Climate Analysis and Technical Assistance for Climate Modelling

Final report on providing technical assistance for mainstreaming climate risk management in the agriculture sector of the Philippines

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1 Introduction

The potential impacts of climate change on disaster risk reduction activities in the Philippines recently resulted in the Global Environment Facility (GEF) approving phase I of the long-term Philippines' Climate Change Adaptation Program (PhilCCAP). The project will apply a systematic diagnosis of current climate related problems, as well as assessing potential changes due to climate change and adaptive options. It also seeks to mainstream climate risk awareness and response into operational planning, especially within the agriculture and natural resource management sectors.

The technical assistance outlined in this report, in parallel with activities undertaken by the Government of the Philippines (GoP), seeks to support the PhilCCAP preparation program by engaging in a risk analysis under current hazard conditions, as well as supporting the generation of future climate scenarios. The assumption is that these future scenarios can then be used in concert with the present risk analysis to evaluate the potential evolution of specific risks in the future. An end-to-end risk assessment is complex and incorporates specialist studies on hazards and their direct damages, as well as consideration of the wider economic impacts and the potential to mitigate damages through risk transfer mechanisms such as insurance and/or financial markets. Therefore, to accomplish an in-depth risk analysis, given the restricted time and resources, it was necessary to focus on a particular sector and region within the Philippines. It is then expected that the methodology and approach can serve as an example for further assessments in other regions and sectors across the Philippines.

After careful consideration of the findings of a previous mission (Benson, 2007) and consultation with stakeholders and interested government departments, it was decided to focus on the agriculture and in particular rice-growing sector, largely due to its importance from a dietary (it provides 65% of the nations caloric intake) and economic perspective (Benson, 2007), as well as it's vulnerability to natural hazards. Given this focus it was decided to limit the range of hazards to the three most important hydro-meteorological hazards; typhoons (winds), floods (heavy precipitation) and droughts. It was also decided to concentrate the risk assessment on Region II as it experienced the highest losses due to typhoons and floods (5%; total 1 million tonnes) as well as drought (2%; total 0.4 million tonnes). A further reason for choosing region II was it's high production levels (highest of all the regions in the Philippines) and consequent economic importance.

Whilst there has been progress in improving yields, due in part to improved varieties, use of fertilizers and better farm management practises, increases in production have recently failed to keep pace with population growth. Land degradation, due in part to the frequent use of chemicals has also led to farmers moving into increasingly marginal environments and this suggests that shocks to production may be more acutely experienced in the future. Current food price inflation experienced in the Philippines over the last few months, due to supply problems partly linked with failed harvests, suggests that small shocks to the supply chain and production can lead to dramatically rising prices.

The work presented in this report results from a scoping study to assess the potential for relating rice-specific climate hazards to rice production (Tadross 2008). It was noted that the Department of Agriculture (DA) over the years has developed several yield-loss matrices, which are used to estimate expected losses due to hydro-meteorological hazards (see Appendix A). The matrices disaggregate losses depending on the period in the crop growth cycle that the hazard occurs and it was suggested that wind, drought and flooding hazards could approximately be related to yield losses using these matrices. Such matrices have been developed over many years, based on DA experienced losses, and are only average approximations for losses – the variability in losses between different hazard events of similar magnitudes will likely be large and dependent on specific local conditions. However, these matrices are important tools as they allow climate hazards to be related to losses without requiring complex crop modelling and site-specific data on soils as well as the application of fertiliser and irrigation. Whilst these latter inputs are certainly important to crop yields one of the main objectives of this study (see below) was to understand the first order effect of climate change on climate hazards that may impact rice production. Using these matrices also allows for the climate hazard information to be directly interpretable and understood by practitioners in the DA.

1.1 Scope and objectives of the report

This report details a set of indicators (using standard meteorological measurements) that describe hydro-meteorological hazards that can be related to direct impacts on rice production. We demonstrate how they are constructed from current station observations and how they can be derived from downscaled projections of future climate. Such indicators are potentially useful in several ways, in that they:

- allow a clear disaggregation of damages related to particular climate events;
- allow the detection of sub-seasonal trends in climate that may be related to climate change;
- allow the derivation of similar indicators from scenarios of future climate;
- can be designed to directly relate to known high-impact events that form the basis for current damage assessments.

