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Rice Terrace Farming Systems
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Bias-corrected Daily Precipitation Estimates in the Ifugao Rice Terraces under Climate Change Scenarios

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Rice Terrace Farming Systems
This working paper series share findings produced as part of the research activities under the Rice Terrace Systems in Rural Asia, a research project of the United Nations University Institute for the Advanced Study of Sustainability (UNU-IAS). The project aims to address dual challenges of both excessive runoff and water scarcity due to climate change by providing ecosystem based adaptation measures to strengthen resilience of the Hani Rice Terraces and Ifugao Rice Terraces.

To find out more, please visit **unu.edu/research/rice-terrace-farming-systems**

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ABSTRACT

Climate change is projected to have significant impacts on water resources. The Ifugao Rice Terraces, a highland socio-ecological production system which largely depends on the preservation of traditional communal management institutions that revolve around the allocation of available water resources and the synchronization of the agricultural cycle, stands particularly vulnerable. This working paper presents bias-corrected daily precipitation estimates under future climate change conditions. A computationally-efficient statistical bias-correction method enabled the analysis of a wide range of scenarios. Projections generally indicate a drying trend of dry months, especially at the end of the century (2091-2100). Significant changes from historical trends are evident in some scenarios. Discrepancies in projections are noted due to the inherent model uncertainties and coarse resolution of the climate models. These future projections are necessary to formulate adaptation measures which can be implemented by the local rice terrace farmers.

INTRODUCTION

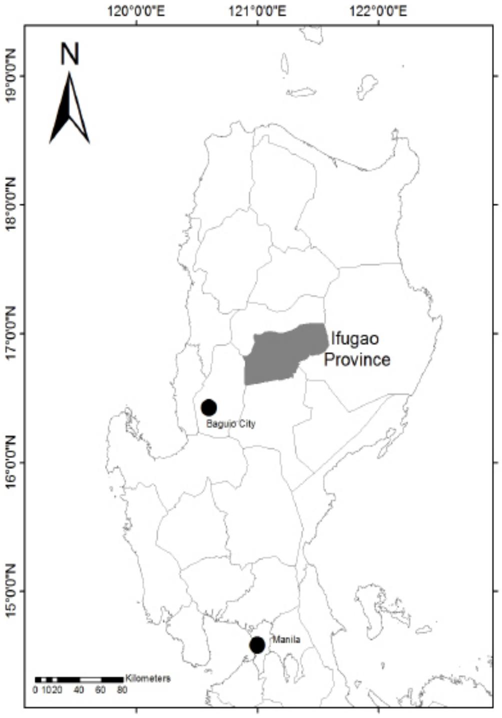
Climate scientists concur that global climate change is now inevitable. It is generally believed that this change is mainly a result of uncontrolled greenhouse gas (GHG) emissions, a by-product of unsustainable development. In the Philippines, the impacts of climate change include: higher hydro-meteorological disaster risk for the population, more hot days, less cold days, more rainy days, more typhoons crossing and affecting southern Philippines (Visayas and Mindanao), and also more heavy rainfall events in Luzon, all of which translate to more heavy rainfall producing typhoons and monsoons for the same average 20 typhoons per year entering the Philippine Area of Responsibility (both a wider redistribution in space and a narrower concentration in time) (Liongson, 2013; PAGASA, 2011). Furthermore, climate change is seen to weaken the overall efficiency of the country's national food security and self-sufficiency, including increasing problems on water allocation and prioritization for water supply for irrigation, domestic water supply, and energy requirements (DA 2011).

The Ifugao Rice Terraces are an outstanding example of a traditional agricultural system which evolved from a deep understanding of the local climate and environment. As a UNESCO World Heritage Site and an FAO Globally Important Agricultural Heritage System, the Ifugao rice terrace landscape goes hand-in-hand with an agricultural calendar that has been attuned to provide the most efficient use of resources throughout the year. The traditional Ifugaos plant during the dry months and harvest during the wet months. In doing so, vegetative growth is timed to coincide with the height of sunshine availability to enhance maximum photosynthetic activity (ITC, 1994 as cited by Gonzalez, 2000). Also, harvesting is done before the height of the rainy season to avoid the oversupply of water that often destroys crops.

