefulness of the CORDEX outputs as well as to improve the representation of the physical processes in regional models.

The conference proposed some concrete actions for further advancing the CORDEX science and to better engage the VIA community:

1. Revisit the CORDEX domains and develop a clear-science based procedure for their selections;
2. Support the development of high-resolution observation datasets and archiving infrastructures such as the Earth System Grid Federation (ESGF);
3. Develop metrics to assess the added value of the regional downscaling model outputs as compared to global climate simulations;

4. Establish end-to-end pilot studies over selected sub-regions together with other WCRP regional initiatives and in partnership with the WCRP Working Group on Regional Climate;
5. Review the multi-model multi-method matrix of simulations to ensure a robust characterization of climate uncertainties;
6. Design and implement capacity building activities that bring together information providers and decision makers towards meeting regional needs.

These proposed actions resulted from the various scientific sessions that are summarized in the present report and which will help improve the experimental framework leading into the second phase of CORDEX (CORDEX-II). It is hoped this will represent another milestone towards the effective delivery of climate services.

For more information, see http://cordex2013.wcrp-climate.org/.

TABLE OF CONTENTS

Evaluation of CORDEX regional downscaling: Present climate and future change

Plenary session A1 "Review of CORDEX and WCRP Regional Climate Science"

Chairs: F. Giorgi, B. Hewitson

Rapporteurs: C. Jones, M. Rixen

Co-chairs of the Science Committee of the Conference welcomed all participants to the Science Segment of the "International Conference on Regional Climate – CORDEX 2013" and noted that this was the third pan-CORDEX event, with attendance doubling each time since the first edition.

The Chair of the Joint Scientific Committee of the WCRP briefly summarized the outcome of the High Level Session and Stakeholder Dialogue, placing the scientific component of the conference into a wider stakeholders' context. A number of important events are shaping the future of the WCRP agenda into six Grand Science Challenges, one of which is focusing on "Regional Climate". He also recalled the importance of CORDEX and its relevance for application into the GFCS key priorities on health, water, agriculture and food security and disaster risk reduction.

The session stressed the need to engage users in co-exploration to build understanding of requirements, as there is currently a huge gap between climate science and on-the-ground decision-making. End-users are facing paralyzing choice from contradicting information and some 'distillery' mechanism is needed to support the decision-making process. It was suggested to seek defensible messages on scales in time and space of relevance to regional users towards the responsible adoption of downscaled data.

The evaluation of downscaled models goes beyond the comparison between RCMs forced by reanalysis and observations, and highlighted the need to assess added value of downscaling against global climate models. The sensitivity of impact projections to data processing, ensemble and bias correction techniques, impact models and socio-economic scenarios deserves more attention. The major challenges ahead of CORDEX include the availability and accessibility of large amount of data, the integration of users and decision makers into regional climate science, and the way to educate end-users on limits to regional climate information.

The value of information is measured by its ability to support a decision. Using climate information presents institutional, knowledge base and practical challenges before awareness can be transformed into action. This will require building better links to the development community, understanding the differences between data, information and knowledge, developing a new science paradigm and seeking expert guidance towards meaningful decision-making.

Initial priorities for CORDEX established in 2009 were reviewed. CORDEX is an experimental framework for assessing regional climate change, with particular emphasis on the comparison, evaluation, documentation and improvements on Regional Climate Downscaling (RCD) techniques and on the support to regional capacity building. Four essential steps for a worthwhile CORDEX were discussed, namely the generation of simulations/projections, the analysis and documentation of results, the availability of data and the engagement in its subsequent use. There is a healthy (to be defined) future for CORDEX to support the translation of research into usable information, by leveraging global (regional) scientific capacity and enthusiasm, and by exposing data to end-users as soon as it becomes available.

Key findings of the regional climate science in the IPCC AR5 WGI were presented. Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in the reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes. Regional examples were presented and the Atlas of Global and Regional Climate Projections was discussed in detail. There is a need to aggregate regional results to allow pictures/trends to emerge and to draw conclusions.

Regional climate projections were analyzed against global models over different CORDEX regions using REMO. The historical period was well represented in both cases. However there are biases in the control period for overlapping regions. Precipitation decreases in temperate oceanic regions in both global and regional models in all domains. In Central Africa, the projected climate is wetter in MPI-ESM, but dryer in REMO. Future studies will investigate how other driving models are modified by REMO and other RCMs.

The Phase I CREMA experiment covers 33 scenario simulations covering 1970 to 2100, the 1976-2005 period being used as a reference. The ensemble includes different GHG RCPs, driving GCMs and RegCM4 physics configurations. The projections showed substantial sensitivity to all these factors (sources of uncertainty). The output from these simulations (about 200 TB) will be made available into the CORDEX data nodes for further analysis and for use in impact assessment studies.

African monsoons in global and regional climate models were reviewed. RCMs driven by the perfect boundary conditions simulate recent climate in Africa with different level of accuracy. The multi-model ensemble average reproduces the observed climatology pretty well. Downscaling of GCMs can reduce spread/biases across GCMs, especially over West Africa. Local-scale processes can be more important than the driving GCM signals. There is a need for more detailed studies on RCM physics. Simulations are openly available via the ESGF and more simulations will be published in the future.

CORDEX climate simulations for Africa using COSMO-CLM (CCLM) were presented. Large-scale features related to precipitation are influenced by the driving GCM regional features, such as the monsoon rain belt. Extreme events like consecutive dry and wet days seem to be more realistic when using RCMs. He further stressed that results of single RCM must not be considered as “significant” or “likely”. Results of different RCMs might be contradictory even if they are based on the same forcing GCM. Thus, a multi-RCM-multi-GCM ensemble based analysis is mandatory to derive statistically significant climate projections for Africa.