These latter two points are highly relevant as they allow the indicators to directly inform and be informed by current governmental disaster management practices. They also, in the initial phase, circumvent some of the requirements for complex crop modelling, which in turn may increase the chances of buy in from government departments as well as allowing a speedier assessment of how these impacts may be expected to change in the future.

It is also of value to consider some potential indirect effects resulting from these hydro-meteorological hazards, which may manifest themselves through changes in water availability. These indirect effects may alter the timing of subsequent cropping seasons, which depend on stored water for irrigation, land preparation and other farm management practices. Such effects may also be an important aspect in the context of climate change, which will likely alter the timing and magnitude of rainfall, and hence the timing of peak water storage and availability, in the future.

One of the major impediments to evaluating the impact of climate change in the agriculture sector is the availability of climate change projections (of appropriate climate variables) at spatial and temporal scales that are suitable for evaluating the impact on crops and farm management practices. This requires 'downscaling' the output from General Circulation Models (GCMs) and involves producing climate change information at higher spatial resolutions. To achieve this we undertake a statistical downscaling of 7 GCMs used in the IPCC 4th assessment report, producing daily timeseries of climate data for the same stations used to develop the climate indicators. This allows the downscaled data to be easily used to derive the same set of indicators in the future climate as well as to easily feed into existing frameworks and evaluation strategies. The approach followed here is similar to that adopted by Naylor *et al.* (2007)

To summarise, the two primary objectives of this report are to:

a. Develop a set of agro-meteorological indicators to quantify and assess the potential impacts of climate hazards on rice production in Region II;
b. Calculate trends in these indicators for the period of available data;

c. Develop an approach for generating climate change scenarios relevant for rice production in particular and the water cycle in general.

The remainder of this report details the data, models and methods used to achieve these objectives.

2 Available meteorological observations

Table 1 below lists stations within Region II for which daily weather data were available from PAGASA – excluding stations with short records less than 10 years which are unsuitable for either trend analysis or downscaling (see later). Most stations are Climat-cooperative stations (only providing rainfall data).

STN_NO	STN_NAME	LAT	LONG	DAILY DATA
	Synoptic Station			
98132	ITBAYAT,BATANES	20.767	121.833	1965 - PRESENT
98133	CALAYAN, CAGAYAN	19.263	121.470	1961 - PRESENT
98135	BASCO, BATANES	20.450	121.970	1951-2001
98232	APARRI, CAGAYAN	18.358	121.637	1951 - PRESENT
98233	TUGUEGARAO, CAGAYAN	17.613	121.728	1951 - PRESENT
	Agromet Stations			
011	ISU,ECHAGUE, ISABELA	16.707	121.673	1977-PRESENT
019	NVISIT, BAYOMBONG, NUEVA VISCAYA	16.487	121.152	1973 - PRESENT
	Climat-Cooperative Stations			
0204	CLAVERIA, CAGAYAN	18.612	121.085	1956 - 1980
0205	LALLO, CAGAYAN	18.203	121.658	1972 - PRESENT
0201	AGGUNETAN LASAM,GATTARAN, CAGAYAN	18.034	121.615	1966 - PRESENT
0202	CAGUMITAN TUAO, CAGAYAN	17.740	121.447	1967 - PRESENT
0203	CARITAN CENTRO, TUGUEGARAO, CAGAYAN	17.517	121.717	1977 - 06/1991
0208	CULLALABO,BURGOS, ISABELA	17.105	121.693	1983 - APR.1991
0209	ILAGAN, ISABELA	17.142	121.887	1966 - PRESENT
0214	SOLANO, NUEVA VISCAYA	16.514	121.176	1967 - 1979
0211	BARAT BAMBANG, NUEVA VISCAYA	16.378	121.044	1969 - 1981
0213	DUPAX,NUEVA VISCAYA	16.311	121.104	1969 - 1981
0212	CONSUELO,STA. FE, NUEVA VISCAYA	16.163	120.935	1967 - 1980

Table 1: Station data, location and period available for Region II. Source PAGASA.

