CGIAR Research Program on
Climate Change, Agriculture and Food Security (CCAFS)

Progress in Climate Science Modelling: A Look Forward

February 2012

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Correct citation:

Richard Washington. 2012. Progress in Climate Science Modelling: A Look Forward.
CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark. Available online at: www.ccafs.cgiar.org.

Published by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

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Abstract

Substantial increases in the reliability of projections from General Circulation Models (GCMs) are not expected any time soon. The model biases that exist tend to be stubborn and often persist from one model version to the next. Many such biases have important impacts on regional climate simulations. For the regions considered here (West Africa, East Africa, and the Indo-Gangetic Plain), higher resolution simulations with Regional Climate Models (RCMs) have the potential to add considerable detail to the outputs from coarser resolution GCMs. Whether the regional modelling effort provides benefits in terms of better constrained impact models remains to be seen. Careful evaluation of results will be required to identify both global and regional models that satisfy basic performance characteristics over the regions of interest. This is a heavy responsibility for the impacts modeller, and considerable creativity will be needed in handling model error and inter-model differences in all the impact methodologies that are used.

Keywords

General Circulation Model; Regional Climate Model; bias; impact.

About the author

Richard Washington is Professor of Climate Science at the School of Geography and the Environment and Fellow of Keble College, Oxford. His research interests are in climate change and variability, particularly in Africa and the global tropics. He has degrees from the University of Natal and University of Oxford and taught at the University of Natal and University of Cape Town. His doctorate was on African rainfall variability and change, which was undertaken jointly between the University of Oxford under Professor Alayne Street-Perrott and Chris Folland's group at the Hadley Centre of the UK Meteorological Office. He took up a University Lectureship position and Fellowship at Keble College in 1999, and a Readership in 2006. Richard is Co-Chair World Climate Research Program African Climate Variability Panel (CLIVAR-VACS) 2006-2010 and served as a panel member of CLIVAR-VACS from 2003-2006. Richard leads the development of the CLIVAR Africa Climate Atlas.

Contents

Acronyms

AOGCMs	atmosphere-ocean general circulation models
AR5	Fifth Assessment
CMIP5	Coupled Model Intercomparison 5
COFs	climate outlook forums
CORDEX	Coordinated Regional Downscaling Experiment
CPN	Climate Prediction.net
ENSO	El Niño Southern Oscillation
IPCC AR4	Fourth Assessment of the Intergovernmental Panel on Climate Change
RCD	Regional Climate Downscaling
RCPs	representative concentration pathways
SRES	Special Report on Emissions Scenarios
SSTs	Sea Surface Temperatures
WCRP	World Climate Research Programme
WG1	Working Group 1
WGCM	Working Group on Coupled Modelling

Introduction

The aim of this component of the report is to provide background information and a perspective on the science of climate modelling over the next five years in relation to knowledge of climate change and variability. Where appropriate, comments are targeted at the African climate system and Asia. Detailed analyses of Asia and the African climate system as represented in models have already been dealt with earlier in the report. This material is not repeated here.

The efforts of the Coupled Model Intercomparison 5 (CMIP5) are discussed first, followed by the Coordinated Regional Downscaling Experiment (CORDEX), both of which form part of the flagship efforts of the co-ordinated work of the World Climate Research Programme (WCRP) in delivering climate information. Taken together, these initiatives will provide the latest generation datasets for climate change projections in forthcoming years. Additional projects contributing key data to climate change studies such as *climateprediction.net* are also discussed. A brief comment on seasonal prediction is included. Comments on uncertainties and progress conclude this part of the report.

Coupled Model Intercomparison Project 5 (CMIP5)

The CMIP5 project is described by Taylor et al. (2011). Another useful document is the CLIVAR Exchanges Special Issue (CLIVAR, 2011). CMIP derives from the WCRP's Working Group on Coupled Modelling (WGCM). The third iteration of CMIP mapped onto the Fourth Assessment exercise of the Intergovernmental Panel on Climate Change (IPCC AR4). CMIP5 is timed to map onto the Fifth Assessment (AR5).

The fundamental aim of CMIP is to put in place a standard experimental protocol for studying the output of coupled atmosphere-ocean general circulation models (AOGCMs), including documentation of models and data storage. The key advantage of CMIP is that it creates the potential for meaningful evaluation of model products. If, on the other hand, each modelling group undertaking climate projections and climate change experiments were left to their own devices, the model experiments and data availability would make inter-model comparison and systematic model assessment almost impossible. Almost the entire international climate modelling community has participated in CMIP since its launch in 1995.

