Statistically Downscaled Projected Changes in Seasonal Mean Temperature and Rainfall in Cagayan Valley, Philippines

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Abstract

Rice is an important commodity in the Philippines. In the Cagayan Valley (CV), rice production provides employment to more than half of the region’s population and any climate variability and change can cause negative impacts on crop production and people’s livelihoods. This paper attempts to understand projected climate changes in seasonal rainfall and mean temperature (2011–2040) to inform climate change adaptation planning in CV. The climate change projections were provided to crop and water resource modeling, agricultural market modeling, food insecurity vulnerability analysis, community-based climate change adaptation planning, and policy simulation. The results are presented for the Provinces of Cagayan, Isabela, Nueva Vizcaya, and Quirino based on the statistical downscaling of three global climate models (BCM2, CNCM3, and MPEH5) and two emission scenarios (A1B and A2). A spatial interpolation technique was utilized in interpolating downscaled climate projections at weather stations to grids, and subsequently aggregated to administrative provinces. Results obtained in the downscaling showed anticipated significant climate changes from 2011 to 2040 in terms of rainfall and temperatures relative to 1971–2000. Consistent signals of climate change were found in many seasons and variables, whereas conflicting signs of changes were found in a few cases. A larger warming effect is projected for a daily minimum temperature than that for the maximum temperature, thus reducing diurnal temperature range. Precipitation is projected to increase in general in the Valley. Regarding seasonality, dry months (March–April–May) will continue to remain dry but during the rainy season, July and November are likely to become more notable wet months. There are also indications of an increasing frequency of heavy rainfall events, prolonged dry spell events and extreme daytime temperatures (especially in Aparri).

Keywords climate projections; climate change; Philippines; downscaling; statistical downscaling; extremes

1. Introduction

1.1 Objective

There are still a high proportion of undernourished people in the Philippines (11.5 % in 2012–2014; FAO et al. 2014) and these people are considered most
vulnerable to the effects of climate variability and changes. Reducing hunger and poverty leading to food security is one of the thrusts of the Analysis and Mapping of Impacts under Climate Change for Adaptation and Food Security (AMICAF) Project of the Food and Agriculture Organization (FAO) of the United Nations wherein the first component is the downscaling of climate change projections and an assessment of the impacts of climate change on agriculture (crop yields, surface water availability, and provincial agricultural markets). The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) generated downscaled climate projections in the Philippines for the project.

A meal is often considered incomplete without a serving of rice in the Philippines. In popular culture, Cagayan Valley (CV) is considered as one of the major rice bowls in the Philippines. In 2014, 58% of CV’s population is employed in the agriculture sector (846,000 individuals), and more than 38% of the region’s total economic output (or more than US$1.8 billion) came from the agriculture, fishery, and forestry sector, in which 75% came from crops (Bureau of Agricultural Statistics 2014). As such, any shock to rice production, including extreme climatic events and changes in rainfall and temperature patterns, could lead to serious disruptions in food security, livelihood, and employment of people in the region. It is therefore of paramount importance to study any possible future climatic changes in CV. The valley is situated in northeastern Philippines (Fig. 1) and is bounded by three mountain ranges: Sierra Madre in the east, Cordillera in the west, and Caraballo in the south, hence the local name “lambak” or valley. CV is composed of four provinces namely Cagayan, Isabela, Nueva Vizcaya, and Quirino. This study excluded Batanes, administratively one of the provinces of the Cagayan Valley Region, from the analysis because it is geographically located in the sea and is outside of the mainland valley system.

It has been observed that the increased frequency of extremely warm nights negatively affects rice yield and quality (Porter et al. 2014). Some studies also show that water stress and daytime temperatures above the maximum threshold leads to spikelet sterility in rice. On the other hand, there may be a positive impact of daytime warming on yields as long as merits owing to an increase in solar radiation, which often accompanies an increase in daytime temperature, are greater than demerits owing to more frequent and severe heat stresses during daytime (IPCC 2014). Peng et al. (2004) reported a decrease in dry season crop yield by 10% for each 1.0°C increase in mean minimum temperature in their experiments conducted from 1979 to 2003 in Laguna, Philippines. Bordey et al. (2012) also proposed that a 1.0°C increase in the minimum temperature causes decreases in yield of approximately 64 kg ha$^{-1}$, and a 1% increase in wet days (in 1 year) translates to a decreased yield of 36 kg ha$^{-1}$. Irrigated rice fields have been expanding in CV but the sustainability of irrigated agriculture depends highly on future changes in rainfall and river discharge. In any case, the impacts of climate change on rice (or any crop) are location specific. The first step of adapting to a climate change is a better understanding of the climate change at the local scale and its local impacts.