Agricultural terrace systems, which can be found in various parts of the world, are highly complex, self-organizing systems, which developed from a delicate balance between the agro-ecosystem, culture and socio-economics, and available water resources (Du Guerny & Hsu, 2010). Externalities, which include climate change, disrupt this balance may weaken the overall stability of the system. In terms of water management, changing rainfall patterns and extremes challenge the applicability of traditional practices which were developed from historical observations. An extensive survey of rice terrace farmers in the Philippine Cordillera (which includes Ifugao) found that the farmers experienced these five climate stressors which increase their vulnerability to climate change: excessive rainfall, typhoon, drought, extreme cold temperature, and fog (Ngidlo, 2013). This study aims to characterize the future rainfall regime in the Ifugao rice terraces under climate change scenarios, so as to provide insight into the necessary adaptation mechanisms to be implemented.

STUDY SITE AND METHODOLOGY

Figure 1: Location Map of Ifugao Province



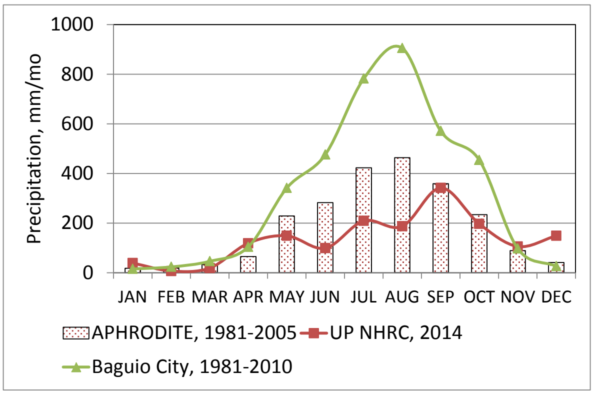
The Ifugao Rice Terraces are located in the landlocked province of Ifugao, about 320 km north of Manila. The province is characterized by mountainous and rugged terrain, with majority of the province having slopes between 18 to 50%. Most of the extensive terrace clusters are located in altitudes between 800 and 1500 masl. The climate in Ifugao is classified as temperate. The high altitudes account for the lower temperatures ranging from 19°C to 24°C. It has a dry season from December to April and a rainy season during the rest of the year. Ifugao is a generally a wet region, with annual precipitation ranging from 2,000 to 3,000 mm per year.

There are no existing continuous long-term rainfall records for the province. In order to overcome this limitation in future studies, an Automated Rain Gauge (ARG) was installed at a selected site in the municipality Kiangan, Ifugao province. The ARG was designated under station name UP NHRC (N 16° 47.393' and E 121° 04.283', Elevation: 800 masl). This ARG sends data at 15-minute intervals to the server of the Advanced Science and Technology Institute, and records can be viewed in real time at http://fmon.asti.dost.gov.ph.

The nearest station with continuous long-term observations is located in Baguio City (N 16° 25' and E 120° 36', Elevation: 1500 masl). For purposes of this study, the historical data were obtained from the Asian Precipitation – Highly-Resolved Observational Data Integration Towards Evaluation of the Water Resources (APHRODITE) database (www.chikyu.ac.jp/precip/). APHRODITE is presently the only long-term, continental-scale, high-resolution daily gridded product, which was developed from an analysis of observations from 5,000-12,000 stations across Asia (Yatagai et al, 2012). Figure 2 shows the comparison between the historical APHRODITE data used for this study (1981-2005), the published Baguio station climate normals from PAGASA (1981-2010), and the 2014 data collected from the installed UP NHRC rain gauge. It can be seen from Fig. 2 that the APHRODITE data reasonably approximates the rainfall trends in the study area, notably the occurrence of the singular peak between the months of July, August, and September, and the dry season from December to April.

Global Climate Models (GCM's), also called General Circulation Models, are considered to be the most reliable tools for simulating the response of the global climate to greenhouse gas emissions. GCM's can provide estimate of climate variables such as temperature and precipitation for past and future periods, under various greenhouse gas emission scenarios. The latest generation of scenarios implemented by the Intergovernmental Platform for Climate Change (IPCC) are the so-called Representative Concentration Pathways (RCP's). The four RCP's, namely RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5, are defined by their total radiative forcing, which is a cumulative measure of all anthropogenic emissions of GHG's from all source expressed in Watts per square meter, by 2100. The four RCP's were chosen to represent a broad range of climate outcomes from various possible socio-economic policies and technological interventions (IPCC, 2013).