CanRCM4 and CRCM5 simulations over the CORDEX- Africa domain were used to evaluate daily precipitation statistics and the monsoon onset-offset over western Sahel. Referring to various observation data sets, important differences in climate indices and frequency distributions over Sahel were noted. Precipitation differences between reanalyzes regarding frequency distribution (e.g. on light precipitations), and width of precipitation bands were found. Simulations showed local monsoon onset differences.

Projections of rainfall events in CORDEX simulations for southern Africa showed that extreme events represent a large fraction of the expression of climate related impacts and are therefore important for vulnerability and adaptation issues. The added value of downscaling GCMs accounting for vegetation variations, complex topography and coastlines was demonstrated and showed an intensification of both wet and dry seasons, with dry spells becoming longer, and precipitations becoming more intense, and a decrease in growing season days. These conclusions have direct implications for agriculture in the region.

Poster session P1 "Regional Focus"

Rapporteurs: Ailikun, Linda Mearns

Regions

Among 70 posters in P1, 50 focused on the EU domain, 12 on Asia, 8 on North, South, and Central America, 5 on Africa, 7 on the Arctic, 2 on the Antarctic and 2 on the Middle East domain. The polar regions are receiving more attention, which development is welcome.

Themes

In terms of themes, 9 posters focused on model development and parameter tests, 38 on model evaluation (mainly temperature and precipitation), 11 on future projections, 6 on impact studies and 5 on miscellaneous topics such as statistical downscaling. The high number of posters on evaluation as opposed to investigation of projections likely reflects the greater availability of CORDEX data for the current period compared to future periods.

Summary and discussion

There were several useful comparative domain studies: (e g. over the Caribbean) and a number of studies of simulations over the Arctic. Domain studies included investigation of domain size and extent as well as horizontal resolution.
There were also some studies that examined variables beyond just temperature and precipitation (e.g., humidity). There are also now more studies of variables and indices (e.g., drought indices) that are important to the impacts community.
The topic of extreme events in regional models was examined in several of the posters, such as extreme precipitation over the Alps in the high-resolution Euro-CORDEX runs. Temperature extremes were also investigated in RCMs in the coastal regions of the Aegean and in Croatia. Improved reproduction of extremes is one of the clear signs of added value in regional model simulations.
A number of studies exercised the models by testing the effect of different parameterization schemes, such as those for convection, and different surface schemes (particularly in the RegCM). These studies are useful to help determine model sensitivity and to evaluate combinations of schemes that work best for a particular model.
It is a good sign that the CORDEX results are already being used for impacts studies, since this indicates a high interest in this type of application. The use of CORDEX results for impacts is an important program goal. As more data becomes available, more studies of this sort will appear.

Poster session P3 “Regional Focus (continued)”

Rapporteurs: A. Gobiet, C. Lennard

Themes

Five broad themes were identified: Monsoons over East Asia, West Africa and South America (10 posters); model evaluations that were regionally specific (12); extremes including rainfall and drought (7); regionally specific future climate change (9); downscaling methods including the combination of dynamical and statistical methods (2). Ten posters that did not fall into these broad categories were also displayed which dealt with lakes, forests, climate classes, adaptative water management, resolution comparison, nudging, RCM-GCM comparison, perturbed physics, the effect of land use change and seasonal prediction.

Regions

The posters considered five regions, namely Africa (25 posters), East Asia (19), South America (6), Australasia (2) and one joint North and South America poster. Of the 25 African posters, 16 were 1st authored by Africans.

Discussion

1. The African and Asian domains have very good uptake of CORDEX data by local scientists. This superbly demonstrates the CORDEX goal of regional capacity development.
2. Most multi-model studies were by groups who were not the model developers. This likely provides for a more holistic and objective assessment of the model output and is a very positive side-effect of CORDEX that perhaps was not anticipated.
3. There were no papers on model development. During questions, one modeling development group requested feedback from the analysis teams as this could help with model development and paper writing. Forming analysis - model developer collaborations is another great opportunity for CORDEX.
4. There were more evaluation studies than projection studies, however, this will change as the projection data becomes available.
5. There were many diagnostic studies (rainfall, temperature) and few process/circulation based studies. Was this a data availability issue? There is large area of potential here for future CORDEX programs with challenges of getting data to local scientists.

Parallel session B1 “Europe and Polar Regions”

Chair: D. Jacob

Rapporteurs: M. Déqué and G. Nikulin

An overview of Euro-CORDEX activities has shown that 27 groups have produced two large ensembles of simulations at 50 and 12km resolution. A few simulations from both ensembles are already openly available (ESGF) and more simulations will be published soon. Provision of simulations to users, with bias correction, is also planned. Selection of GCMs for downscaling, filling of the GCM-RCM matrix and added value of hi-res simulations are discussed.

In the same effort, the Med-CORDEX project focuses on the Mediterranean region. 22 groups with atmospheric, ocean and coupled RCMs are involved running simulations at both 50 and 12km resolution. The completed simulations are available at the Med-CORDEX database. An improvement of the simulated precipitation in hi-resolution simulations was demonstrated. The first results show that projected climate change signal (temperature and precipitation) is not the same in the atmospheric and coupled RCMs.

Summer heat waves and interannual variability of the frequency of hot days are well simulated in the Euro-CORDEX ensembles (50 and 12km) and do not depend on horizontal resolution, although on average, the 12km simulations have a colder bias compared to the 50km ones. RCMs agree on evapotranspiration regimes in Scandinavia and the Mediterranean while they disagree in Central/Eastern Europe. The main drivers in the ensemble spread are land-atmosphere interactions and convection.

An evaluation study includes 8 Euro-CORDEX simulations at 50km and 9 at 12km resolution with 8 different metrics calculated for sub-regions. Wet and cold biases dominate at both resolutions and are not reduced with the increased resolution. Overall, there is some progress compared to ENSEMBLES (reduced warm bias in southern Europe) but no general improvement.