Dynamically downscaled climate projections have been done in the Philippines with a regional climate model and limited set of Global Climate Models (GCMs) and emission scenarios (PAGASA 2010a). This study would like to complement the former projections using the statistical downscaling (SD) of
three GCMs and two emission scenarios. The low computational requirement of this statistical approach provides an opportunity to look at a range of possible future projections. This study presents the results of downscaled projected changes in seasonal mean temperature and rainfall in CV during 2011–2040.

1.2 Climatology

While Philippine climatology is defined by a monthly rainfall distribution categorized into four climate types (Coronas 1920), Type-1 to -4, CV has three climate types (Fig. 1). Climate Type-2 has no pronounced dry season with maximum rainy period from November to April. Areas under Type-2 are usually found in the eastern portion of CV. Climate Type-1 has a well-defined wet season from July to September and dry season from December to April, and this part is found in the western side of CV. Predominantly, CV is under Climate Type-3 with short dry season from January to March and is rainy for the rest of the year.

There are three PAGASA weather stations in CV. Two of which (Tuguegarao and Aparri) are synoptic stations, and the last is an agrometeorological station found in Isabela State University–Echague Campus. Owing to longer periods of observations in Aparri and Tuguegarao, this study looked mainly at the two former stations. The observed monthly mean temperature is highest in the months of March, April, and May (MAM) and lowest in the months of December, January, and February (DJF). Tropical cyclones are most frequent during the months of June, July, and August (JJA) and September, October, and November (SON) and less frequent in DJF and MAM. The highest total number of tropical cyclone occurrence from 1948 to 2009 is observed in Cagayan (118 times), followed by Isabela (84), Nueva Vizcaya (51), and Quirino (48). Wet season in Aparri and Tuguegarao is observed during JJA–SON (PAGASA 2010b).

1.3 Existing Studies on Climate Projections in Cagayan Valley

The PAGASA–Millennium Development Goal Fund (MDGF) reported (PAGASA 2010a; referred to as MDGF report hereafter) projected changes in seasonal mean temperature and rainfall for the period 2006–2035. The objective of the report was to prepare climate change projections for MDGF Priority Provinces in the Philippines. Three climate scenarios (A1B, A2, and B2) were dynamically downscaled by Providing Regional Climates for Impact Studies (PRECIS) with an output grid resolution of 0.25° (25 km) from either ECHAM4 (A2 and B2) or HadCM3Q0 (A1B) as boundary conditions. Some newly established provinces were not included in the report as well as some provinces that are not identified as priority.

In 2014, the United Nations Development Programme (UNDP) commissioned a report (UNDP 2014) to generate climate projections in Cagayan River Basin (CRB), wherein more than 85 % of the basin’s land area is found in the four provinces of CV. The UNDP report used six variations of GCMs to project mid-century (2031–2060) changes in rainfall: HadCM3Q0, HadCM3Q3, HadCM3Q10, HadCM3Q11, HadCM3Q13, and MPEH5 (as non-HadCM representative). There are no projected changes in temperature available in the report. The dynamical downscaling was conducted using the output extracted from the UK Hadley Center–PRECIS Southeast Asia Climate Analysis and Modeling (Rahmat et al. 2014) experiment generated from HadRM3P regional climate model and different boundary conditions with an output grid resolution of 0.22°. Mean monthly and zonally averaged values for CRB obtained from ERA-40 were used to compare/validate with the control climate (1971–2000) of the six variations of GCMs. Other climate variability and patterns were not examined.

Some of the limitations of the two studies include coarser grid resolution and differences in the definition of geographic boundaries. This study presents station-level-downscaled data interpolated to a higher spatial resolution, thereby resolving topography while recognizing the density limitation of observation networks in the country, especially in mountainous regions. Furthermore, this study used a more recent basemap from the National Mapping and Resource Information Authority (NAMRIA) in defining new provinces and changes in geographic boundaries.

