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Uncertainties in regional climate change projections: Part I: Choice of global climate models for regional downscaling

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

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One of the main goals of the ClimaRice II project is to reduce uncertainties in future monsoon projections. The IPRC regional climate model (IPRC_RegCM) has been used to simulate the current and future climates over both Cauvery and Krishna basins. This technical brief summarizes the issues in setting up of a regional climate model such as spin-up time, required climate parameters, selection of model domain and resolution and issues related to lateral boundary conditions. The brief also summarizes the comparison of uncertainties involved in the global climate model and how this will influence the southwest and northeast monsoon seasons over the Indian region. The next brief will investigate the uncertainties in the IPRC_RegCM simulations, particularly over the Cauvery and Krishna basins.

Introduction

There is ample evidence that the climate on Earth is changing, and further changes cannot be avoided (Solomon et al. 2007). Forced with increases in green house gases emissions, present-day climate models' projections indicate significant changes in the behavior of major monsoon systems, including the Indian monsoon. In particular, the impacts of climate change on extreme events and on the spatial and temporal distribution of the monsoon rains will certainly impact rice production and food security in India. For both scientific community and state agencies, reducing the uncertainties in future food production in the region is a big challenge. To achieve such targets, the need of the hour is to reduce uncertainties in future projections of regional monsoon characteristics.

Climate change projections from models are inherently uncertain because a model can never fully describe the system that it attempts to specify. In addition, for future projections the models cannot be calibrated because they are simulating a never before experienced state of the climate system. It is well known that uncertainties in climate model projections *cascade* into impact models (e.g., economy hydrology, crop, ground water etc) and thereby influence policy decisions related to adaptation. In ClimaRice II, the IPRC regional climate model (IPRC_RegCM) has been used to simulate the current and future climates over both Cauvery and Krishna basins. The primary reason for using a regional model is that over both the river basins, the steep orography along the Western and Eastern Ghats (Annamalai and Udaya Sekhar, 2009) influence the seasonal rainfall distribution. In addition, both these river basins receive excessive rainfall due to passage of tropical cyclones and extreme rainfall events. Therefore, a very high resolution regional climate model that can resolve the meso-scale features associated with the orography and capture the rainfall intensity associated with the small-scale synoptic systems is necessary for simulating the current climate and projecting its future state. The results from IPRC_RegCM serve as input to impact models. On the other hand, the success of regional projections by IPRC_RegCM, among other factors, depends on the "ability of simulation of monsoon characteristics by the coarse resolution climate models chosen to force the regional model at its lateral boundary". In this brief, we share our experience of uncertainty in lateral forcing by two global climate models and ECMWF Reanalysis (ERA-interim). The integration with ERA-interim for the period 1989-2008 serves to understand the ability of the IPRC_RegCM in capturing the current climate. It should be noted that both global climate models are successful in simulating the broad aspects of monsoons but differences in details such as timing and intensity are present.

Issues in setting up of regional climate model

The underlying strategy of the regional climate model downscaling is that the

General Circulation Models (GCMs) or alternately referred to as global models can provide the response of global circulation to large-scale forcings and regional climate models can account for the effects of local forcings (Giorgi and Mearns, 1999), such as orography and changes in land-surface conditions. Based on our experience, we suggest care must be taken on the following issues while running the regional climate model.

a) Spin-up time

The spin-up time can be referred as the time taken by the lateral boundary information to spread through and perceived in every part of the model domain and generate the dynamical equilibrium. The information learned from the spin-up issue is that for a few days of model simulation, noise produced at the lateral boundaries would dominate the simulation. Usually the spin-up time can be of few days (approximately 10 days) and these days will be neglected in the analysis.

b) Climate variables

Generally, there are six climate variables mainly used to force the lateral boundary conditions in the regional climate model. The parameters used at different vertical levels (from surface to top of the atmosphere) are zonal and meridional winds, temperature and specific humidity. The other two parameters are sea surface temperature (SST) and sea level pressure that are used at surface level.

c) Selection of model domain

The selection of model domain size is critical in simulating the mean conditions over the Indian monsoon region or the area of our interest. If the model domain size is smaller and the region is closer to the lateral boundaries, the greater the influence of the lateral boundary conditions on the regional model output rather than effect of downscaling (Seth and Giorgi, 1998). The choice of domain should be large enough to allow full development of internal meso-scale circulations and regional forcings, and their interactions. The simulation of realistic rainfall climatology over the Indian monsoon domain depends crucially on the magnitude of sea surface temperature over the tropical Indian Ocean, and the moisture laden low-level circulation that connects the southern Indian Ocean to the monsoon domain.