There are several features which are new to CMIP5 compared with CMIP3 (there was no CMIP4). First, climate models have evolved since the AR4/CMIP3 and most are now at least slightly more complex. Second, prediction of climate in forthcoming decades is being attempted systematically and explicitly for the first time. Third, the emission concentrations used to force the models are slightly different from AR4 and their naming system is entirely different. Fourth, there is a major attempt to provide very full model documentation for the models used. Fifth, the way in which the models are tuned or developed is not as consistent as for AR4. In CMIP5, some models are tuned to climatological conditions (in other words, tuned to reproduce features of the long term mean climate) while others are tuned both for climatological conditions and their ability to reproduce the trend in mean surface global 20th century temperature. Sixth, the set of experiments making up CMIP5 is more comprehensive and extensive than CMIP3.

Three key dates with respect to CMIP5 deliverables are as follows:

February 2011: First model output is expected to be available for analysis,

31 July 2012: By this date papers must be submitted for publication to be eligible for assessment by Working Group 1 (WG1) of the IPCC.

15 March 2013: By this date papers cited by WG1 must be published or accepted for publication.

The IPCC's AR5 is scheduled to be published in **September 2013**.

CMIP5 consists of three key kinds of experiments:

- Decadal hindcasts and predictions simulations;
- "Long-term" simulations; and
- "Atmosphere-only" (with prescribed Sea Surface Temperatures, SSTs) simulations for especially computationally-demanding models.

Decadal hindcasts and prediction simulations (10- to 30-years), some of which will be initialized with observed ocean state and sea-ice, represent a new challenge for AR5. The hindcasts feature ten-year integrations with initial dates towards the end of 1960, 1965, 1970, 1975,1980, 1985, 1990, 1995 and 2000 and 2005 but extending through the end of the next 10 years. Three member ensembles are envisaged. In addition, extended integrations with initial dates near the end of 1960, 1980 and 2005 but running to 30 years complete the first kind of experiments. Some progress has been made with decadal prediction schemes at the UK Met Office (Decadal Prediction System: DePreSys). However, the model integrations are not usually simply a matter of introducing observed ocean anomalies to the model because models have the capacity to invoke responses which quickly remove the imposed anomaly. Accompanying model development is therefore normally necessary. Thus far, decadal prediction systems have delivered modest skill with respect to parameters such as ocean temperature anomalies. There are few if any examples of rainfall prediction schemes on these timescales. Any tendency to adopt the decadal runs as near time projections should be strongly resisted in favour of a suit of analyses which carefully investigate the capabilities of the models on these timescales. As such, this is a task for the climate science research community more than users of climate information. There are potentially much higher priorities for the climate user community, inviting as the decadal predictions may seem.

Long-term (century time-scale) simulations are initialized from the end of freely evolving simulations of the historical period and are achieved with AOGCMs, some of which may be coupled to a carbon cycle model.

The Special Report on Emissions Scenarios (SRES) scenarios used in IPCC AR4 (see IPCC 2000; IPCC 2007) have been replaced by "representative concentration pathways" (RCPs). These begin in year 2006 and continue through the end of year 2300. The RCPs are labelled according to the approximate target radiative forcing at year ~2100 (for example, RCP4.5 identifies a concentration pathway that approximately results in a radiative forcing of 4.5 W m^{-2} at year 2100, relative to pre-industrial conditions).

In order to accommodate computationally demanding models, for example treatments of atmospheric chemistry, 'time-slice' experiments for both present day and future (notably 2026–2035) are planned. In the case of future time slices, sea surface temperatures derived from coupled model experiments will be used to drive the atmospheric models.

Exploration of carbon response is also part of CMIP5. Taylor et al. (2011) describe the experiments as follows: two carbon cycle feedback experiments are planned. In the first, climate change is suppressed (by not letting the radiation code "see" the increasing CO_2 concentration), so the carbon cycle responds only to the changing CO_2. In the second, the climate responds to CO_2 increases, but the CO_2 increase is hidden from the carbon cycle. The surface fluxes of CO_2 will be saved in these experiments and compared with those from the corresponding "core" experiment in which the carbon cycle simultaneously responds to both climate and CO_2 concentration changes. From these fluxes, the strength of carbon-climate feedback can be expressed in terms of the difference in allowable emissions or in airborne fraction.