The SMHI family of Euro-CORDEX scenarios (9 GCMs downscaled, both RCP4.5 and 8.5) has been presented and compared to the driving GCMs. Large-scale circulation biases in the regional ensemble originate from the driving GCMs. At the same time the spread in future climate projections in the regional ensemble is often reduced compared to the global one. The selection of GCMs for downscaling was discussed in terms of large-scale circulation, teleconnections, SST, carbon cycle.

The “medicanes” (Mediterranean hurricanes) can be identified in observations, and also evaluated in Euro-CORDEX and Med-CORDEX simulations. The medicanes may become more intense in the future scenarios. A higher horizontal resolution results in higher intensity of the medicanes in some models while coupling with ocean leads to less intensity.

In the Arctic region, fewer scenarios are available: 4 simulations by atmospheric RCA4 and 2 runs by the coupled version RCAO. An increase in precipitation is observed in all seasons. The sea ice extent change shows differences between the global and regional models, with a stronger decrease in sea ice in the global models. Changes in RCAO are more independent of the global models.

As far as the Greenland ice sheet is concerned, the MAR regional model has been used for calculating the ice sheet surface mass balance (SMB). The current climate changes over Greenland are underestimated by the CMIP5 GCMs and the large spread in the SMB future projections is mainly related to the CMIP5 GCMs.

Parallel session B2 “North, Central and South America”

Chair: A. Frigon

Rapporteurs: R. Arrit and S. Solman

An overview of the on-going and planned activities on CORDEX over the various domains covering the Americas was presented. Studies focusing on the North American CORDEX domain (4) were devoted to identify the added value of RCMs; to explore the various sources of uncertainties on the regional climate projections, namely the uncertainty due to the choice of the driving GCM, the RCM and resolution and to compare the regional climate change signal as derived from the RCMs and the driving GCMs. The added value of the CORDEX simulations over the North American domain was highlighted by results from simulations performed with two RCMs that were carefully evaluated in terms of seasonal means, annual cycles, diurnal cycles, extreme events and process-based metrics. Particular emphasis was given to the evaluation of the RCMs by using statistical analysis tools (such as RCMES). It was demonstrated that this kind of evaluation tools could help gaining physical insight into model behavior compared to more common simple analysis methods.

An important outcome from the model evaluation studies suggested that careful analysis of physical mechanisms could explain differences between model simulations and observations. The impact of resolution (50km, 25km and 10km) on the quality of the simulations was explored with the CRCM5 RCM and it was demonstrated that the higher resolution does not always imply better results. Lessons learned from regional programs such as NARCAPP provided useful insights on the forthcoming CORDEX activities for the North American domain.

Studies focusing on the Central America and Caribbean domains were devoted to understand both the quality of the RCMs simulations, the impact of resolution and the regional climate change signal based on understanding the main physical mechanisms behind key processes in the region. One of these studies was focused on evaluating the interannual variability of the regional climate over Central America by using 2 configurations of the RegCM4 RCM nested into two GCMs. A detailed analysis was presented on the key physical mechanisms triggering the interannual variability signal over the region for both present climate and future scenarios. A study assessing the sensitivity of the RegCM4 RCM to convective schemes and resolution in reproducing specific climatic features over the Caribbean allowed identifying the optimum model configuration to perform long-term simulations.

Finally, a summary of the status of CORDEX-South America was presented and results from a set of 7 RCMs nested into 3 GCMs were discussed. It was highlighted that biases in the GCM-driven simulations over South America depend more on the RCM than on the driving GCM. Moreover, identified temperature-dependent temperature biases and precipitation-dependent precipitation biases suggested applying bias correction methods carefully.

Parallel session B3 “Central, South, East Asia, Australasia, Middle-East”

Chair: L. Stevenson

Rapporteurs: A. Kitoh and R. Krishnan

Provision of climate information for decision making, especially at the regional and local levels, requires a better understanding of the response of regional and local climate systems to global climate, and in turn their influence on the global system. The presentations in this session discussed various aspects of regional climate downscaling over Monsoon Asia (Central, East and South), Australasia and the Middle-East. The regional downscaling issues discussed for the South Asian region include – (a) Elevation dependency of temperature trends since 1950s using CORDEX regional climate models (RCMs) and validation with in-situ observations (b) Changes in the mean summer monsoon circulation and rainfall, future projections of extreme rainfall events (c) Assessment of skills of RCMs in capturing rainfall and circulation anomaly patterns during monsoon breaks over India and the associated precipitation enhancement over the Himalayan foothills (d) Simulation of orographic monsoon precipitation over the narrow Western Ghats escarpment in CMIP5 models and CORDEX RCMs, The talks relating to CORDEX East Asia discussed (a) The importance of resolution and the need for sub-domains with high-resolution to resolve the regional climatic features (b) Potential for improving interannual variability of rainfall over the West North Pacific region using regional ocean-atmosphere coupled models. In the context of dynamical downscaling for the Austrasian region, the presentation highlighted the importance of the selection process of CMIP GCMs and RCMs necessary for deriving usable regional climate information. The focus of the CORDEX-MENA (Middle East and Arabian domain) presentation was on assessment of climate change impacts on water resources. The presentation highlighted the importance of RCM ensemble simulations for assessing regional precipitation changes and hydrological modeling in the Middle East and Arabian Sea domain.