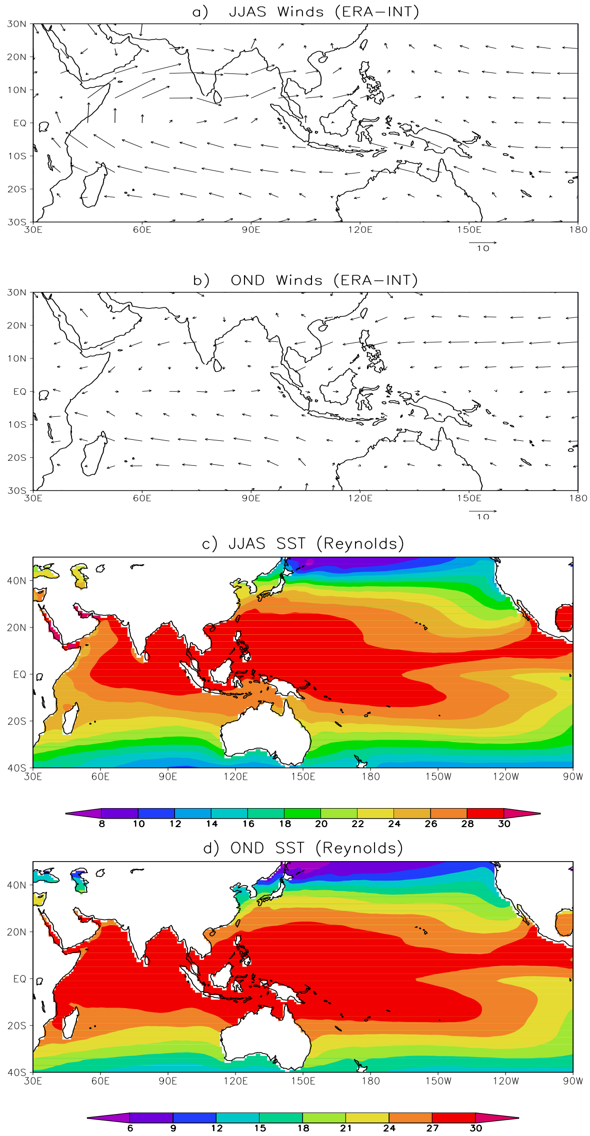

Figure 1: (a-b) ERA-interim reanalysis wind vector (*m/s*) climatology over the Indian monsoon region; (c-d) Reynolds SST climatology (^oC). The JJAS represent the boreal summer (southwest and OND represent winter (northeast) season.

Figure 1 shows climatologies of low-level wind circulation pattern (a-b) and sea surface temperature (SST; c-d) during southwest monsoon (June through September) and northeast monsoon (October through December) seasons, respectively. The main moisture source for the monsoon rainfall comes from the adjoining oceans that experience warm SST. Due to both higher wind speed and warmer SST, more evaporation (or moisture) occurs over the southern Indian Ocean, Arabian Sea and Bay of Bengal regions (Stowasser et al. 2009). In other words, evaporation is directly related to SST and wind speed, and more evaporation means more moisture to the region. Another important element for a realistic monsoon simulation is adequate representation of orography along East Africa, Himalayas, Tibet, Burma, and Western and Eastern Ghats. Therefore, we selected the domain size from 20°S to 40°N and 60°E to 120°E for downscaling using the IPRC_RegCM.

d) Selection of resolution

The horizontal resolution employed in the regional model should be high enough to capture the effects of regional topographic features on meso-scale processes leading to local rainfall and circulation. As mentioned earlier, the positive feedback between rainfall and circulation is an important factor in the intensification of tropical cyclones and extreme rainfall episodes. In addition, the model resolution should provide sufficient information for specific applications such as agricultural and hydrology impact studies (which requires climate data at few kilometers intervals). For these purposes, we fixed the horizontal resolution at 25 km (0.25 x 0.25 deg). The computational time required for simulation mainly depends on the domain size and resolution. Time required for running the regional climate model with the resolution of 50 km and 25 km is 8 and 24 days respectively for one year simulation.

e) Lateral boundary condition

The regional climate model is initialized and forced at the lateral boundaries by the global model output. The successful and realistic outcome of the regional model mainly depends on the initial state of the atmosphere and the lateral boundaries of the model domain (Wu et al, 2005). The climatology of the regional model is determined by the contribution of lateral boundary conditions from GCMs and the physical parameterizations employed in the regional model and their interaction with the dynamics and orographic effects (Giorgi and Mearns, 1999). So, if there are uncertainties in GCMs then that are expected to "cascade" into the regional model. In ClimaRice II, outputs from two GCMs, GFDL_CM2.1 and CCSM4 will be used as lateral boundary conditions to force the IPRC_RegCM. These two models have been intensively used in climate change studies and have demonstrative skill in capturing the monsoon precipitation basic state and certain aspects of variability. Next, we highlight the differences in these GCMs. Two most important variables such as vertically integrated specific humidity (or precipitation) and low-level circulation field that is instrumental in moisture transport to the monsoon region are chosen.

