論文の内容の要旨

Abstract of Dissertation

Development of Statistical Bias Correction and Downscaling Scheme for Climate Change Impact Assessment at a Basin Scale

（流域スケールでの気候変動影響評価のための
バイアス補正とダウンスケーリング手法の開発）

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Water is the a segment of all of the main components of society and socioeconomic sectors. Increased population growth, rapid urbanization and industrialization, land use and land cover changes all together with warming climate change overload the water stress. During the past decade, a number of devastating heavy precipitation occurrences show the evidence of climate change and their impacts cause enormous human suffering and economic damages. To address troublesome extremes, Global climate models (GCMs) are the primary tool for understanding how the global climate may change in the future. It is well known that the continental scale projected climate change is more reliable than the regional or national scale level projection in GCM. Detailed mechanism of cloud formation and its feedback still unknown especially in the small scale internal dynamic of cloud microphysics. That's why precipitation in GCM shows high variability both intensity and pattern correlation compared to ground or satellite data. According to the aforementioned structure of GCM, most of the GCM shows the error in intensities and frequency of precipitation. Therefore, these deficiencies are the barriers for direct usage of GCM in the impact assessment study of local or basin level multidisciplinary aspects .

GCM precipitation is characterized by undervalue of heavy precipitation, low intensity rain but every day rain with long drizzle rain days errors and poor to represent the inter-annual seasonal change in the smaller scale of GCM grid. To establish the inclusive and effective ways to exclude the bias of GCM, downscaling resolve the scale discrepancy between climate change scenario and the resolution required for impact assessment. The statistical downscaling scheme establishes statistical links between large scale weather and observed local scale weather and the computational load is very cheap and effective. But it requires very long decade observation data set. The increasing reliability and availability of recent work on statistical downscaling reach various methods using variety in ways. Here this study develops the simple, comprehensive and efficient statistical bias correction together with the multi-model selections for target basin.

First of all, the choice of GCM is essential for impact study at the catchment scale when the reasonable and reliable response is sought. Most of GCMs are very weak in simulation of substantial seasonal evolution like the Asian summer monsoon, east Asia monsoon and etc. At least the representative regional or seasonal climate signal should come out if their performance is reasonably well during the hindcast run. In this study, choice of GCM mainly depends on the pattern correlation and root mean square error (RMSE) against reference data and compared to mean of multi GCMs. If the GCM is a fairly good one, its scores will be higher in correlation and lower RMSE than mean of all. The main parameters for evaluating in GCMs are precipitation, outgoing longwave radiation around the local focused domain and specific humidity, sea surface temperature, sea level pressure, wind components and some time air temperature within the regional domain. Through the scores systems, it can be clearly classified the suitable GCM and not an appropriate one. Other important criteria for selection of GCM is a bimodal or single mode of seasonal pattern. Merging total scores of each parameter compromising highest correlation

and minimum error and climatology inter-annual seasonal pattern to measure the quality of a GCM to choose.

After the most relevant multi GCMs are selected, bias correction is carried out for every gauge on the ground and their respective GCM gridded precipitation during the control period of 1981-2000 and near future projection period of 2046-2065. Here SRES A1B scenario is used as it describes a balance rate of development both in energy source and technologies parallel in the future world of global population and economic growth. Estimate of high quantities of distribution of many meteorological variables (corresponding eg. to 10-, 50- or 100-yr return values) are important for various dimensions of civil engineering works. So it is important to obtain their accuracy and uncertainty under projected climate change.

Extreme event statistics are challenging: the meaning itself is very extraordinary cases and so they are in the tail position of the probability density function and it cannot be assumed to be Gaussian or Normal distribution. The most widely used statistical methods of extreme value analysis are either block maxima or annual maximum series (AMS). Our study also tested this approach in bias correction extreme defined by the lowest value among AMS as a threshold and then adjusted to Gumbel or lognormal distribution of gauge record. However, this technique did not consider the other extremes in the same year which are much higher than other years' maximum. The corrected results show GCM annual maximum precipitation intensity bias are removed very well but still there are large inconsistency of a number of extreme events. This error attributes the entire spectrum error in the inter-seasonal pattern. So it should be fixed the number of extremes and this approach is called peak over threshold series including all of the most highest extreme over the specific threshold inclusion of one event per year. This POT series leads to the Poisson process model for threshold exceedance and the generalized Pareto Distribution (GPD) is used to fit for their magnitude. The method is applied to each grid point time series to examine the scenario changes of extreme precipitation. The choice of threshold in GPD is supported by the mean excess function related to different threshold which are assumed to top 1 percentile intensity or 99 percentile precipitation of long term records of observations. Through the sensitivity of location parameter, the threshold of extremes in recorded gauge and frequency of extremes can be decided. By using the same number of extreme events from GCM time series, the shape and scale parameters of GPD can be estimated from the excesses above a high threshold and the GPD function is adjusted to fit. In this way, bias corrected GCM extreme are calculated by using the transformed function between ground recorded extremes and GCM extremes. By applying the same transformed function and same extreme threshold for GCM scenario data, it can be easily recognized the increasing or decreasing changing trend of both intensity and frequency in the near future.