2. Data and methods

2.1 Statistical downscaling

GCMs are the simplified representation of the earth’s climate system simulating the physical processes of atmosphere and ocean. However, most GCMs have spatial resolution of approximately 200 km (~2° × 2°), and to overcome such a limitation, downscaling techniques can be performed to translate a coarse horizontal resolution to a finer resolution while considering regional and local climate variability. Downscaled climate data have better application to climate change adaptations and policy-making strategies. There are two primary techniques in down-
scaling: dynamical and statistical. While we recognized that this is not the first mention of DD, the purpose of this part is to differentiate DD from SD. The first mention is a review of literature and I think it is more important to discuss DD vs SD in the methods. Dynamical downscaling attempts to reproduce physical processes considering regional and local climate variability and observations, whereas statistical downscaling establishes an empirical relationship between the local climatic condition (predictand) and the large-scale atmospheric condition spanning across the different layers of the atmosphere (predictor) to predict target variables such as precipitation and temperature.

Reanalysis dataset can be used as quasi-observations to generate climate data in lieu of actual observations. The use of quasi-observations as predictor is called downscaling in a perfect prognosis condition. Manzanas et al. (2015) experimented on downscaling daily precipitation (through Generalized Linear Model) in the Philippines obtained from ERA-Interim (~0.78° × 0.78°) and JRA-25 (~1.125° × 1.125°) in the period 1981–2010 and concluded that ERA-Interim (1979–2010) has a better performance if compared with actual observations. Both predictor datasets have been regridded using bilinear interpolation to 2.0° to overcome differences in spatial resolution. Validations are done at the 10-daily, monthly, and seasonal scales, after aggregation from the daily scale of SD. The choice of predictors in downscaling generally includes atmospheric elements such as meridional/zonal wind (U/V), specific humidity (Q), temperature (T), geopotential height (Z), and sea-level pressure (SLP) at different atmospheric pressure levels from surface (1000 hPa) to upper troposphere (250 hPa). In the same study, the authors identified a set of predictors for maximum/minimum temperature (U850, Q850, and T1000) and precipitation (U850, U300, Q850, and T1000) to be used for downscaling.

There are three GCMs under the Coupled Model Intercomparison Project Phase 3 hence the acronym CMIP3 used in SD via the FAO–MOSAICC Portal (http://mosaicc.da.gov.ph): BCM2, CNCM3, and MPEH5. The portal was developed for ease of climate data sharing among the modelers of climate impact studies. The SD utilized historical daily data (1981–2010) at 47/33/36 PAGASA Stations (precipitation/Tmin/Tmax) employing the generalized linear model nearest neighbor) technique for precipitation and the Analogue technique for Tmin/Tmax (nearest neighbor). The former technique assumes that similar local climate patterns follow similar atmospheric conditions, whereas the latter considers the uniqueness of local climate patterns as applied to different predictors. Large-scale climate mode such as El Niño Southern Oscillation (ENSO) can be captured in SD given good station records.

In climate change projections, the Special Report on Emission Scenarios (SRES) from the IPCC Fourth Assessment Report (AR4) are often used to describe the future world based on different driving forces: human activities, technology, policies, and greenhouse gases emissions. In the Philippines’ case, the SRES choice should be based on its capability to sustain climate change adaptation strategies wherein both A1B (business-as-usual scenario) and A2 (differentiated world scenario) seems to be plausible.

In summary, this study generated statistically downscaled daily projections for three variables (precipitation, Tmin, and Tmax) at station level using three GCMs (2011–2040) with two scenarios (A1B, A2) and 20C3M (1971–2000).

2.2 Spatial interpolation and scales of analyses

Downscaled data at station level were spatially interpolated using the Analyse Utilisant le RELieff pour l’HYdrométéorologie (AURELHY) technique (Bénichou and Le Breton 1987) for the whole country using all stations. To compensate for the limited density of stations, this technique incorporates topography for the spatial interpolation of downscaled variables. It combines a prediction with a multivariate regression model based on variables derived from the topography and kriging of the residuals using four main steps: 1) derivation of landscape descriptors from the topography, 2) principal component (PC) analysis of the landscape predictors, 3) linear model fit of the variable to interpolate with selected principal components and prediction on the interpolation grid, and 4) kriging of the residuals. Kriging is an interpolation technique used to predict the output surface using the measured spatial correlation of known points. In addition to geographic coordinates, elevation, and distance to sea as predictors for AURELHY, 14 PCs were used for Tmin and Tmax and 40 PCs for precipitation. Interpolation was performed to obtain 10-km-gridded data for the Philippines. The gridded data were further aggregated to 81 provinces. The provincial aggregation satisfies the requirements of most climate change impact study researchers, namely economists, and aids policy makers in local government units with climate-change-related decisions.
2.3 Statistical Downscaling in Cagayan Valley

