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Future Projection of Himalayan Monsoon Season Precipitation by CMIP5 Models under Warming Climates

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I. Introduction: Livelihood of the Himalayan people depends largely upon precipitation. Any variability on its regular pattern exacts profound social and economical costs.

In response to increasing anthropogenic forcing, the global monsoon precipitation is expected to amplify over most of the global region [1]. However, the response varies from region to region owing to various factors such as topography, forcing etc. [2]. Recent studies found that monsoon precipitation over India is likely to increase under the global warming scenario with enhanced variability [3, 4]. Similarly, it has also been found that precipitation over the Himalaya particularly over Nepal is poorly comparable with all India rainfall [5]. Since, study on precipitation over the world's unique geographical region, Himalaya under warming scenario is very limited, this study is aimed to investigate the future precipitation change over the Himalaya.

II. Models, Data and Methodology: We employed 26 general circulation models (GCMs) participating in Coupled Model Intercomparison Project Phase 5 (CMIP5) to evaluate their skill in simulating present monsoon season (June-September) precipitation (MSP) climatology (1979-2005) over Himalaya (20-35 ^{0}N latitude and 75-94 ^{0}E longitude). The skill of the models was judged based on their ability to represent annual cycle, spatial pattern and variability using Taylor diagram. Global Precipitation Climatology Project Version 2.2 monthly data was used for the model evaluation. The best model was selected whenever normalized standard deviation (STD) lies in 0.8-1.2, correlation coefficient (CC) $>$0.5 and centered root mean square (RMS) difference $<$1. To assess the future change, simulations from Representative Concentration Pathway 2.6 (RCP2.6), 4.5 (RCP4.5) and 8.5 (RCP8.5) of selected best models of 2070-2099 were compared with the historical runs of 1970-1999. Monthly precipitation of each model from one ensemble (r1i1p1) run was used.

III. Results and Discussions: All the models reproduced annual cycle of mean precipitation over the Himalaya more or less accurately with CC is greater than 0.7. Among them, only 13 models met the criteria mentioned in section II for reproducing annual cycle. We found that simulating the spatial pattern over the complex terrain became a major challenge for the models. Out of the 26 GCMs, only nine of them were comparatively better than others to reproduce spatial pattern with high CC, less variability and error. Likewise, simulation of the STD of MSP was also found to be a problematic one. Taylor diagram of MSP indicated that only nine models performed relatively well. Our analysis revealed that neither of the models performed equally to simulate all three matrices used in this study. Thus, only five models; HadGEM2-ES, MPI-ESM-LR, MPI-ESM-MR, NorESM1-M and NorESM1-ME were selected based on their skill to simulate all three matrices. Ensemble projections of the best models under RCP8.5 scenario indicated that MSP might be increased by 11 % compared to present climatology with amplified variability over heavy rainfall zone. Multi-model mean annual cycle of monthly precipitation showed the enhancement of monthly precipitation during monsoon season.

IV. Conclusion: Precipitation over the Himalaya simulated by 26 GCMs was evaluated. No model was found to simulate all aspects of MSP equally. Relatively, high resolution earth system models performed better than the low resolution models. Ensemble mean of five reliable models projected that the MSP will increase over the Himalaya in future warmer climate with enhanced variability over the heavy precipitation zones.

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