Comparison of uncertainties involved in different forcing fields

a) Selection of boxes

Figure 2 shows boxes selected at the lateral boundaries (Box 1 and Box 2) and we compare only the moisture field here. Over the other boxes, one over the Arabian Sea (Box 3) and another over Bay of Bengal (Box 4), low-level wind and moisture fields are compared that are deemed to influence rainfall during southwest monsoon (Box 3) and northeast monsoon (Box 4) seasons, respectively.

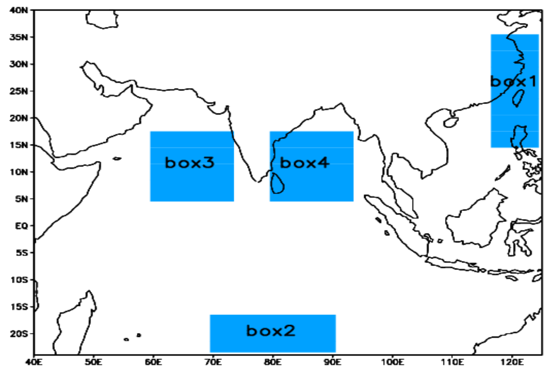

Figure 2: Selection of boxes to compare the uncertainties from different global climate model.

b) Evolution of vertically integrated specific humidity

Figure 3(a) shows the daily climatology of vertically integrated specific humidity or precipitable water averaged over **Box 1**. Throughout the annual cycle, a good agreement exists between CCSM4 (red line in Fig. 3a) and ERA-interim (green line in Fig. 3a). While the annual cycle is well represented in GFDL (blue line in Fig. 3a), there are considerable differences in the amplitude of specific humidity. For instance, during the peak southwest monsoon season in July-August the difference exceeds 20 mm. This weakness is expected to result in weaker monsoon climatology in the IPRC_RegCM when it is forced at the lateral boundaries by the GFDL model outputs.

Figure 3(b) shows the annual cycle in precipitable water over **Box 2**. Here, the GFDL output has a good agreement with ERA-interim as compared to their relationship in **Box 1**. But, CCSM4 is stronger than both GFDL and ERA-interim. The moisture transport from this region (Box 2) appears important for northeast monsoon (Fig. 1a). For regional downscaling, one inference from Figs. 3a-b is that both the southwest and northeast monsoons may be stronger when forced by CCSM4 output.

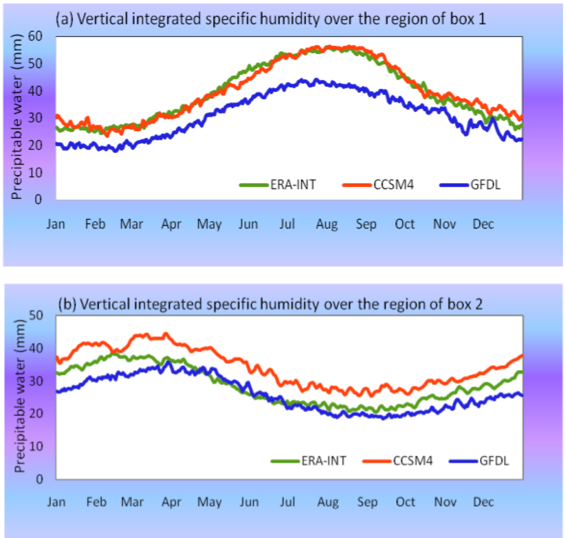

Figure 3: Temporal evolution of daily climatology of vertically integrated specific humidity averaged over **Box 1** (a) [Lon=115 to 124 and Lat=10 to 35] and **Box 2** (b) [Lon=60 to 100 and Lat=-24 to -15].

c) Circulation and vertically integrated specific humidity over Arabian Sea

It is observed from Figure 4(a) that among the three forcings there is a good agreement in wind speed over the Arabian Sea. A closer look suggests that the difference between ERA-interim and CCSM4 is 0.93 m/s and between ERA-interim and GFDL is 1.04 m/s. It needs to be mentioned here that the wind speed determines the total evaporation over the Arabian Sea and that in turn plays an important role in the rainfall distribution during southwest monsoon season.

The accumulated vertical integrated specific humidity (Fig. 4b) during southwest monsoon season over the Arabian Sea is higher by 887 mm in CCSM4 compared to ERA-interim and 1082 mm compared to GFDL. The differences in the vertically integrated specific humidity will have a strong influence on the precipitation in the model simulation during the southwest monsoon.