From the SD described in Section 2.1 and interpolation in Section 2.2, this study analyzed four provinces in CV. The following sections will discuss SD results either at station levels (particularly Tuguegarao and Aparri) or at province levels (four main provinces of the region: Cagayan, Isabela, Quirino, and Nueva Vizcaya). There is no station in Isabela, Quirino, and Nueva Vizcaya to compare records and projections. The seasonality of climate in the Philippines is largely driven by the ENSO cycle and associated rainfall patterns. With the good records in the two stations, this climate mode is sufficiently captured hence there are no expected large differences in the seasonality and rainfall distribution among the four provinces. In the same manner, temperature does not greatly vary across the country given that it is tropical and predominantly a lowland. While the number of stations used in SD (at national scale) may pose uncertainties in the projections, especially if analyses are to be performed per region, it is expected that the same conclusion would be made for CV even if more stations were available.

3. Results

3.1 Validation

Manzanas et al. (2015) already reported validations of SD ERA-Interim at stations against observations (daily for Tmin/Tmax and aggregated 10 days for rainfall) during 1981–2000. Here, we make comparisons of downscaled 20C3M runs of the three GCMs, which are used as control for computing projected changes, with station observations to confirm that annual cycles are reproduced by downscaled GCMs. Tables 1a and 1b present computed Pearson Correlation using mean monthly observed precipitation, Tmin and Tmax (1971–2000) in Aparri and Tuguegarao and 20C3M (with the same variables) during the same period. All computed R (0.9 for all variables and GCMs) at 0.01 significance level suggests that the control climate is able to capture the historical mean annual cycle of all variables from 1971 to 2000.

Looking more closely, Fig. 2 shows mean monthly rainfall at two stations comparing observation and 20C3M runs. In Tuguegarao, there is an overestimate of rainfall in November–April and an underestimate in May–October by GCMs compared with the observations. In Aparri, all three GCMs capture the annual cycle of rainfall climatology with some underestimates in September–December.

Figure 3 shows the mean Tmax and Tmin in CV (as an average of four provinces) comparing observation and 20C3M runs. All downscaled GCM 20C3M outputs were able to capture the annual variability of maximum and minimum temperature in CV with some warm biases during most GCMs and most months.

3.2 Rainfall

Projected changes are computed by subtracting the control period’s mean (20C3M) from the mean of the corresponding target period (2011–2040). They are also shown as relative (%) deviations from the mean in the control period (0 % = no deviation). There is a general trend toward wetter conditions in the future among the three GCMs in Tuguegarao and Aparri (Fig. 4) in terms of total annual precipitation (except for BCM2 A1B in Aparri Station). In Tuguegarao, total annual precipitation is projected to increase in all scenarios. A2 scenario shows a larger increase in rainfall than that in the A1B scenario. In Aparri, MPEH5 and CNCM3 suggest a wetter climate in this location in both emission scenarios for the total annual rainfall, whereas BCM2 shows a drier climate or small increase (A2) in rainfall.

In both stations, the future projections show more pronounced double peaks in the annual cycle of rainfall compared with the 20th century—the first peak between July and September and the second in November. In fact, July precipitation shows substantial increases (typically +50 to +100 mm) in all models, scenarios, and stations, suggesting a shift of rainfall distribution to earlier in the rainy season. This trend is in line with the finding by Villafuerte et al. (2014) which reported long-term trends in daily rainfall in the Philippines (1951–2010), and a wetting condition in stations located in northwest and central Philippines (CV is found in this area) in the months of July–August–September (JAS). Villafuerte et al. (2014) further asserted that the long-term movement of western North Pacific subtropical high associated with reduced activity of 850-hPa westerly wind over the sea west of the Philippine archipelago may possibly be the cause of wetting trends in JAS.

