ClimaRice II Technical Brief #16 – March 2013

Uncertainties in Climate Model Projections - Implications on Applications

CLIMARICE II: "Sustaining rice production in a changing climate"

H. Annamalai, IPRC, University of Hawaii (hanna@hawaii.edu)

1.0 Introduction

The climate system comprising the atmosphere, ocean and land is inherently nonlinear with feedbacks occurring at numerous space and time scales. The lack of quality observations of the interactive processes among the atmosphere-ocean-land components is a major impediment in our understanding of the various feedbacks. In addition, the future behavior of the climate depends on physically based mathematical models that are run on supercomputers. It should be borne in mind that a model can never reflect the observed state on its entirety. Given observational constraints, lack of complete understanding of the system and model limitations, any future state of the climate projected by a model is bound to have uncertainties. The level uncertainty partly depends on the model's ability to handle the feedbacks. Another source of uncertainty lies in the amount of emission of greenhouse gases in the future. To account for this, various emission scenarios based on socio-economic conditions are developed, and a range of climate model simulations projecting the future behavior of the climate system are performed. As a control simulation, the models are integrated to simulate the current climate (or a baseline period). Climate modeling centers around the world are actively involved in such an exercise. The suite of simulations from all the climate models are collected and made available for analysis.

2.0 How to select a climate model?

Given the above limitations in climate model simulations, a systematic approach needs to be taken to choose "realistic" models. Since the future state of the climate is validated against the current climate, one reasonable approach is to examine the models' ability to capture the "current climate" realistically.

Researchers develop a set of analysis in conjunction with appropriate physical interpretations to assess the models' strengths and weaknesses in representing the current climate and its variations. In the last decade or so, numerous research articles have been published that describe the various features of the climate as simulated by the models. While significant advancements have been achieved in representing global climate, simulation of the Asian monsoon by the climate models has been very challenging.

Based on comprehensive analysis of many models that participated in the IPCC assessments, the GFDL_CM2.1 and the NCAR_CCSM4 showed realistic simulation of monsoon rainfall climatology and its variability in the current climate (Annamalai et al. 2007; 2013; Meehl et al. 2012). It should be mentioned here that even these two models have certain errors that are not negligible. Compared to observations, the models have a dry bias (less rainfall) over the monsoon region, and still have systematic errors in capturing aspects of regional rainfall.

3.0 Downscaling coarse-resolution climate models: Cautions and implications

In general, horizontal resolutions employed in global climate models are coarse (~100 – 200 km). Among various reasons, availability of computer resources and compatibility of physics processes pose constraints in running the climate models at very high horizontal resolutions. For example, a model tested and tuned for a particular horizontal resolution fails when its resolution is increased without changes made to the physics package. Thus, model development is laborious and time consuming.

Assessment of the impact of anticipated climate change on agricultural yields, hydrology, health etc has enhanced the demand for delivering climate information at very high spatial resolution (~10-20 km). This is because the coarse-resolution model outputs are not readily usable for application purposes, for example, rice yield along a river basin or delta region. Among many factors, topography of the region influence the regional climate and therefore the resolution of the model needs to be sufficient enough to represent the orography realistically. For example, the Cauvery river basin is a “hot spot” regarding orography and test model simulations suggested for a 25 km spatial resolution for adequate representation of the regional climate (Annamalai et al. 2011).

To derive regional climate details for application purposes, one approach is to drive a very high-resolution regional model with coarse-resolution model outputs. As mentioned above, in the region of interest, these coarse-resolution models should have demonstrative skill in representing current climate and its variations. This is important because a coarse-resolution model that captures the climate over Europe realistically may fail to capture the climate over India. Care must also be taken in choosing a regional climate model, in particular its ability in simulating current climate. Depending on computer resources, by gradually increasing the resolution of the regional model, numerous test runs have to be performed before deciding the “optimal” resolution. This procedure was adopted in the present project to realistically capture the regional details along the Cauvery and Krishna river basins (Annamalai et al. 2011).

Despite such careful assessment and procedure, one should not expect a regional model to simulate rainfall and other climate variables as “observed”. A customary wisdom is to examine the regional model simulated rainfall and compare it with observed rainfall – the results will be disappointing!

In reality, we do not know (or have the sufficient observations) all the "inputs" that nonlinearly interact to produce "precipitation" - our desired output.