Figure 2: Comparison of rainfall observations



It is well-known that GCM output precipitation cannot be directly used to force hydrological models for climate change impact analysis, if realistic results are desired (Nyunt et al., 2014). This is because GCM's typically run at coarse resolutions which do not capture local (basin-scale) climatic conditions. Hence, spatial downscaling is required. Spatial downscaling refers to the process of deriving fine scale local climate from GCM's for use in climate change impact assessments at the local level. In mountainous areas, it is especially important to incorporate fine-scale information into coarse GCM projections because of the altitude-dependence of temperature and precipitation which are not captured at the GCM resolution (Mejia et al., 2012). Several downscaling techniques have been developed for this purpose, and they can be categorized into two general classes: dynamic and statistical downscaling methods.

Dynamic downscaling converts the GCM output to local data through the use of a regional climate model (RCM), with GCM outputs as boundary conditions. RCM's are considered to be the most informative downscaling approach, but require considerable computational resources to perform.

Statistical downscaling techniques are computationally efficient and easily reproducible, but rely on the assumption that statistical relationships will remain valid under future conditions. They use correspondence models between GCM contemporary climate, and real world observations. The efficiency of statistical downscaling enables the use of many different GCM models and scenarios output to provide a wide range of projections, which is useful considering model uncertainties (Mejia et al, 2012; Tebaldi & Knutti, 2007).

This study employs a statistical downscaling technique known as quantile-quantile mapping method of GCM bias-correction, which corrects precipitation frequency and intensity by carrying out frequency analysis (Mishra & Herath, 2014).

In this study, models included in the Coordinated Regional Downscaling Experiment (CORDEX) East Asia database (https://cordex-ea.climate.go.kr/) were investigated. These regional climate projections (~50km resolution) are based on a family of GCM's developed by the Met Office Hadley Centre called HadGEM2-AO. The data used here are the results from by the Korean Meteorological Administration (KMA) and the National Institute of Meteorological Research (NIMR).

For comparison, global precipitation outputs (~120km resolution) from the GCM of the Meteorological Research Institute (MRI) of Japan, as included in the 5th Coupled Model Intercomparison Project (CMIP5), were also investigated.

The RCP's considered were RCP 4.5 and RCP 8.5. RCP 4.5 is a stabilization without overshoot pathway to 4.5 W/m^2 at stabilization after 2100, through the use of various policies and technologies to minimize greenhouse gas emissions (Thomson et al., 2011). RCP 8.5 is characterized by comparatively high greenhouse gas emissions and absence of climate change policies resulting to a radiative forcing of 8.5 W/m^2 in 2100 (Riahi et al., 2011).

RESULTS AND DISCUSSION

Figure 3 shows the comparison of the observed rainfall data to the different model outputs for the period of 1981-2005. Note that RegCM4, SNU-WRF, YSU-RSM, and HadGEM3-RA, are regional climate projections derived from the HadGEM2-AO GCM under the CORDEX project.

It can be seen from Fig. 3 that there are considerable biases between observed data and raw model outputs. Furthermore, two models, namely HadGEM3-RA and MRI are able to capture the seasonal rainfall trend better than the other models. Thus, for the remainder of this paper, only results concerning these two models are considered.

Figure 4 shows the results after applying the quantile-quantile mapping for minimizing the model biases. Bias-correction successfully minimized the errors. Errors before correction ranged from -45.35% to 299.35%, while errors after correction ranged from -23.45% to 29.17%.

Once bias-correction of the two models for the historical period had been completed, raw model outputs under future climate were also bias-corrected. This ensures that the future projections reflect the local fine scale climatic factors.

Climate projections for near-future (2041-2050) and far-future (2091-2100) periods were investigated. As stated earlier, conditions under RCP 4.5 and RCP 8.5 were analyzed. Thus, projections for a total of eight scenarios were generated. Figure 5 and 6 shows the summary of these projections.