Relative changes in rainfall by province are computed dividing the difference between the future and the control by 20C3M mean. Figure 5 shows that projected seasonal changes in rainfall in Quirino and Nueva Vizcaya are mostly statistically significant across seasons, GCMs, and scenarios indicating a strong climate change signal in these provinces. However, climate change signals are also statistically significant in Cagayan and Isabela except in SON. The tests of significance were conducted using t-test
In seasonal terms, MAM is projected to have the highest changes in CV (A1B: 40 %, A2: 20 %) using MPEH5. Conversely, CNCM3 A2 projects negative percent change in MAM suggesting dry conditions. DJF and SON have consistent positive percent changes indicating strong climate change signals wherein most projections in DJF are statistically significant. Inter-model and inter-scenario differences are evident in MAM and JJA. As DJF are relatively drier months, SON is projected to have the largest increase in rainfall in absolute terms. Comparing

Table 1. Pearson correlations of observation and 20C3M mean monthly (a) rainfall and (b) maximum and minimum temperatures in Aparri and Tuguegarao.

|                       | Aparri Obs. (1971–2000) | BCM2 20C3M | CNM3 20C3M | MPEH5 20C3M |
|-----------------------|-------------------------|------------|------------|-------------|
| Obs. (1971–2000)      | 1                       | 0.98       | 0.96       | 0.89        |
| BCM2 20C3M            | 0.98                    | 1          | 0.91       | 0.89        |
| CNM3 20C3M            | 0.96                    | 0.91       | 1          | 0.91        |
| MPEH5 20C3M           | 0.89                    | 0.89       | 0.91       | 1           |

|                       | Tuguegarao Obs. (1971–2000) | BCM2 20C3M | CNM3 20C3M | MPEH5 20C3M |
|-----------------------|-----------------------------|------------|------------|-------------|
| Obs. (1971–2000)      | 1                           | 0.96       | 0.93       | 0.95        |
| BCM2 20C3M            | 0.96                        | 1          | 0.94       | 0.96        |
| CNM3 20C3M            | 0.93                        | 0.94       | 1          | 0.96        |
| MPEH5 20C3M           | 0.95                        | 0.96       | 0.96       | 1           |

*a* all correlations are significant at the 0.01 level (2-tailed)

|                       | Aparri Obs. (1971–2000) | BCM2 20C3M | CNM3 20C3M | MPEH5 20C3M |
|-----------------------|-------------------------|------------|------------|-------------|
| Obs. (1971–2000)      | 1                       | 0.98       | 0.99       | 0.99        |
| BCM2 20C3M            | 0.98                    | 1          | 0.99       | 0.99        |
| CNM3 20C3M            | 0.99                    | 0.99       | 1          | 0.99        |
| MPEH5 20C3M           | 0.99                    | 0.99       | 0.99       | 1           |

|                       | Tuguegarao Obs. (1971–2000) | BCM2 20C3M | CNM3 20C3M | MPEH5 20C3M |
|-----------------------|-----------------------------|------------|------------|-------------|
| Obs. (1971–2000)      | 1                           | 0.96       | 0.97       | 0.98        |
| BCM2 20C3M            | 0.96                        | 1          | 0.99       | 0.99        |
| CNM3 20C3M            | 0.97                        | 0.99       | 1          | 0.99        |
| MPEH5 20C3M           | 0.98                        | 0.99       | 0.99       | 1           |

*all correlations are significant at the 0.01 level (2-tailed)
two emission scenarios, A2 shows a larger increase than A1B in the CNCM3 projections in SON season, whereas BCM2 and MPEH5 suggest a larger increase for A1B than that in A2. In other two seasons (MAM and JJA), there are more cases for rainfall increase projections, while CNCM3 shows a decrease in rainfall in some provinces as opposed to the other two GCMs.

3.3 Temperature

The range of projected warming varies a lot among seasons: up to 0.9°C in Tmin and Tmax (Figs. 6 and 7). For Tmax, it is common among all GCMs and emission scenarios to have a smaller projected temperature change for JJA, which is less than or equal to 0.4°C (Fig. 7). BCM2 projects a larger Tmax warming particularly in DJF and SON under A1B scenario, compared with other GCMs (Fig. 7). The difference between A1B and A2 is not very obvious and consistent across GCMs at the provincial level in this relatively near future (2011–2040).

The analysis of aggregated projected annual Tmax and Tmin (2011–2040) in CV reveals a higher increase in Tmin compared with Tmax. The rate of increase in Tmin under A1B is 0.07°C per year and 0.05°C per year for Tmax. Under the A2 scenario, the rate of temperature increase is slightly smaller: 0.05°C and 0.04°C per year (Tmin and Tmax, respectively). This differentiated projection for Tmax and Tmin suggests that diurnal temperature range will be smaller in the future.