Taken together, the CMIP5 data set is vast compared with CMIP3. It remains true that CMIP3 was under-investigated, particularly for regional climates and particularly for Africa. Without an order of magnitude change in the resources (human and computational) available to analyse CMIP5 data, it is unlikely that the understanding of the data set will be any better than CMIP3. Model runs are effectively being done much faster than they can be understood by the community. Full treatment of one of the CMIP5 models is about as complex as understanding the real atmosphere, although it is made easier by the potential availability of many variables. Earlier sections of this report pointed to model biases. On the whole, the biases are stubborn and often persist from one model intercomparison to the next. Model biases have a particularly key impact on regional climates.

Coordinated Downscaling Experiment

Data from CMIP3 in IPCC AR4 has been widely used in climate model projection studies. In many cases, the spatial resolution of the global models is too coarse given the impact or application being studied. At the same time, regional model runs to downscale the global model data are computationally expensive and beyond the means of many institutions.

CORDEX was set up to do the following:

1) Develop a framework to evaluate and where possible improve Regional Climate Downscaling (RCD) techniques for use in downscaling global climate projections.

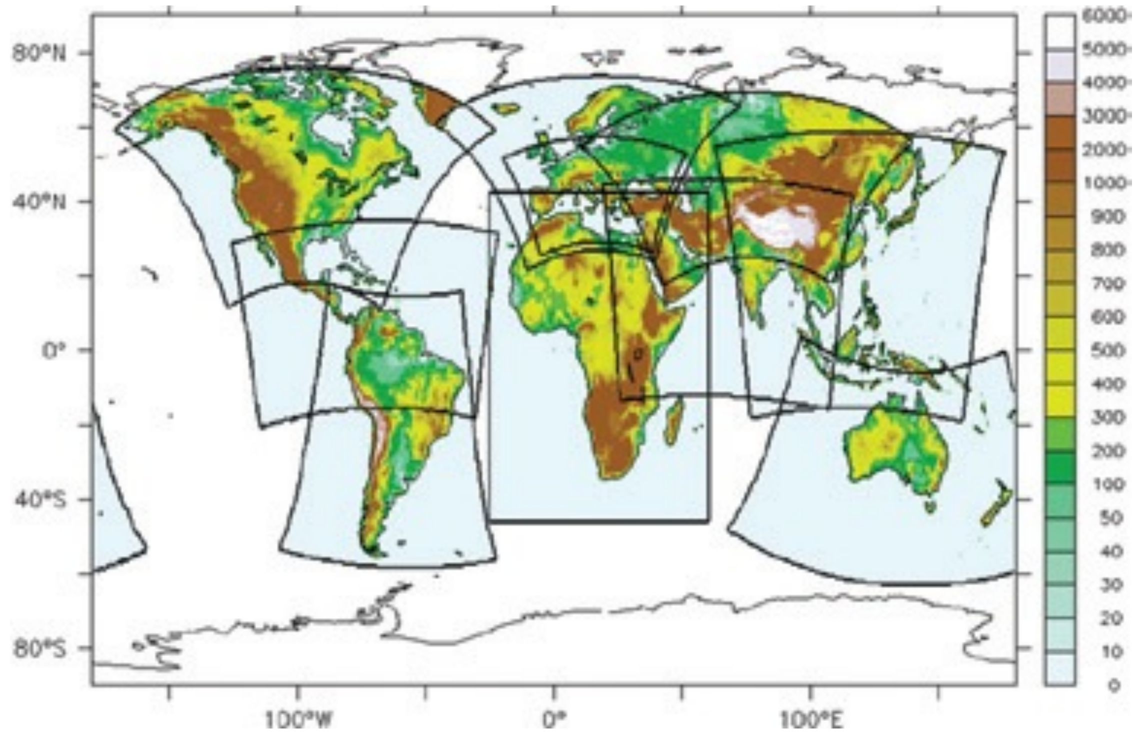
2) Foster an international coordinated effort to produce improved multi-model RCD-based high resolution climate change information and related uncertainties, over regions worldwide.