Methodologies for regional downscaling

Plenary session A3 "Regional downscaling techniques, status and progress"

Chair: A. Tilche

Rapporteurs: J. Christensen, F. Giorgi

An overview of dynamical downscaling methods was provided, stressing the regional focus of atmospheric models, eventually complemented by other components, and the link between CORDEX and CMIP. Fixed and variable resolutions, one way and two-way nesting techniques, surface and lateral boundary conditions were discussed. The added-value of RCMs stems from reduced computational cost allowing a better resolution of Navier-Stokes equations, orographic forcing and precipitation patterns resulting in a better representation of extremes.
A perspective on on-going statistical downscaling methods in Australia was presented, aiming at providing application ready datasets to be released in 2014 for the 20th century (1950-2005) and RCPs 4.5 and 8.5 scenarii over 2006-2100. ESD techniques are based on daily meteorological analogues and are challenges by the growing size of outputs, the limitation on available predictands and mapping between station observations and ESD grid. More reanalysis products are becoming available for ESD. The choice of predictors is limited by GCMs and requires orthogonality of predictors and a stable relationship in time. Products require post-processing and bias corrections. Their limitations, including those arising from scaling, should be communicated.
Sources of uncertainties in regional climate information were reviewed. Differences in observed precipitation estimates were emphasized. There is reasonable confidence in the multi-model average as an estimate of the observed precipitation. The same cannot be said for precipitation estimates from many of the individual models. Good simulation of the annual cycle implies that underlying processes are reasonably-well captured. Assessing the signal to noise ratio between ensemble runs shows which features of the projections on detailed changes are reliable. The significant biases in many models could imply a lack of confidence in their ability to generate realistic future climates.

The need to develop systematic set of observations, diagnostics and metrics, and associated tools for evaluating regional climate models was emphasized. Observations are required for RCM model development, evaluation, improvement and uncertainty assessment and can build on the GCM heritage. Compensating model errors can result from naïve comparisons between models and observations. RCMs so far have not undergone the same level of model development and (process-oriented) evaluation as GCMs. Tools such as the RCMES, the Earth System Grid Federation and associated obs4MIPs effort can support downscaling science.

Metrics are required to assess model performance versus a variety of observations. Basic metrics (e.g. biases, Taylor diagrams, etc using reference fields such as CRU, TRMM 3B42 and ERA-INTERIM) should be applied to all regions by default, complemented by region-specific (process-or user focused) assessments. The need for common grid interpolation was emphasized.
The Earth System Grid Federation and the European Network for Earth System Modelling were presented, with details on CMIP5 archive data service providers, data access and metadata viewing modalities and usages. The trade-off between resolution, duration, ensemble size and model complexity was emphasized. New products are coming on-line, such as those from the EU SPECS project (seasonal-to-decadal climate prediction fort he improvement of European Climate Services). As for CMIP5, ESGF can publish CORDEX data in two categories: (1) restricted to non-commercial use (2) open for any users. Option

(1) can severely reduce the impact of the data, cause confusion and divert users for less reliable datasets.
The climate is quite variable in the absence of greenhouse gas forcing (i.e. Natural Variability, NV) in particular for smaller scales and “extremes”. There appear robust small-scale features in the (greenhouse gas) forced climate change (FCC) signal. Capturing FCC with a limited number of integrations is non trivial, and depends on the ratio between FCC and NV. In general, it works better for temperature than for precipitation, and better for averages than for extremes. Bias correcting data may degrade results if the bias is due to NV.
Most of the warming over the past 50 years is attributable to human influence on climate. Whilst we understand what is happening to global temperature, it is the weather and extremes that really matter which requires science to back up the “Loss and Damage” agenda. A probabilistic event attribution approach was presented, based on the weather@home regional climate models and was illustrated in the context of the autumn 2000 flood.

Projected climate change signals of REMO over overlapping CORDEX domains differ, not only in magnitude but also in direction, with larger discrepancies in precipitation than temperature. Not clear influence of the domain size or position was detected.

The Regional Climate Science for the third US National Climate Assessment highlighted the growing temperature and longer growing season, and some more common extreme weather events. Larger changes are projected for the future.
A joint empirical-statistical and dynamical downscaling method to improve regional climate projections was presented which confronts results from both methods and takes into account the total uncertainty from different scenario, forcing models and techniques.

A statistical downscaling portal end-to-end tool for regional impact studies was presented which uses an ensemble of ESD methods under the Perfect Program approach with a set of predictors available from different reanalyzes. The portal includes free datasets and users can upload their own data. It was recommended not to use the tool as a black box and to collaborate with downscaling experts.

Poster session P2 "Methodologies"

Rapporteurs: Andrew Robertson, Samuel Somot

The 76 posters of this session addressed the following main topics leading to some key questions that could be tackled by CORDEX in the future. In brackets, we indicate the approximate number of posters dealing with a given topic.

Added-value of higher-resolution RCMs (10): Most studies to date have been conducted as reanalysis driven runs, in evaluation mode. Could added-value be shown in historical CMIP-driven mode and in future projections?

Sensitivity tests to parameterizations and nesting (9): Many studies test physical parameterization choices and the use of spectral nudging. Could we synthesize the benefit and limits of Spectral Nudging? Are RCM scenarios sensitive to physics choice or to physics inconsistency with the driving GCMs?

Combining/Comparing statistical and dynamical downscaling (15): How can statistical and dynamical downscaling be used to complement each other? How could we assess the stationarity hypothesis that is most problematic for ESD but may also afflict RCMs?

New methods for RCM evaluation (20): Evaluations use satellite data, station data, specialized super-sites, regional high-resolution gridded datasets, daily statistics, tracking methods, extreme, process-oriented evaluation. A few evaluations are conducted in a multi-model framework. As usual, the tougher question is how to go from model evaluation to model improvement?

Regional climate change uncertainty (9): Statistical/ensemble methods are used to evaluate uncertainty. An important outstanding question is how to design global/regional climate model ensemble to optimally tackle the uncertainty assessment issue, and whether the CORDEX framework could be further developed to address this need? A related question concerns the need for statistical method development.

Cloud-resolving RCMs (4): This is an exciting new development but the challenge remains to demonstrate the added-value of these new tools in climate mode?