There are also several cases of cooling projections. The Tmax projection (Fig. 7) of Nueva Vizcaya shows a cooling trend in DJF-MPEH5 and JJA-BCM2 in A1B. Nueva Vizcaya is close to Baguio weather station (refer to Fig. 1 for location purposes). An investigation of temperature variability at Baguio in the past reveals that Tmax during 1979–2010 decreased while Tmin increased (see Fig. 8b). In Quirino province, Tmax shows a cooling in JJA–BCM2 both in A2 and A1B. The nearest station, Casiguran, which is also surrounded by mountains like the Quirino province, exhibits the observed cooling of Tmax for the period 1979–2010 (Fig. 8a). In a report by PAGASA (2010b), both stations situated at elevated areas (Baguio and Casiguran)
registered increasing rainfall patterns for the period 1951–2008. Changes in mountain precipitation associated with convective precipitation in daytime may contribute to Tmax cooling. If the observed trend continues, it is possible that cooling in the future may actually be a possibility in these locations and the neighboring mountainous provinces. The rainfall projection also suggests that total rainfall will likely be larger in the rainy season and heavy rainfall events will be more frequent (see next Section 3.4).

3.4. Extremes

It is expected that the frequency of extrema or extreme events will change in the future. This section takes the simulation by MPEH5, as it reproduces the observed annual cycle of rainfall and temperature better than other GCMs, and discusses the projected changes in extremes. Comparing the MPEH5 20C3M with the actual observations from 1971 to 2000 shows almost exactly the same count (Table 2). However, it should be noted that the general trend is similar in other two GCMs, and they are presented in the same table.

Threshold values for each extreme event were selected based on the 99th percentile rank of the climatological normals of rainfall (Aparri: 79 mm, Tuguegarao: 70 mm) and TMAX (Aparri: 35.9°C, Tuguegarao: 39°C). Adjustments were subjectively made to increase or decrease threshold values for each station.

a. Prolonged Dry Spell Event

One count of a prolonged dry spell event is defined as five or more consecutive days with less than 1 mm

![Fig. 3. Comparison of mean monthly temperature between the observation and 20C3M (1971–2000) in Cagayan Valley, as the average of four provinces (top to bottom): a) maximum temperature and b) minimum temperature.](image-url)
Fig. 4. Projected rainfall under two scenarios (left to right, A1B and A2) and at two stations (top to bottom, Tuguegarao, Aparri) in 2011–2040 compared with 20C3M (1971–2000).

Fig. 5. Projected changes (%) in seasonal mean rainfall by province (from left to right): a) A1B and b) A2.
Fig. 6. Projected changes in seasonal minimum temperature (degrees C) by province (from left to right): a) A1B and b) A2.

Fig. 7. Projected seasonal change in maximum temperature (degrees C) by province (from left to right): a) A1B and b) A2.
of rain. The total number of extreme events is counted from its frequency in more than 10,000 days in the baseline period (1971–2000; 20C3M) and compared with those in the projection period (2011–2040) of the same length (Table 2). In Tuguegarao, 43 % or 123 counts (A1B) and 15 % or 99 counts (A2) increases in the number of dry day events are found. In Aparri, the rate of increase is much greater—53 % or 113 counts (A1B) and 46 % or 108 counts (A2).

b. Heavy rainfall events

One count of a heavy rainfall event is defined as an event with five or more consecutive days with more than 100 mm of daily rainfall. In Tuguegarao, 61 % or
95 counts (A1B) and 29 % or 76 counts (A2) increase in the number of extreme heavy rainfall events is projected (Table 2). In Aparri, the rate of change is similar at 60 % or 85 counts (A1B) and 53 % or 81 counts (A2). All other GCMs are also provided in Table 2. This further suggests that the increased frequency of heavy rainfall events is a big contributor to the increased total annual precipitation. The analysis of dry days and heavy rainfall events together indicates that the increase in total annual precipitation does not translate to wetter conditions throughout the year on a daily basis.