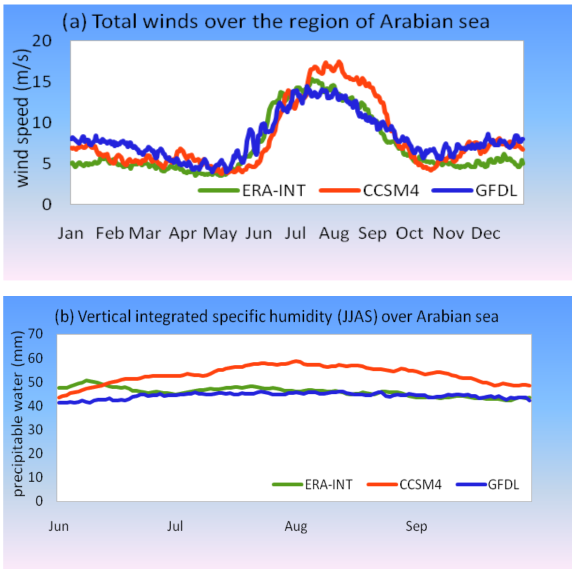

Figure 4: (a) Temporal evolution of total winds climatology and (b) moisture field for south west monsoon season over the Arabian Sea [**Box 3**: Lon=60 to 73 and Lat=5 to 17]

d) Circulation and vertically integrated specific humidity over Bay of Bengal

We clearly notice from Fig. 5a that compared to ERA-interim, the total wind speed is higher in both GFDL and CCSM4 models during the north east monsoon season which influences the rainfall over southern India. This is also reflected in precipitable water (Fig. 5b). In particular, when estimated over the whole season, the difference is about 928 mm between CCSM4 and GFDL, and 738 mm between ERA-interim and GFDL. This difference in the forcing fields will impact the precipitation in the IPRC_RegCM integrations. Though the uncertainties exist among the forcing fields, all the models capture the large-scale monsoon features over the Indian domain.

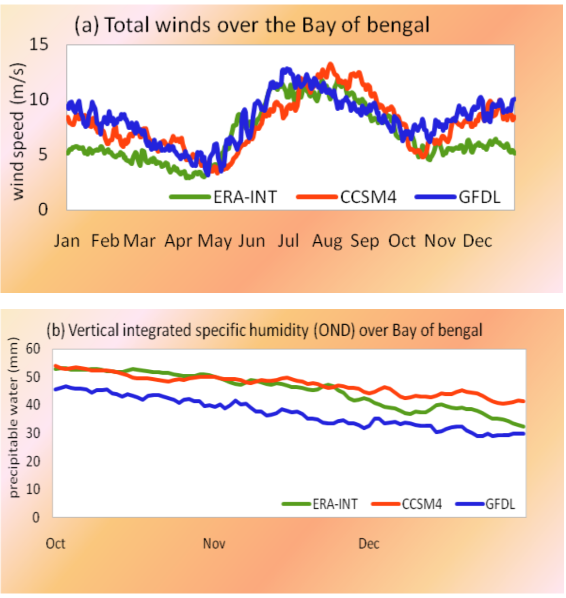

Figure 5: (a) Temporal evolution of total winds climatology and (b) moisture field for north east monsoon season over the Bay of Bengal. [**Box 4:** Lon=80 to 93 and Lat=5 to 17]

Summary

This brief summarizes the issues in setting up of a regional climate model such as spin-up time, required climate parameters, selection of model domain and resolution and issues related to lateral boundary conditions. The brief also summarizes the comparison of uncertainties involved in the global climate model and how this will influence the southwest and northeast monsoon seasons over the Indian region. We selected two most important variables viz., vertical integrated specific humidity and wind circulation pattern and noted that there are more uncertainties in the moisture field than the circulation pattern. The effect of these uncertainties in the IPRC_RegCM simulations, particularly over the Cauvery and Krishna basins will be investigated next.

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ClimaRice II Project (2009-2011)

ClimaRice II is an integrated project that aims to test and validate climate change adaptation techniques related to rice production, in close co-operation with farmers and local agencies in two study areas in the Cauvery River Basin, Tamil Nadu, and Krishna River Basin, Andhra Pradesh, in India.

The overall goal is to contribute to the regional and national adaptation strategies to sustain rice production and ensure food security amidst changing climate. The partners are:

- Bioforsk - Norwegian Institute for Agricultural and Environmental Research (Project Co-ordinator)
- Tamil Nadu Agricultural University, Coimbatore, India
- International Pacific Research Institute, Hawaii, USA
- International Water Management Institute, Hyderabad, India

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