Multi-component RCMs (10): Recently added new components in RCMs include aerosols, urban, and air-sea-river coupling. The extent to which we need to go towards complex regional earth system models is an important question, as well as identifying for which regions and applications this is important.

New methodologies in impact studies (4): Important issues here include the use of on-line vs off-line impact models, for specific application (e.g. pollen dispersal), and in this case how biases in the RCM need to be handled, whether before or after running the impacts model?

RCM database status (1): The choice between a regional database (initial CORDEX workplan) and the ESGF facility (new initiative) still remains to be clarified.

Parallel session B4 "Dynamical methods"

Chairs: C. Jones, E. Kjellström

Rapporteurs: A. Rinke and M. Rixen

The session started with overview of advantages/disadvantages of different downscaling methods. The question has been raised whether bias corrections of driving GCM data are a must for dynamical downscaling. The presentation of a global high-resolution AGCM study showed its usefulness for studies on extremes (e.g. tropical cyclones, Indian summer monsoon).

A particular recurrent topic was whether RCMs produce different (more credible) projections than driving GCMs. Studies over Africa, compared perturbed physics a GCM ensemble with an RCM ensemble and showed that both GCM and RCM agree on the drying over West Africa which is associated with changing atmospheric circulation patterns. However, these patterns are not reflected in dry years of present-day reanalyzes. Therefore, one may conclude that we can put the same (reduced) confidence in both GCM and RCM, if we believe the variability within West African precipitation reanalyzes.

To understand regionally and seasonally different precipitation changes, it has been recommended to decompose the seasonal mean precipitation changes in various parts, for example frequency/intensity changes, precipitation type, wet/dry spells. This method has been presented to be successful for details of precipitation changes over a complex-topography area (Switzerland).

The effect of increased horizontal resolution has been discussed for present-day Europe simulations. No systematic improvements in monthly climatology are seen using higher resolution, but the spatial patterns of extremes are better represented and mesoscale features become feasible. The method of spectral analysis was demonstrated to be a useful tool to extract additional information by higher resolution. The question has been raised whether the models need adaptations of their parameterizations (e.g. cumulus convection scheme) if they are used at different resolutions.

The comparison of two multi-model projects, namely ENSEMBLES and Med-CORDEX stressed the difficulty to compare those different projections on climate indices, because they used different resolutions, GCM forcing and emission scenarios. The question has been raised on how to interpret and communicate these projections and their differences to the impact community.

An analysis on storm surges over the Mediterranean Sea showed that wind-driven features are better represented by the models than sea level pressure-driven contributions. Under climate change, it is projected that the intensity of marine storminess decreases, but large differences among the individual simulations are obvious. The largest fraction of uncertainty has been attributed to the choice of the driving GCM.

High-resolution simulations over South Africa showed that its climate is projected to be warmer and drier, but the temperature variability is expected to decrease. The suggestion that the climate system could become less variable in future is under debate and has been discussed.

The influence of domain size and resolution has been investigated for Indian summer monsoon simulations, driven by ERA-INTERIM data. A smaller domain size slightly improved the simulations. Further sensitivity studies for different domain sizes are useful. It has been raised that this should be done also for GCM-forced simulations. A higher horizontal resolution does not improve the representation of the monsoon climate significantly, as opposed to heavy precipitation which has improved.

Parallel session B5 “statistical downscaling”

Chair: B. Timbal

Rapporteurs: R.E. Benestad, B. Hewitson

The work presented in the session involved a large range of different methods in empirical-statistical downscaling (ESD): Linear (regression, canonical correlation analysis), non-linear (analog), weather generators, and post-processing of regional climate models (RCMs). One talk presented a comparison of a range of different techniques, and found differences in performance. This clearly suggests that the results are sensitive to the choice of model and the strategy. For this reason, it is important to take into account the context, the type of data, and the intended use of the results. ESD needs to be tailored for the particular use for which it is intended, and should make use of both physics and statistics know-how.

Inter-scalar dependencies provide the basis for downscaling, and it is therefore important to consider the choice of 'large scale' and 'small scale' impacts on results. One talk presented a comparison between downscaled results to 0.11º and 0.44º gridded data for mean and heavy precipitation. In this study, 4 RCMs and a regression-based ESD were used, but concluded that there was no clear added value in the higher resolution. Another finding was that there were comparable biases for RCM and ESD for heavy winter precipitation, but in summer, only the best RCMs were comparable with ESD. Another talk presented models' ability to predict seasonal temperature cycle in Europe, where ESDs ranked better than bias-corrected RCM results. The ranking for trends, however, provided more mixed results.

There have been some questions about bias correction: is quantile mapping for bias correction justified, and should it be regarded as a form of ESD? There are ways to post-process RCM results to better reflect real local climate characteristics. One talk presented a Bayesian algorithm using ENSEMBLE RCMs. Bayesian statistics is used for a probabilistic description, in this case for seasonal regional climate change. Users and stakeholders ask for high-resolution data, and height dependency is an issue for the Alps where the warming is found to increase with height. The number of 'summer days' was found to double by 2085 compared to present values, and the thermal growing season length was found to increase.

One talk covered crop models explaining the need for higher resolution and unbiased results. Six RCMs from the ENSEMBLES project had been used, and a parameter transfer function had been applied as a means for bias correction. In addition to the RCMs, the work involved a weather generator to predict precipitation. An evaluation of T_{min} suggested a good fit for annual variations in T_{min}, but not in summer which is important for the crops. The precipitation was not considered as relevant in this case due to impact of irrigation. The bias-correction gave good results in one location but not for another. For projected climate change, the strategy was to combine different methods: WG+RCM or WG+Bias correction.