To get a clearer idea of the spatial coverage of these stations Figure 1 shows their location with respect to the primary rice growing areas. PAGASA stations are represented by black squares and have the identifiers –clim (climate), -am (agromet) and –syn (synoptic) following the names to indicate the available range of observed meteorological variables. As mentioned previously the climate stations only provide rainfall observations, which is a severe limitation to their use for developing indicators. Many of the indicators developed in the following section utilise temperature measurements, either to suggest a direct impact or for calculating evapotranspiration. Additionally there are many gaps in the station records, which for 7 stations end before 1991 and so do not provide enough data for climate change downscaling. For these reasons it was decided to not use the climate stations in the following analysis, though data from 4 of the stations could be used in conjunction with rainfall-only hazard indices. PAGASA also indicated that there are many gaps in the records from Itbayat and Calayan synoptic stations and that they were therefore not useable in the present analysis. This left only 2 synoptic stations in region II (not including Basco synoptic station which is situated on an island to the north of the mainland) and the 2 agromet stations, of which the data for Nvisit was not provided again due to missing data. Therefore the following analysis is restricted to the Aparri, Tuguegarao and ISU stations which span a reasonable portion of the length of the Cagayan valley, but do not include the far southern rice growing areas, or the higher altitudes to the west and east. Data for these regions were also discussed with

PAGASA but unfortunately were unavailable. Stations in the CAR region would have been useful to estimate the amount of water received in watersheds that perhaps overlap the CAR region yet feed the water sources in the Cagayan valley. Regions at higher altitude may be expected to experience climate change differently to those regions at lower altitude and hence potential water available for irrigation may be altered in currently unascertained ways.

