論 文 の 内 容 の 要 旨

論文題目 Changes in precipitation and temperature extremes over South Asia using dynamical downscaling of climate change prediction results
（気候変動予測結果の力学的ダウンスケーリングを用いた南アジア域における降水と気温の極値変化）

氏 名 MEHWISH RAMZAN（ラムザン メーウィッシュ）

Climate change is very diverse in nature with large spatial coverage. The impacts of climate change can be seen via its fingerprint in term of extreme unpredictable weather. These weather extremes are associated with both natural and anthropogenic activities. Understanding these extremes requires an ample amount of available observations to determine the cause of the change. Unfortunately, the quality of observation datasets varies from region to region which lessens the confidence in studying regional details. Example of one such region is South Asia where the observation coverage is sparse in last few decades with almost no digital long-term record of the past climate in most of the regions.

In order to compensate such data lacks, climate models are very useful tools in studying the historical climate and can also be used for future projection studies. The use of climate models provides homogenous data record over large time scale. One cannot classify the model as good or bad. Therefore, it raises a question as which model to be used. One answer to this question will be that; it depends on the purpose of your study. For example, General Circulation Models (or GCMs) usually have coarse horizontal resolution (>100km). They can provide us with the large-scale picture of the phenomena such as El-Nino Southern Oscillations (ENSO), Intertropical Convergence Zone (ITCZ) Positions and Maiden Julian Oscillation (MJO) etc. On the other hand, if we need to study only some particular region of the earth then the GCMs shows constraint in providing finer details for that region of interest. Therefore, to study one specific region we need Regional Climate Models (RCM) of relatively high resolution than GCM, which can compensate our demand for regional study.

In current study, the Regional Spectral Model (RSM) originally developed at the National Center for Environmental Predictions (NCEP) by Juang and Kanamitsu in 1994 is applied to downscale the South Asian region using high resolution. The outcome of this research will contribute to the World Climate Research program (WCRP), which initiated an effort to generate high-resolution regional information for all land parts of the world. The project under which these efforts are being conducted is known as Coordinated Regional Climate Downscaling Experiment (CORDEX). The domain size of this study ranges from 7°E to 128°E and 10°S to 50°N with 256x169 grid size and 50km resolution. CORDEX-South Asian experiment (CORDEX-SA) using RSM is initiated with an aim to choose the optimum Convective Parameterization schemes (CPs), by determining their skill in reproducing the precipitation over South Asia. Downscaling of South Asia poses great challenges to the modelers. A few of them is mentioned below.

First is the heterogeneous nature of South Asian monsoon identified by previous researches, so that it is indeed a challenge for the model' s performance that how realistically it can capture this climatic phenomenon. The second well known problem faced by models in simulating South Asian precipitation is the wet bias of Atmospheric GCMs over the Equatorial Indian Ocean (EIO), which according to some researchers is associated with insufficient resolution and inappropriate model physics selected. The third challenge faced by coarser resolution models is to capture the South Asian complex topography composed of highest Himalayan and Karakorum ranges towards north, Hindu Kush ranges towards northwest, Suleiman ranges towards west of Pakistan and small hills such as eastern and western Ghats of India, Aravalli and Vidhyan ranges, Myanmar prominent peak, Nat Ma Taung (also known as Mount Victoria). All these topographic barriers play an important role in shaping the monsoon mechanism in South Asia. Multiple AGCMs or Atmosphere-Ocean coupled models are also being used in South Asia, which usually features large-scale phenomenon.

My research uses RSM to first capture the disastrous event of 26 July 2005 when Maharashtra, Mumbai received 944 mm of rain in 18 hours which claims hundreds of lives, impacted large infrastructure and badly hit the agricultural sector of the metropolis state of India. Such short-term extreme event becomes the motivation to determine the skill of four CPs that includes; new Kain Fritsch (KF2) scheme, Relaxed Arakawa Schubert (RAS) scheme, Simplified Arakawa Schubert (SAS) scheme and Community Climate Model version 3 (CCM) scheme. The time period selected for CPs evaluation is from 25 July till 28 July 2005, with 24 July 2005 as a spin-up day. The comparison of four selected CPs and their ensemble showed SAS scheme has relatively better reproducibility of precipitation than other convective schemes for the whole CORDEX-SA domain and for sub-domains such as South Asia, Pakistan and Myanmar. The wet bias over the EIO is also minimized more significantly by the SAS scheme than others. The physical ensemble experiment of four CPs does not minimizes the wet bias over equatorial Indian ocean as it combines the over estimations of KF2, RAS and CCM schemes making it less reliable as compared to SAS convective scheme.

The dynamic downscaling approach which nests the RCM over GCM in the domain of interest sometimes create systematic biases in newly formed regional model domain. In order to remove or minimize those biases multiple approaches are adopted. One such method is Scale Selective Bias Correction (SSBC) method. The systematic biases are minimized by using the combination of spectral tendency damping correction and areal averaging of temperature, humidity and pressure, or by replacing the spectral tendency nudging with field nudging, which removes the errors of large-scale inter-annual variability of seasonal mean. It applies nudging only to the rotational components of wind that is present as a default option (SSBC_def) in RSM. The third method is the application of full wind nudging along with vertically weighting damping coefficient method (SSBC_new) instead of height independent damping coefficient. The later two SSBC methods are applied for 10 years sensitivity experiments for CORDEX-SA. The result of analysis shows that due to the greater relaxation time at the ground level provided by SSBC_new, the RSM shows somewhat realistic results for precipitation as compared to SSBC_def. The high spatial correlations and low root mean square error shown by SSBC_new further confirm its capability in simulating South Asian monsoon precipitation for the selected time period.