To complete the correction of number of rain days errors, we use the ranking order statistics in descending order. By assuming the same wet days to GCM output in the control period and defined that value as the threshold for correction of wet days frequency. The equal threshold intensity is used in the climate scenario and the analysis of dry spell or drought trend can be detected. The final one is the bias of normal precipitation and all of the intensities between high GPD threshold and the threshold for wet days frequency are defined as normals both in GCM and gauge data. The two parameter gamma distribution is selected for bias correction and the shape and scale parameters for all of twelve calendar months are estimated by the simple methods of moments. Then, all of calendar months grouped precipitation is adjusted for fitting the gamma distribution and the gamma inverse function of observation are the bias corrected function for GCM precipitation. Through the above procedures, statistical bias corrected precipitation of GCM are achieved and the bias corrected result can capture the seasonal variability very well both in each point scale and spatial distributed surfaces in all months. Not only seasonally but also intensities of the extremes or tail of the distribution are a good match too.

But it has been noticed that there is a big gap between projected GCM climate model resolution and the end user needs. The above bias correction method is very convenient for downscaling of GCM precipitation for the river basin with dense rain gauge network by applying each gauge and its corresponding GCM gridded series. The new downscaling scheme based on high temporal and high spatial resolution satellite data called the Global Satellite Mapping of Precipitation (GSMaP) was established. GSMaP algorithm was implemented to integrate passive microwave radiometer data with infrared radiometer data in order to have high temporal (1 hour) and spatial (0.1 degree) resolution global precipitation estimates. So these favorable properties of GSMaP are used as an intermediate surrogate layer for downscaling of bias corrected GCM is newly developed and tested in Sri Lanka and Cambodia.

Verification and evaluation of GSMaP estimates are done by independent observed data from rain gauges. This study emphasizes on the spatial pattern of GSMaP to keep for downscaling scheme and the intensity is corrected against the in-situ station data. The main problem is poor temporal correlation between the in-situ rain gauge and its GSMaP data. The bias adjustment method is done by grid to grid or grid to basin and bias is adjusted monthly climatological scale in monthly distributed weight delineation and 3-hourly bias adjustment is used for daily distributed weight calculation. In 3-hourly bias correction is merged to the daily scale and check the applicability of poor gauge river network. Then the evaluation is done as cross validation checking at the other GSMaP. The results of monthly distribution can be downscaled for bias corrected normal rainfall and daily scheme can be used in the flood frequency analysis and flood risk reduction. The area average top 6 events analysis show there is no typical pattern for extreme events in western Cambodia but the monthly downscaled results proved bias corrected and downscaled precipitation reproduce the intraseasonal variation very well in climatological although some show very small overestimation. For finer application in near real time basis or flood and flash flood projection, accurate estimates of rain volume are very crucial. So it can be analyzed the future extreme intensity pattern through correcting GSMaP distribution pattern over the focused region. To confirm the applicability, further more detailed analysis through basin area average streamflow analysis should be inquired.

This study has been checked its applicability to various climate regions in the world. The pilot study sites are Pampanga River basin, Angat River basin and Kaliwa River basin in the Philippines, Yoshino river in Japan, Medjerda river from Tunisia, Kaluganga river in Sri Lanka and Citarum river in Indonesia. It is prominent that pilot rivers are in different climate as Philippines, Indonesia, Sri Lanka are under the equatorial monsoonal climate, Tunisia is in the warm temperate semi arid region and Shikoku island Japan is similar in the warm temperate climate but fully humid and dry summer. In all of river basin are different in interseasonal pattern, the amplitude, distinct extreme intensities. But the developed bias correction method can remove bias in all components of GCM bias effectively in all of these river basin except Yoshino river in Japan. That basin has an amazing varying climate and hot summer plus cold winter. During June to October, typhoons are profound with very high intensity from the Pacific but in summer there is some water shortage problem in some area in the northern side.

The major conflict in bias correction method is a very notable difference in number of heavy rain events in GCM and rain gauge data. This may be due to the GCM failure of typhoon or cyclone estimation and also the dissipation of Asia monsoon in so early stage compared to actual data. In Yoshino river, bias correction was investigated during the Baiu season and typhoon season separately by trial and error. Finally the mean of frequency between June, July and August September work well. The main failure in the GCM mechanism of small scale local phenomena like typhoon are rarely captured. Another interesting scientific findings from bias corrected applications are all selected GCMs agree in the increasing trend of extreme in Philippines clearly and evident decreasing trend of extreme rainfall and total rainfall by all GCM in Tunisia.

Finally, this study had contributed the handy and efficient tool for the climate change impact study in the basin scale, statistical bias correction method, by addressing the major deficiencies of GCMs, multi-model selection method to reduce a certain uncertainty and high temporal and high spatial downscaled distributed weight for monthly or seasonal and daily pattern for downscaling of bias corrected precipitation. The proposed statistical bias correction method focus the overall error of GCM precipitation such as underestimation of heavy precipitation, low seasonal representation and big discrepancy in number of rain days all together. The proposed method had been checked its applicability in the different climate in the different part of the world. The most advanced satellite based downscaling scheme can be applied nearly in global scale resulting the high temporal and spatial downscaling pattern by adjusting the bias of satellite data through the ground and keep the pattern for distributed weight simulation. The daily corrected area average top extremes show the random feature of distribution and no typical common pattern. It means more data analysis or detailed seasonal analysis should be investigated furthermore.