Figure 3: Comparison of observed data and raw model outputs for 1981-2005 period

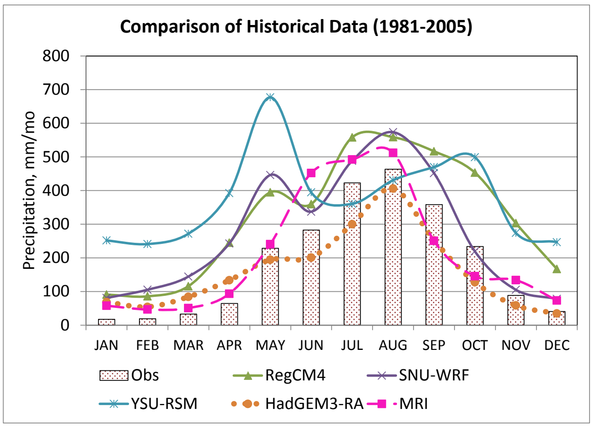


Figure 4: Comparison of observed data and bias-corrected model outputs for 1981-2005

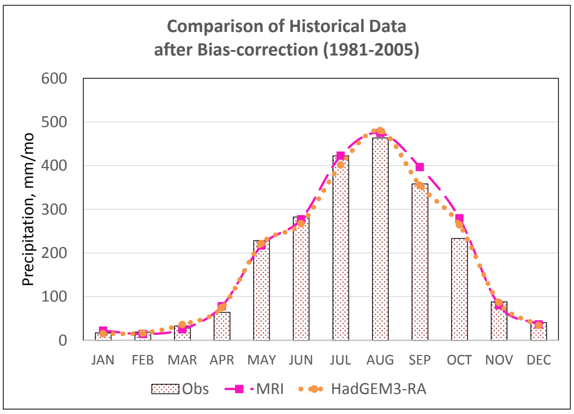


Figure 5: Bias-corrected precipitation estimates for 2041-2050. Columns represent projections based on RCP 4.5. Error bars represent the difference from RCP 8.5 projections.

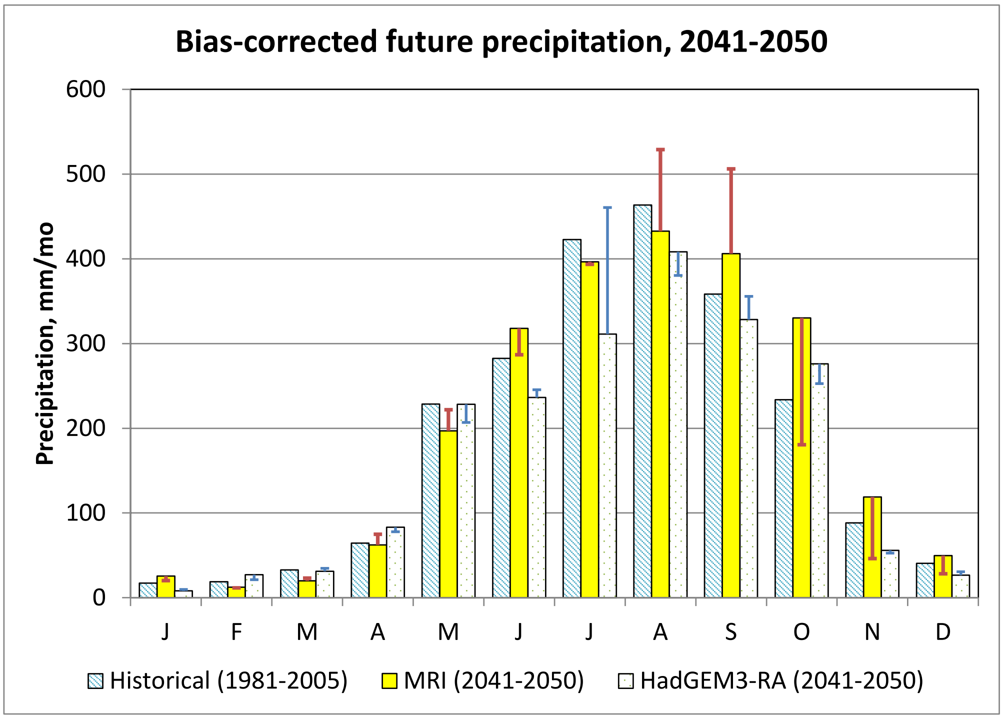
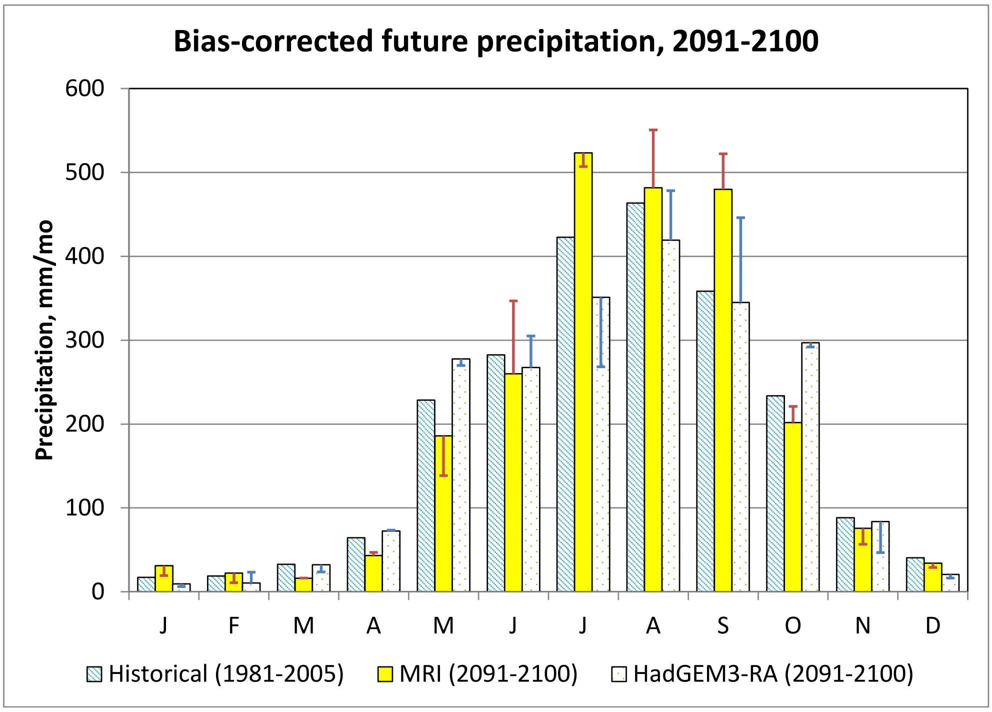