The typical ESD study involves some evaluation of skill: correlation, bias, and RMSE. Cross-validation approaches are often used to avoid 'artificial' skill. It is difficult to compare gridded and station data for evaluation purposes, as gridded data and single station measurements often have different characteristics. Nevertheless, the downscaling step is only one part of the chain in the propagation of uncertainties, starting from the choice of emission scenarios and global climate models. It is assumed that the skill for the past reflects the future model performance, although this is not certain. The COST-VALUE project is an effort to validate regional climate models and integrate the research community. The scientific community has been scattered, especially on ESD. Validation efforts need to reflect the diverse end-user requirements and should address the usage of results specifically.

An observation from the general CORDEX conference was that scientists working on RCMs rarely employ ESD, even though ESD offers ways to diagnose the RCM performance. Most of the ESD studies presented in the session made comparisons with RCM-based results.

Parallel Session B6 "Observations Data and Global Circulation Models"

Chair: J. Schmetz

Rapporteurs: M. Doherty, D. Waliser

Talks from ESA and EUMETSAT on generating high quality Climate records from satellite presented complementary approaches covering more than half of the ECVs required for the Global Climate Observing System. Effort is being placed on developing robust and traceable methods for achieving climate quality data from varied satellite Earth Observing systems. Key requirements to maximize the use of these data are to provide uncertainty estimates along with the observations and to adhere to climate model output standards [e.g. Climate Forecast (CF) compliant] in the corresponding products. The challenging job of inter-calibrating across different platforms is being addressed with coordinated international activities (e.g. GSICS, Global Space-based Inter-Calibration System), to increase the number of useful observations available, while meeting the requirements for fidelity in the long-term climate record. Modeling and Earth Observation teams are working jointly to develop and qualify long-term climate quality, decadal records through coordinated international activities. Continuous effort will be needed to sustain such activities into the future.

Two talks addressed the question of how to strategically select Global Circulation Models (from the Coupled Model Intercomparison Project, CMIP) for downscaling - an issue for which climate metrics are needed. Two methods were presented: one based on a strategic decision making framework for model elimination based on either poor simulation fidelity or redundant representation, the other based on taking into account observation uncertainty in the model evaluation, where the latter is focused specifically on the driving fields from GCMs (e.g. T(z), U(z)).

A successful effort for utilizing observations within a regional reanalysis system was presented, as needed for capturing observed characteristics of variability and extremes in regional climate models. This included a very high-resolution example (2km) over central Europe. During discussions, the cooperation between universities and Met services (e.g. in Germany) was identified as a useful means for enabling regional model developments and for providing support to users of the regional climate models requiring sustained (operational) infrastructures usually not accessible to university groups. It was also recalled that re-analysis work needs sustained funding on timescales that exceed those of a typical research project (e.g. >3years).

An approach to using observations to implement land use changes in Regional Climate models was presented, based on the sensitivity of regional climate to small (e.g. +/-5%) changes in albedo. The method characterizes land-use shifts with albedo derived from observations, and uses this to account for the sensitivity of the RCMs to albedo. It was noted that the approach could be extended to all observable vegetation parameters in climate models.

Applications, impacts and services

Plenary session A5 "Applications of regional climate information"

Chair: C. Goodess

Rapporteurs: R. Kumar Kolli, A. Morse

This was one of the most diverse session in the conference in that it covered the application of regional climate models including CORDEX models as well as comparison to GCM driven impacts outcomes too. The presentations reviewed a wide range of application and impact areas and approaches involving the use of downscaled climate information. Many of the papers discussed the importance of correctly communicating the outputs of these integrated modeling studies to the users and decision makers. In the seamless end-to-end process of conveying impact information to the user and decision-making communities it highlighted the importance of using appropriate and understandable visualizations, and of providing user relevant analysis and data sets. Therefore this session reflected the broad spectrum of activities along the end-to-end chain of climate model to user impact and application.

There were 15 papers presented with examples from Africa, Europe, the Middle East and North America. The papers covered a wide and interesting range of impact fields and activities including: drought frequency and drought vulnerability; malaria; water resources and energy; Disaster Risk Management through early warning, frameworks and information systems; Africa and integrated tailored approaches; crop modeling and bias correction; trees and the climate past, present and future; soil erosion and kinetic energy of raindrops; marine ecosystems; the cryosphere; severe weather – high night time minima temperatures; agriculture and farm financial vulnerability.

The papers covered a range of techniques and communication issues including: the use of the new CORDEX RCM data archives; making the use of RCM data seamless when using multiple models; how the Global Framework for Climate Services (GFCS) can facilitate the dissemination of CORDEX outputs in a user-targeted manner; and, the use of information within the IRI map room. There were a number of sector specific impact assessment models discussed and how they have been integrated with RCM outputs as drivers including disease models for malaria in Africa, crops, marine ecosystems, glacial mass balance and forest models. The ways in which uncertainty is conveyed was highlighted in more than one talk. The importance of using impacts as a validation tool for RCMs and their subsequent value to society was another important theme. Some of the specific topics covered included: the use of insurance informed by climate information for fast recovery, the use of RCMs with great lakes for understanding climate impacts on these important multi-sector and multi-user water resources; investing in early warning use which is more than just producing impact outputs but learning how to incorporate such outputs within warning systems; the understanding of regional and national capacity and how best to use and adapt its use of climate and impacts model information; addressing the problems of capacity building from low start points especially in the developing world; the uncertainty estimated through the use of different cloud schemes for impacts; the use of heat index concepts for impacts, circulation composites to parameterize impacts; and how to make the information useful for farmers through farm-scale downscaling linked to financial planning for farming and the usefulness of expert opinion.

Poster session P4 “Applications”

Rapporteurs: K.K. Kanikicharla, F. Zermoglio

The posters of this session addressed a wide range of topics leading to some interesting insights on the current use of climate change information in various applications. These include:

Responses to climate change were addressed by evaluating adaptation, mitigation and disaster management options under a changing climate. Several studies reviewed the current and potential future impact of climate change across critical sectors: water, human ‘comfort’, agriculture and coastal zones. Observed Changes and Model simulations were confronted for specific uses in the framework of the Global Framework for Climate Services.