You can tune a hydrology or crop model - because most of the inputs are known and observed - However, modeling "nature" (that is poorly observed and understood) is not that simple! In simple terms, climate models are provided with best estimates of historical time varying forcing factors (e.g., greenhouse gases, aerosols, land use changes etc) and integrated forward in time. Note that these are free simulations and not constrained by observations. Therefore, the years (time axis) are “representative” and not “calendar” years. In addition, statistical interpolation schemes need to be applied to transform coarse-resolution (~100 – 200 km) global model outputs to regional model resolutions (~ 20 km) at its lateral boundary. This procedure also introduces certain uncertainty.

One should know that climate is a “distribution”. Take rainfall over the Cauvery river basin for example: for a given 30-40 years, many years witness “near-normal” rainfall and few years experience droughts and floods. Given the above constraints and uncertainties, climate scientists assess the ability of models in capturing the distribution in the current climate and assess its changes in a warmer climate (Turner and Annamalai 2012). On regional scales, our confidence in projecting changes to the statistical properties of droughts and floods is low. In order to make such statistical assessment in high-resolution regional climate model, very long integrations (~ 100 years) both in the current and future climate scenarios are needed. Within the computational resources we have, such an exercise is not possible at present.

4.0 Climate projections for application models

In the second phase of ClimaRice II project, keeping in view the unavoidable uncertainties in regional climate projections, a three-step approach was proposed for utilizing the climate information for application purposes over Cauvery and Krishna river basins. Given the small-scale nature of the study area, high-resolution climate projections are indispensible. Prior to dynamical downscaling, first we selected two coarse-resolution climate models that have appreciable skill in simulating monsoon characteristics of the present-day climate. This selection approach eliminates aspects of model uncertainty since future projections are measured against present-day climate.

Another level of uncertainty is due to the pathways through which future anthropogenic forcing is expected to occur. To account for this, secondly we selected two emission scenarios, namely A1B or RCP6.0 and Y1B. Then, we performed a suite of high-resolution (~25 km) regional model integrations. Third, these suite of regional model solutions serve as inputs for hydrology and rice yield models.

In application front, one common approach is to use a statistical model to assess the climate impact (e.g., rice yield). In such a approach, the regressions coefficients obtained for current climate conditions are assumed to be invariant, and used to estimate the future rice yield. We recognize that errors in climate model cascade into application models and introduce even larger uncertainties. This in conjunction with limitations in statistical approach places severe constraints in climate change assessment studies.

5 Discussion

While the new generation of climate models show certain improvements over the monsoon region (Sperber et al. 2012; Meehl et al. 2012), large systematic errors still exist. Therefore, reliable projections of future climate, particularly regional rainfall changes, are bound to have large uncertainties. It is fair to mention that sustained efforts are underway to develop very high-resolution climate models to capture regional climate and its variations, but it is a slow process. The need of the hour is to make use of the model simulations in the "best possible" ways. That is, using objective approach to understand the "science", and inform the inherent "uncertainties" to policy makers. In the ClimaRice II project, we have made sincere attempts to do so.

6. References

Annamalai, H., K. Hamilton and K.R. Sperber 2007: South Asian Summer Monsoon and its relationship with ENSO in the IPCC AR4 simulations. *J. Climate*, **20**,1071– 1092.

Annamalai, H., et al. 2011: Modeling the current and future climate over the Cauvery river basin. Linking Science, stakeholders and policy – Sustainable rice production on a warmer planet.

Annamalai, H., M. Mehari and K.R. Sperber, 2003: A recipe for ENSO-monsoon diagnostics in CMIP5 models (submitted)

Meehl, G., J. Arblaster, J. Caron, H. Annamalai, M. Jochum, A. Chakraborty, and R. Murtugudde, 2012: Monsoon regimes and processes in CCSM4, Part 1: The Asian-Australian monsoon. *J. Climate*, **25**, 2583-2608,

Sperber, K.R., H. Annamalai, et al. 2013: The Asian Summer Monsoon: An Intercomparison of CMIP5 vs. CMIP3 Simulations of the Late 20th Century. *Clim. Dyn.*, (in press)

Turner, A., and H. Annamalai 2012: Climate change and the South Asian summer monsoon. *Nature Climate Change* **2:** 1-9, doi: 10.1038/NCLIMATE1495