Figure 6: Bias-corrected precipitation estimates for 2091-2100. Columns represent projections based on RCP 4.5. Error bars represent the difference from RCP 8.5 projections.



Characteristics of Rainfall Changes

According to the outcome summary of the IPCC WG1 in the AR5, the total concentration of CO2 will determine the temperature increase, and thus the change of climate conditions. Thus, RCP 4.5 in the far future and R 8.5 in the near future are expected to provide similar results. This is clear from a comparison of MRI 4.5 projections trends estimated from 3 point moving averages od monthly rain for the year 2091-2100 (FF) and the MRI 8.5 projections for the 2041-2051 (NF) shown in Figure 7.

To understand the trends in rainfall change the monthly rainfall values smoothened with a 3 point moving average of the MRI 4.5 and MRI 8.5 projections for the near future (NF) are compared with the current (historical) rainfall shown in Figure 8.

Compared to present, the rainy season will start late and will last longer under the RCP4.5 scenario. There will be no significant increase in the month to month rainfall values. Under RCP 8.5 (or far future under RCP 4.5) there will be a significant increase of the rainfall during the peak rainy periods of June and July, but less rainfall during October to February season.

The corresponding figures for HadGEM3-RA show slightly different pictures. Figure 9 is for the RCP 4.5 and RCP 8.5 projections for far and near future scenarios. The figure shows a higher rainfalls in the peak rainy season of far future RCP 4.5 compared with RCP 8.5 for the near future whereas they were similar in MRI projections.

Figure 10 shows the comparison of historical and future rainfalls. It can be seen that the trends show decreasing rainfall during the peak rainy season and slightly decreasing rain in the dry season.

Figure 7: Seasonal rainfall (moving average for 3 months) of the MRI model show identical patterns for the RCP 4.5 far future and RCP 8.5 near future scenarios.