Policy mechanisms to deal with transboundary water management issues under a changing climate were presented. Tools to facilitate access to complex climate information and to communicate uncertainty were discussed.

Several of the posters began their investigation from the perspective of a specific development challenge (e.g. water availability in the future, increasing productivity of apple farms), and then explored these changes through modeling. Others examined the ways in which climate data can be interpreted and used through the lens of specific sector applications such as disaster management. There was a limited focus on response options and choices to emerge from some of the impacts work, which suggests strengthening CORDEX efforts in better tailoring products to meet end-user requirements.

Plenary session A6 "Future directions for Regional Climate Science and CORDEX"

Chair: G. Asrar

Rapporteurs: C. Goodess, W. Gutowski

Dr Daniela Jacob – From GCM to RCM – from ESM to RESM

The presentation brought together the WCRP and IGBP perspectives, reviewing the history of GCM development as presented in IPCC reports, focusing especially on GCM evolution as producing evidence for a direct link from the influence of human activity on climate to climate's impact on society.

The following questions were raised: Where does regional modeling fit within this evolution and the network activities under these organizations? Why are we interested in regional climate and regional systems? RCM development has been moving from curiosity-driven research to demand-driven, bridging climate modeling and regional to local interests. The RCM community can now look at climate processes in more regional detail, however this prompts a further question: do we have enough resources to do a full analysis of added value? And have we allotted adequate time to do it?

The RCM community has shown some added value relative to GCM simulation, but as the RCM community has moved to higher vertical and horizontal resolutions, it has not always seen the expected improvement. This is perhaps not surprising, as the community has done less work on parameterizations, which can be scale-dependent. There is much room for improvement. Developing RCMs was a good step to make, but there has been little feedback from RCM development to GCMs, especially in terms of parameterizations. This is a missing link in information transfer.

RCMs have tended to follow GCM development steps, such as producing ensembles and developing regional earth-system models to mimic global earth-system models. However, were those the right directions to follow? The RCM community needs to consider what is the demand for regional information and ask itself if the demand is being met. Responding to this demand could yield different development pathways and also present substantial challenges. RCMs may not yet fit that purpose. There needs to be more attention given to RCMs and their parameterizations, and the models should perhaps be more tightly linked to individual applications.

It was asserted that RCMs have now matured and should not be simply regional outlets of GCMs. They should not blindly follow GCM development directions and mimic all what they do. Directions can be different, through close collaboration with different communities and disciplines that could use regional information. This would be promoted by the secure involvement of young scientists with long-term funding.

Dr Ray Arritt – Seasonal to decadal regional forecasts

The presentation started with a core issue of seasonal to decadal regional forecasts: they are not quite weather forecasts, but not quite climate simulation either. These forecasts represent a transition from an initial-value problem (weather forecast) to a boundary-value problem (climate simulation), though like climate simulations, the main interest is in statistical properties of the forecast. There has been an evolution in the forecasting from seasonal to decadal prediction, with a huge demand from the user community.

Early research projects such as DSP, PROVOST and DEMETER showed that ocean initialization is key, but benefits of using an actual dynamical ocean model have been less clear. Multi-model ensembles were recognized as important.

The first attempts at downscaling seasonal forecasts started in the late 1990s, using both dynamical and statistical downscaling. One example is MRED, which downscaled wintertime seasonal forecasts from the NOAA Climate Forecast System to 32-km grid spacing using 7 RCMs focused on North America. Each RCM used 10 initial conditions, yielding a 70-member ensemble. In MRED, the highest precipitation skill occurred in the southwestern and southeastern U.S., which are regions with strong ENSO signal. This result reaffirms that, ultimately, forecast skill depends on the skill of the driving global model.

There is typically large spread among realizations in global seasonal forecasts because of sensitivity to initial conditions. Thus, downscaling several ensemble members is essential. Downscaling appears to have little effect on ensemble spread. Current programs include the North American Multi-Model Ensemble, a global simulation program operating in real time, but the program is not routinely saving data needed for downscaling. There is evidence that downscaling can bring added value (additional skill) to seasonal forecasts, but forecasting really needs 5-10 realizations each of multiple GCMs.

On longer time scales, the feasibility of decadal predictions is still an open question and skill remains to be demonstrated. Temperature skill at this point for interannual to decadal prediction largely depends on having externally forced trend.

Although programs such as MRED have focused on dynamical downscaling, the International Research Institute for Climate and Society has found that statistical downscaling (regression based) gives as good results as dynamical downscaling, and it is much cheaper. There is thus lots of scope for comparing statistical and dynamical downscaling, particularly where there is adequate training data, but this remains a problem, such as for wind and radiation data.

The presentation concluded with a hypothesis: Downscaling from multiple GCMs is more useful compared to developing the same size RCM ensemble from a single GCM.

<u>Dr Filippo Giorgi – Future directions in CORDEX long-term projections: emerging issues concerning regional climate projections</u>

Four issues were emerging from the conference:

Issue 1 – Improve dialogue & co-exploration with end-users.

A climate scientist view of the CORDEX paradigm highlighted regional climate downscaling as the driver of the program. However, an emerging theme at the conference was that users and sectors driving demand should be playing an important role in driving the science of CORDEX. Thus, climate scientists in general and CORDEX in particular need to ask: What is downscaling for and who cares?

Issue 2 – Added value.

