Evaluation of orographic precipitation over Central Asia and its simulated change under a warming environment

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The Central Asia (CA) region located in the central part of the Eurasian Continent receives little precipitation and thus most parts are classified as arid/semiarid. Here, life and ecosystems largely depend on river discharge from the western Tibetan Plateau. As agricultural water stress has caused shrinkage of the Aral Sea, CA is fragile environment where human–nature interaction plays a key role in hydrological sustainability. It is believed that glaciological water is an important water resource for the CA region; however, if glacier accumulation decreases because of reduced precipitation, water stress could become an increasing problem.

According to the IPCC report based on CMIP5 models, CA precipitation by 2080–2100 is expected to increase by about 10%; however, this prediction is unreliable because numerical simulations are inconsistent. Furthermore, because CA largely depends on mountain water resources, we need to predict future precipitation change for mountain areas. For most models, representation of orographic precipitation is difficult because of resolution limitations. Thus, CMIP results must be downscaled with reference to quantitative observational data. To create an ensemble of multiple models, especially when using “teacher” data, the performance of the multimodel superensemble (MMSE) technique provides excellent results for monsoon Asia.

This study applied the MMSE technique to monthly precipitation data of CA (35°–60°N, 50°–85°E), focusing on spring (March–May), which is the rainy season in CA. First, we applied the MMSE to CMIP5 “historical” monthly precipitation in spring in accordance with APHRODITE data. Although the APHRODITE dataset can represent the orographic pattern well, it has fewer input data recently; hence, we only used data for 1980–1990 (11 years). We used all 20 registered climate models from the CMIP5 archive. We used 10 years’ data for “training” to decide weighting parameters in accordance with APHRODITE. Then, we “simulated” the final year using the derived parameters. We compared the “simulated” values with APHRODITE data of that year. We repeated this process 11 times such that the data for each year were forecasted by the MMSE.

Comparison of the precipitation pattern of each model to APHRODITE revealed higher correlation coefficients (CCs) for the MMSE result (SUP) (0.6–0.8) than for each model (0.2–0.6) for all years.

The MMSE result for the Middle East (Yatagai et al., 2018) showed the SUP produced the best pattern for each year; however, the long-term trend did not match the observations. Hence, we tried used an SUP with the top six models that showed high CCs between the time series of CA mean precipitation and each model. We selected those models that simulated interannual variation of total precipitation in the CA area as a reflection of how each model simulated the dynamic structure based on the observed forcing. Based on this selection, we applied the MMSE using APHRODITE observational data. The CCs of the top six models in terms of temporal correlation were 0.55, 0.53, 0.48, 0.47, 0.34 and 0.33. Among the other models, some showed strong negative correlation with APHRODITE (CC = −0.65, −0.49 and −0.38); thus, we could exclude them from the MMSE.

We determined the weighting using two sets: a) the 6 models superior in representing the horizontal variation and b) the 6 models superior in representing the temporal variation for the 11 years. Then, we applied each weighting to the superensemble for RCP8.5 scenario precipitation over CA, especially the high-mountain area. Set a) showed a trend of increasing precipitation in some months in spring; however, set b) showed a robust decreasing trend in all months.

Considering it reasonable to place greater trust in model outputs that are good at representing interannual precipitation variation in CA, we pessimistically predict that spring precipitation in the 2100s will be reduced in the mountain region of CA.

Keywords: Multimodel Superensemble, CMIP, APHRODITE, Glaciological water resources