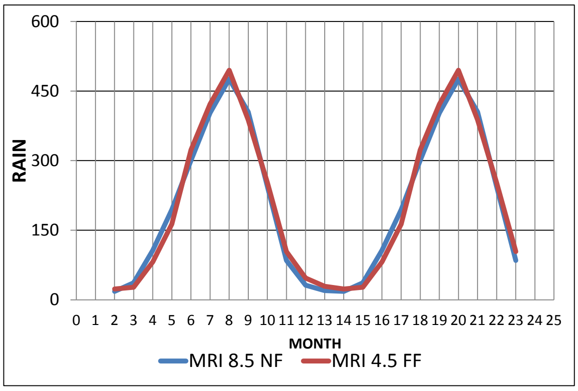


Figure 8: Comparison of MRI projections with historical trends

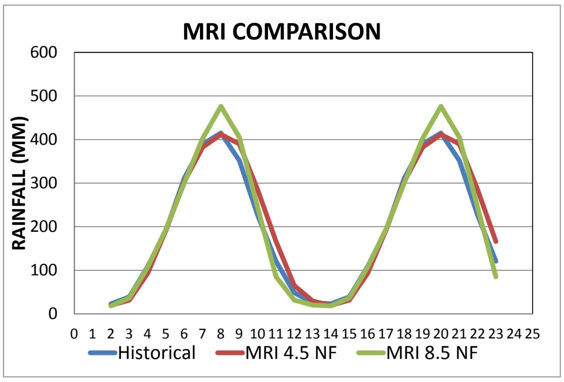


Figure 9: Seasonal rainfall (moving average for 3 months) of the HadGEM3-RA model

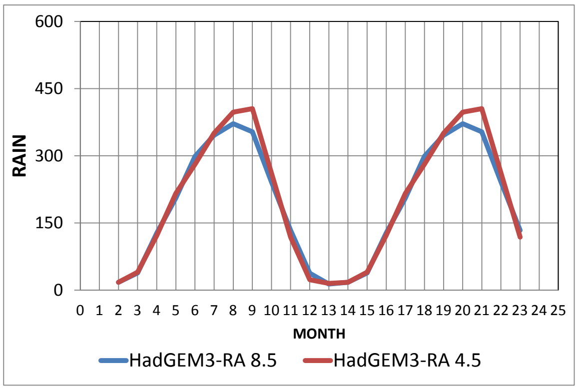
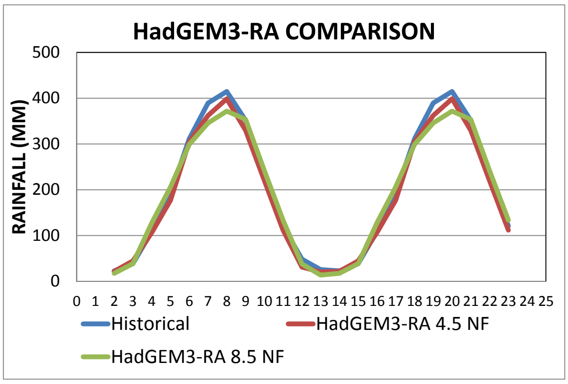


Figure 10: Comparison of HadGEM3-RA projections with historical trends



It can be observed that the MRI and HadGEM3-RA projections tend to not agree with one another. However, the projections generally indicate less rainfall for the dry season. The discrepancies might be due to the inherent uncertainties typically present in climate models. Furthermore, the models run at coarse resolutions which do not capture the effects of topography on local climates. Results can be potentially improved by using a hybrid downscaling approach, where global projections are first dynamically downscaled to at least 5 km, and then bias-corrected using observed station data.

SUMMARY

This paper presented various bias-corrected daily precipitation estimates for the Ifugao Rice Terraces under climate change scenarios defined by RCP 4.5 and RCP 8.5. The quantile-quantile mapping method which was used in this study successfully minimized the biases present in the raw GCM outputs. This computationally-efficient approach enabled the analysis of several combinations of GCM, RCP, and time period in consideration. It is important to consider a wide range of projections, because there are inherent uncertainties in models. The future projections indicate significant deviation from historical trends, and this has direct implications for the rice terraces, which depend heavily on the allocation of available water resources through traditional management practices. Projections of climate change impacts can be improved further by using continuous long term observations from station data, and the installed ARG will fill that need as it accumulates more data.

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