3) Promote greater interaction and communication between the climate modelling and end-user communities, in order to better support impact – adaptation – vulnerability activities and national to regional decision making.

CORDEX includes both statistical/empirical and dynamical (regional modelling) downscaling efforts. Much of the emphasis is on regional modelling. Several domains for regional modelling have been agreed upon (Figure 1) and Africa is designated as the domain of highest priority. The approach with regional modelling simulations is for CORDEX to coordinate the running of several models, each forced by a suite of global models and emission pathways at 50 km resolution.

To date, progress with completing runs has been slow, primarily because the six-hourly fields required to force the regional models are amongst the last priority for the modelling groups to archive. As a result, very few six-hourly fields have yet been made available. In addition, configuring regional models to perform reasonably over some regions, for example southwest Asia, has taken longer than initially planned. Some regional model runs have been completed (for example over the Africa domain at 50 km horizontal resolution).

Figure 1: CORDEX regional modelling domains

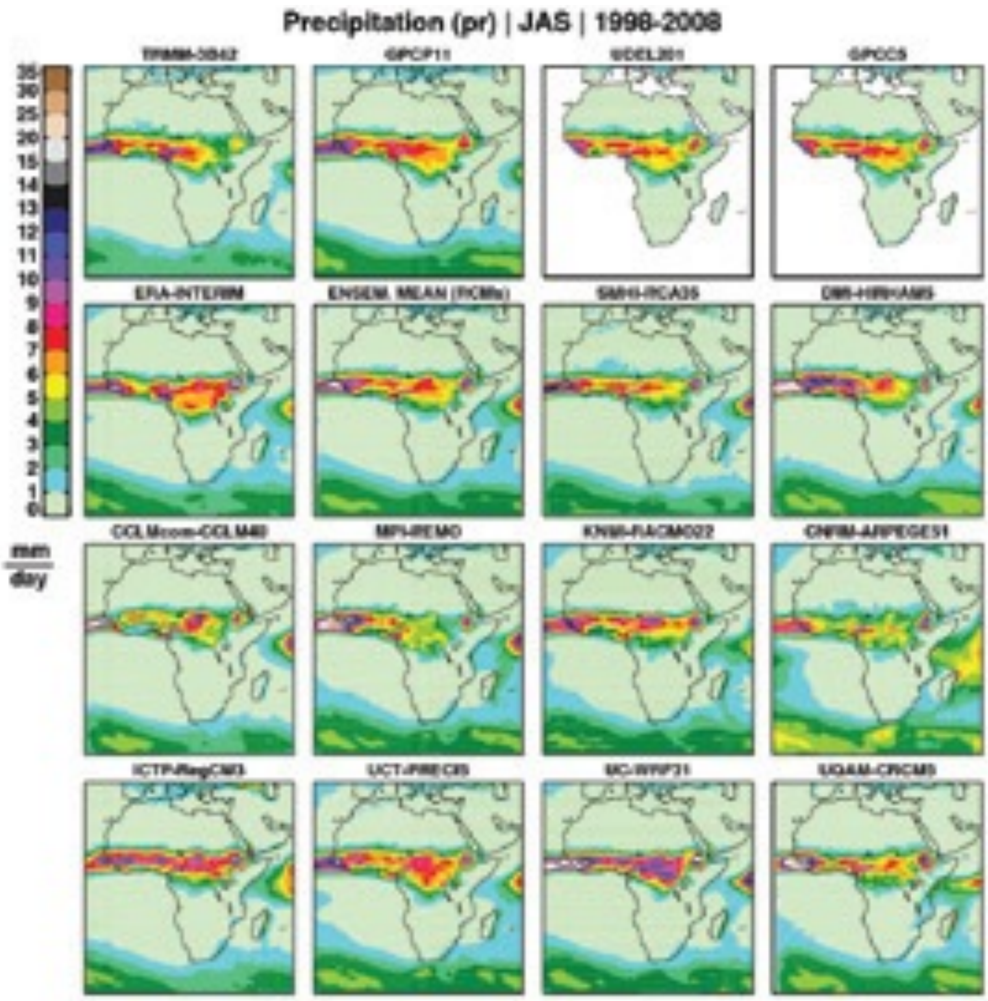


Control runs through the historical period have been completed. The climatology resulting from different regional models shows a large degree of spread in some parts of Africa (Figure 2) even when forced by the same six hourly boundary data.