After the aforementioned sensitivity experiments, the optimized model options are selected to run the historical and future simulations driven by Hadley Center Global Environmental Model version2 (HadGEM-AO) of National Institute of Meteorological Research of Korea Meteorological Administration. The atmospheric part has 1.875° x 1.25° horizontal resolution and 38 vertical levels with top altitude of 38km while the ocean part has 1° horizontal resolution with 40 vertical levels. The selected model options includes SAS convective scheme with SSBC_new.

RSM simulation for 20th century analysis are conducted for the time period of 1980-2005 and their results are validated using multiple datasets of varying resolutions in order to determine the performance of RSM in all aspects (land only, land and ocean, high resolution etc.) for surface precipitation as it is known as the difficult variable to validate. The results of surface precipitation validation shows RSM performance greatly depends upon the type of observation dataset used as it shows higher spatial correlation and more realistic intra-seasonal variability if both land and ocean parts are included in the validation process. The inter-annual variation of precipitation further confirms the RSM skills in capturing observation trend fairly well as compared to HadGEM. The results of 20th century analysis for surface air temperature showed improved performance of both driving parent model (HadGEM) and RSM, which can be attributed to the fact that temperature has large spatial homogeneity therefore global and regional models showed nice reproducibility with slightly warm bias in summer (JJA) and cold bias in winter (DJF).

To determine the future climate change, 21st century analysis is conducted from 2020 till 2100 using two Representative Concentration Pathways scenarios (RCP4.5 and RCP8.5). The result of surface air temperature shows an increasing trend for both RCP4.5 and RCP8.5 scenarios as compared to current climate of South Asia. However, steeper increase is observed for RCP8.5 scenario than RCP4.5. The spatial analysis shows increased temperature in winter of both RCP scenarios, which starts increasing from higher latitudes and progressing towards the tropics. For surface precipitation, the first half of 21st century (2020-2050) showed decreased precipitation in most parts of South Asia while the later half (2051-2100) showed increasing trend especially in mountainous regions of South Asia. The wind vector and precipitation analysis showed that due to the presence of huge mountain chain all around the South Asian region (starting from west of Pakistan to its north than extending towards east making a roof top over Nepal, India and Bangladesh) hinders the precipitation and wind to transcend the topographic borders between South and Central Asia. Due to the windward directions of these mountains for South Asia, precipitation becomes more localized phenomenon as compared to temperature. The leeward sides such as Afghanistan, and parts of Tibet remains drier as compared to monsoon hit South Asia.

To assess the climate extremes in South Asia various indices are analyzed to understand their causes and occurrences. The first index in this context is Hydro-climate Intensity (HY-INT) index with reference to global warming. This index is defined as the multiple of "wet days intensity" and "dry spell length" over a certain period of time. The HY-INT will increase if either one or both of its components will increase. The results of HY-INT for future projections of South Asia show an increasing trend, which is mainly contributed by the increasing wet days intensity over Pakistan, India, Nepal and Bhutan regions. The HY-INT spread over South

China and Southern Indonesia (Kalimantan region) is due to the increase in dry spell length during the mid and far future.

Extreme Indices for temperature and precipitation are calculated using the Expert Team on Climate Change Detection and Indices (ETCCDI) definitions. These extreme indices include; One-day maximum precipitation (Rx1day), summer days (SU) when maximum surface air temperature (Tmax) is greater than 25°C and tropical nights (TR) when minimum surface air temperature (Tmin) is greater than 20°C. The RSM simulated indices are validated against the observed global gridded land based temperature and precipitation climate extreme indices (HadEX2). Two reanalysis datasets available on ETCCDI Extreme Indices archive are also included in this study. The result of 20th century evaluation for Rx1day shows more realistic results for RSM simulations as compared to the two selected reanalysis datasets. For extreme temperature indices (SU and TR), RSM shows almost similar spatial pattern when compared to observation and both reanalysis indices. The future projections for Rx1day shows decreasing one day precipitation in near future (2020–2039) which shifts to increasing trend in mid future (2050–2069) and far future (2080–2099) over almost all parts of South and South East Asia. The number of summer days shows steady increase in all the three time slices mentioned above. The spread of increasing SU in future spans 20°N to 40°N and slight increase along the Western Ghats of India. TR will increase in future starting from three points of origins; one will start from South-East Asia, the second will starts from Western Ghats of India and the third will start from Middle East progressing to the western Baluchistan province of Pakistan.

The quantitative analysis of daily precipitation and temperature shows an increase in mean and 99 percentile in future. However, the comparison between mean and extreme under RCP4.5 and RCP8.5 shows more increase in 99 percentile than mean values. The percentage of change is much larger for northern Pakistan followed by South Asia and then Myanmar.

The entire research is present in dissertation from Chapter 1 to Chapter 6. Chapter 1 is based upon introduction. Chapter 2 describes the setup of sensitivity experiment. Chapter 3 is based upon the 20C analysis of RSM simulations and the validation of its simulations. Chapter 4 describes the future projection studies for South Asia. Chapter 5 describes the extreme indices results for 20C and 21C RSM simulations. The final section is based upon Chapter 6 which includes the conclusions and recommendations.