There are many examples of added value from RCM downscaling. One example is the simulation of West Africa climate in the ICTP CREMA simulations (Mariotti et al., 2013). However, that work deliberately chose 2 ‘good’ GCMs. To look at real added value, there is a need to investigate more pertinent exotic variables, such as African Easterly Wave (AEW) activity, as measured by variance in the 700 hPa meridional wind (3-5 days band and, more important, 6-9 days). RCMs tend to have more activity, particularly in the latter band. One can also see distinct differences in projected precipitation changes in the RegCM RCM and

Hadley GCM, and in their AEW signals, with little change in the GCM and a decrease in the RCM, so one would trust more the RCM in this case. In addition, when looking at PDFs of daily precipitation, the GCM matches coarsely gridded observations well, and the RCM matches better the more finely gridded observational data set.

Added value is not necessarily found at the regionally averaged scale, in mean biases. Rather, it is best found for higher order moments, regional circulations, local topographical detail etc. Looking for added value can provide important information to assess the model performance. Thus, we need to evaluate our models on more process-based grounds. In addition, we need high-resolution observational data sets to evaluate added value. Added value is an important issue; it was suggested to have a specific task group to investigate it.

We should be careful with bias correction, especially in the context of added value. It does not necessarily solve all problems.

Issue 3. Uncertainty

What effect does downscaling have on uncertainty? There is a concern that downscaling widens the uncertainty bounds, but widening the uncertainty bounds is not necessarily bad. We need large ensembles to explore uncertainty in regional projections. That is the whole point of CORDEX.

Issue 4. Competing demands to improve regional climate projections.

Model complexity, simulation length and ensemble size, and resolution or domain size all compete for computing resources. Which way should we go? This is not an easy question to answer.

An assessment of the added-value of higher resolution is needed. There are quite a number of examples exploring this. For example, in West Africa, there is an improvement in precipitation when going from 0.44 to 0.22 to 0.11 degrees grid spacing. However, one should also consider climate system complexity when attempting to produce good simulations. For example, dust is important in some regions.

In addition to these issues, what should one do about observations? There are various datasets in some locations, such as MAPS-OBS at nominally 5 km resolution for Alpine regions. However, what is the real resolution of the observational data sets? Station density? If we are serious about higher resolution simulation, we need consistent observation datasets. We do not meet these requirements for all of Europe. What about the rest of the world?

Related to issue 4, what should be the future simulation framework for CORDEX? Perhaps multi-model ensembles as large as possible, but with increased resolution and comprehensiveness (model complexity of processes). What should be the next resolutions? 25km, 12km? Is the higher computational demand worth going to much finer resolutions? This needs evaluation. Perhaps pilot sub-domains at 12km and higher would be useful to explore.

<u>Dr Bruce Hewitson – CORDEX-ESD: gaining traction: the other side of the story.</u>

The outcomes of the first empirical statistical downscaling (ESD) CORDEX workshop, held late September 2013 were reported. This was the first in a series of 3 workshops. The first was to design the experimental framework. The next two meetings will not be open because the workshops are constrained by funding.

The current status:
(a) Participation requirements have three tiers of participation. The first one is required, but the other two are optional.
(b) The workshop defined agreed data sets (training predictors and predictands) to use.
(c) There were three initial experiment domains defined:

1. South American grid;
2. High density station 'clumps' on each continent;
3. Global distribution of approximately 50 stations.

The workshop established a working group to develop metrics (and code).

An invitation was issued to all ESD practitioners to engage within the program. This is not a context to determine the best ESD method. Rather, the goal is to ask what maximum value can be achieved.

Discussion based on questions to the presenters

1. We really need to include the impact community in the evaluation process. What happens when we force impacts models? We need to start framing experiments right from the start from the user perspective, and users should be involved in exploration of added value.

2. On RESMs: What should be the priority of the new components? We need clearer prioritization for adding new components, such as cities, lakes, and regional oceans. The priority may vary between regions. Again, this needs to be done in dialogue with users and the applications communities. We may need to build different models, so the topic needs lots of discussion from both sides. It is a different way of doing things, and we cannot really have a globally set agenda. There is a need for more dialogue and more flexibility but always with a scientifically sound background.

3. Added value. There are hundreds of articles on RCM experiments, but it is disappointing that more have not more robustly established added value. Maybe this is one reason why RCMs are so absent in IPCC high-level messages. So, how then does one motivate these deeper analyses within CORDEX? There is a need for more co-ordinated activity and better definition of what we mean by added value, which may be different for different applications. A task force on added value could be a good idea. RCMs likely not used by IPCC because the community has not put forward a sufficiently co-ordinated message, though there will be more use of RCMs in the Working Group 2 report of the AR5.

4. Some would like to see more papers on adaptation, so perhaps CORDEX needs to engage more with the adaptation community, such as at the Fortaleza conference next year.

5. Is there a danger of overselling at 'grey' timescales of ~5-10 years? There is a disconnect between what scientists are saying and what is appearing in the media. The decadal prediction community is very aware of dangers of overselling and is quite skeptical.

6. There is a need for more model development, which prompts the questions: how to foster and encourage this? How can CORDEX promote this? Perhaps we should follow the GCM community and promote MIPS focused on specific areas? This may be really important if going to ~10km scale (or less). Are our models really up to this? We need to devise some more specific experiments. Perhaps one way to do this is to build better links with WCRP core projects.

7. How do users e.g. from the impacts community get to the regional information? Those with Windows machines face problems in this regard. Also, there are difficulties for many in using NetCDF. There needs to be a simple handbook that would cover items like getting started with NetCDF, using CORDEX data, and some alternative data processing tools.

However, then what users do with this data? How do they distill it? There needs to be a basket of solutions. Not all responsibility should be on end-users. For example, do they really need to use NetCDF? Such knowledge can help some scientists do their work, but for others, there needs to be contextual understanding and co-exploration of the data on various topics such as the meaning of bias correction. Good guidance material can only go so far by itself, as there needs to be more emphasis on 'translators' of the data. We also need work and research on knowledge transfer, including the social dimensions of bridging the gap between modelers and users.

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