The spread of results for precipitation will be much larger when different global models are used to force the regional model. In theory the regional models will be able to cope better with the representation of areas of complex topography and/or land surfaces. What is clear from the initial runs of the CORDEX suite of regional models over Africa is that statistical post-processing of the data to maximise the climate change signal will be inevitable. The regional models do not simply offer a ready-made solution for impact assessment. One of the emerging problems in relation to regional model runs is that even when forced with reanalysis data, which can be thought of as a globally complete data set which most closely matches the real world, some models are not able to replicate interannual variability (for example, floods and droughts) associated with El Niño Southern Oscillation (ENSO). There is no doubt that this situation will worsen when the regional models are forced by global climate models instead of the more tightly constrained reanalysis data sets.

While the CMIP5 data set presents a great challenge in terms of analysis, the CORDEX dataset is several factors larger in terms of the resources needed for analysis. Both the forcing model from CMIP5 and the regional model need to be analysed to be confident in the model behaviour. Some press releases have therefore been overly optimistic in relation to CORDEX. One example is: “African cities and villages will soon have access to detailed data on how climate change may affect them until the next century.”[1] The certainty contained in the statement is not warranted. Much analysis of the CORDEX data will be required before the data can be put to use by the user community.

Figure 2: July to September mean precipitation for 1998-2008. Four observational estimates are shown: the combined satellite-gauge data sets from TRMM and GPCP11, plus land-only gauge data from the University of Delaware and GPCC5 (top row), the accumulated 12-24 hour forecast precipitation from ERAinterim.(second row, first column) and the ensemble mean precipitation (from 10 RCMs) and the individual results from each model are shown in the remaining rows.



[1] Available from http://www.scidev.net/en/climate-change-and-energy/adaptation/features/localised-climate-data-for-african-villages.html. (Accessed 11 February 2012.)

Climate Prediction.net and Weatherathome

The Climate Prediction.net (CPN) project led in its initial phase to the generation of a very large data set of climate model projections under changed greenhouse gases and sulphates. Whereas the CMIP3 and now CMIP5 data sets feature approximately 20 models, some of which are closely related to each other, the CPN started with the same global model but perturbed model parameters to produce a very large ensemble of runs completed through distributed computing on desk top PCs. The Weatherathome experiment extends this idea and features the running of regional models over selected domains, which include southern Africa. The schedule of runs and domains in Weatherathome is a function of the production of executables for running on home PCs and the uptake of the experiments. At present the availability of the latter exceeds the former so that there is a lead time of several months should a domain and experiment of interest be required.

Seasonal Prediction

Very brief comments on seasonal prediction are provided here. Seasonal prediction schemes have seen a clear plateau in skill in recent years. Early gains in prediction skill out to six months that were made during the 1990s have not been matched by similar increases in the 2000s despite more sophisticated modelling schemes. Progress has nevertheless been made, particularly in super-ensembles of model runs which combine multiple runs of several different models. Such efforts have been shown objectively to enhance skill. Similarly, progress has been made in rolling out the predictions, particularly through the climate outlook forums (COFs) in Africa. There remains a particularly key gap between the seasonal prediction timescales (nominally six months into the future) and climate change timescales (nominally the 2030s) (see earlier comments on decadal projection runs in CMIP5).

Uncertainties and Progress

Climate model development imposes heavy demands on computer processing time through increasing resolution and complexity. Both these demands have increased hugely with CMIP5, notably the spatial resolution component and the need for regional model runs. The task of streamlining six hourly global model output to drive regional models is very large. If it were possible to run global models at the same sort of resolution as regional models (about 50 km) this resource consuming step would be by-passed. Nevertheless, the hallmark of CMIP5 and AR5 from an impacts perspective is likely to be high resolution climate models derived from regional models. Whether the regional modelling effort provides returns in terms of better constrained impact models remains to be seen, and it will take an enormous effort to answer even this question. What is reasonably clear from the development of global models is that the performance of global models at regional space scales has not improved drastically over the last ten years. In some cases, the model errors have become more noticeable as the models have become more complex. Indeed, it is sometimes even difficult to say precisely why an improvement in model simulation of a particular regional climate has occurred given model development. There is therefore much responsibility on the part of the impacts modeller to evaluate climate models, including regional models, and to be creative in the ways that model error and inter-model differences are approached in their methodologies.

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