### c. Extreme daytime temperature

One count of an extreme daytime temperature event is defined as a day with Tmax that is greater than 38°C in Tuguegarao. The station will see an increase of 25 % or 486 counts (A1B) and 53 % or 593 counts (A2) in the number of extreme daytime temperatures (Table 2). In Aparri, where average air temperature is considerably lower than that for Tuguegarao, a different threshold of 36°C was used. The projected rate of increase on an extremely hot day is 386 % or 286 counts (A1B) and 325 % or 259 counts (A2), suggesting a shift in the extreme tails of probability distribution as well as the changes in the mean (figure not shown).

### 4. Discussion

This study presented possible ranges of future projections in precipitation, Tmax, and Tmin from the three GCMs and two emission scenarios. We were able to find consistent signals of climate change in many seasons and variables, while the conflicting signs of changes were found in a few cases.

The results are in general consistent with dynamically downscaled MPEH5 A1B of the UNDP report, in which increases in rainfall were projected for all seasons (DJF: 16.3 %, MAM: 5.3 %, JJA: 6.0 %, and SON: 2.7 %). The MDGF report results differ slightly, which found a decrease in rainfall for MAM (−9.8 %), but the study used HadCM3 for A1B so it cannot be directly compared with the UNDP report and our study. From our SD, only CNCM3 under A2 scenario projected a drying trend for MAM. All of these studies using A1B suggests (including this study) wetting climate changes in DJF, JJA, and SON amidst differences in the magnitude and percent changes.

Projected mean temperature change under this study is lower by approximately 0.5°C compared with projections from MDGF report across all seasons and scenarios. Changes in maximum and minimum temperatures are not provided in the MDGF report. This study projects an increase in Tmin in A1B (DJF: 0.3°C, MAM: 0.6°C, JJA: 0.3°C, SON: 0.3°C) and A2
(DJF: 0.5°C, MAM: 0.5°C, JJA: 0.2°C, SON: 0.4°C).

Projections by the three GCMs are considered equally plausible—there is no particularly inferior model in reproducing past climate among the three. The non-stationarity of climate forcing and different abilities of models to respond to forcing suggest that there is no guarantee that a better performing model in the current time period continues to perform better in the future. Depending on climate change mitigation efforts in the next decades, either emission scenario is possible. Therefore, the climate projections need to be interpreted carefully where agreements among models and scenarios are weak.

Regarding seasonality, dry months (MAM) will continue to remain dry, but within the rainy season, July and November are likely to become more notable wet months. Natural climate variability and extremes may be more important than mean changes in climate in a relatively near future.

The results of this study have implications for agriculture and food security. Upon examining the cropping calendar in CV (Philippine Statistics Authority 2014), MAM (dry season) is generally the harvesting period. Greater temperature increases in Tmin (during dry season) than that in Tmax is a concern given that rice is known to be sensitive to warm nighttime temperature. However, an increase in Tmax should not be ignored because of possible heat stress on crops in addition to the projected increases in extremely warm days. The general trend for wetter climate is good for irrigation and rain-fed rice. However, our analysis suggests that extreme heavy rainfall events will also increase; hence, an uncertainty arises as to whether the increase in rainfall is beneficial or otherwise. To understand the resulting impacts, we are now working closely with crop modelers that use our climate projections for impact assessments.

5. Conclusion

This study presented the results of statistically downscaled climate projections for CV. A larger warming rate is projected for Tmin than Tmax, thus reducing diurnal temperature range. Precipitation is expected to increase in general in the valley. As changes in rainfall seasonality, frequency, and intensity of normal and heavy rainfall events are key to agriculture and the livelihoods of the valley’s population, more research is needed to better simulate rainy season climate and gain more confidence in the projected changes of rainfall patterns.

To overcome the limitations identified in previous studies, this study integrated station-level-downscaled climate data with a topography-resolving higher spatial resolution in recognition of the limitation of density of observation networks in the country especially in mountainous regions. Furthermore, this study used a more recent basemap in defining new provinces and changes in geographic boundaries. With the validation tests, historical climate patterns were sufficiently captured by the GCMs indicating a good establishment of statistical relationship between the observations and the projections. Ultimately, the tests of significance confirm consistent climate change signals among the GCMs and scenarios in many cases.

Although this study focused on CV, the statistical downscaling was carried out for the whole nation. More analysis on differentiated climate change signals in the flat land and mountains is expected. As a follow-up, the author team also plans to statistically downscale the AR5 projections of multiple Earth System Models and Representative Concentration Pathways.

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