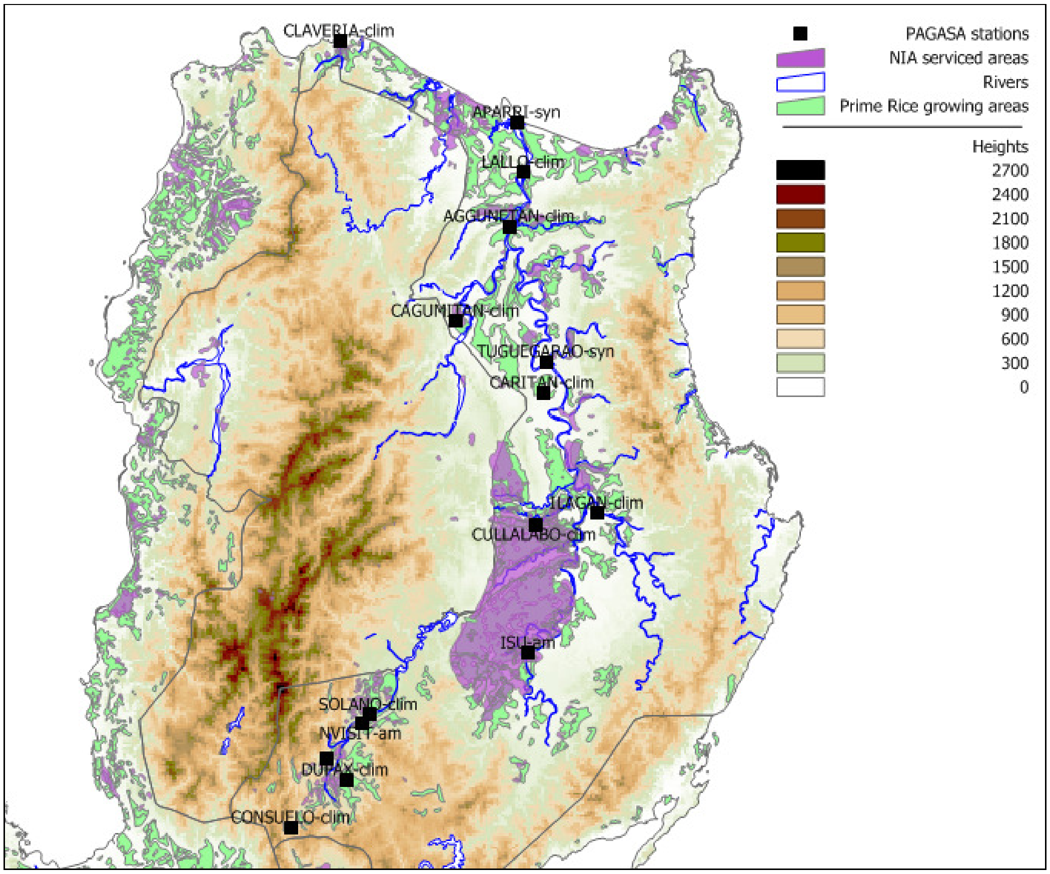

Figure 1: Synoptic (-syn), agrometeorological (-am) and climate-cooperative (-clim) stations available for Region II from PAGASA (■). Primary rice growing areas marked in **green**. NIA irrigated areas in **purple**. Data source PAGASA/PhilRice.

The data from the three stations were first subject to quality control tests which included:

1. checking for negative rainfall;
2. rainfall > 500 mm in one day
3. minimum temperatures greater than maximum temperatures;
4. minimum and maximum temperatures greater than 6 standard deviations from the long-term (full dataset) mean value
5. inhomogeneities due to changing instruments or location.

Any data fulfilling these criteria were set to NA. The 5th test utilised software distributed by ETCCDI[1] and described in Wang *et al.* (2007). All the data tested indicated shifts at different points in the timeseries, though these were not large and (subjectively) within reason. The exception was a shift of approx -3 °C on 1st June 2001 in the minimum temperature data for

[1] http://cccma.seos.uvic.ca/ETCCDMI/software.shtml

Tuguegarao station (see figure 2). This shift was reversed on 20th February 2005 and so it was decided to remove all data after 1st June 2001.

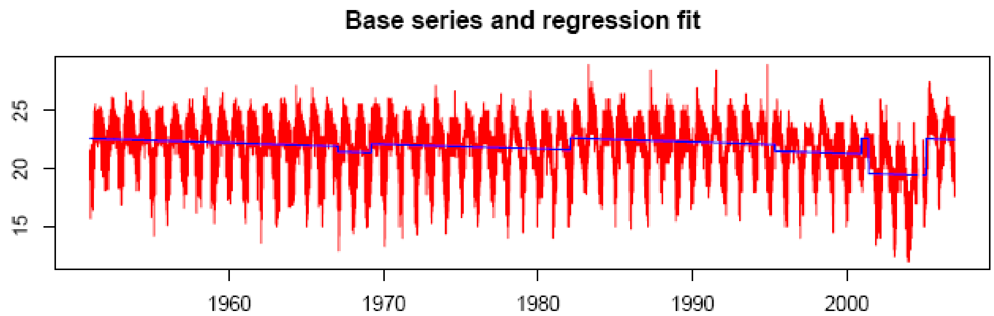

Figure 2: Timeseries of daily minimum temperature at Tuguegarao station. Note the shift of approx -3 on 1st June 2001.

For each of the 3 stations and for the periods indicated in table 1, the following atmospheric observations were provided:

1. Daily Precipitation
2. Maximum daily temperature
3. Minimum daily temperature
4. Daily wind speed/direction
5. Relative humidity

These data were used to derive the climate indicators explained in the next section as well as providing the observations for the statistical downscaling of the 7 GCM scenarios of future climate in section 5. The statistical downscaling is currently only set up to work with estimates of rainfall and temperature - as the indicators were designed to work with both observations and projected future climates, only rainfall and temperature will be discussed further in this report.

3 Indicators of high-impact climate hazards

Indicators of hydro-meteorological hazards, which significantly affect the rice crop were noted in discussions with several agencies, particularly at PhilRice who produce the "PalayCheck System" guide to irrigated lowland rice management. Salient indicators, which were often noted for cropping and post-harvesting in Region II, include: the start of the rains which are needed for land preparation and sowing, high temperatures during flowering, excessive rains during crop growth and harvesting as well as high winds causing lodging of a mature crop (these latter two are often synchronous during the passage of typhoons). Between harvesting and selling to traders, most palay is dried, with mechanical drying facilities generally inadequate (PCARRD, 2001); UNDP, 2004 estimate that only 50% of total production in Isabela can be dried mechanically, the remainder is dried in the open air. Therefore heavy rains at the end of the cropping cycle hamper both harvesting and drying activities

Rice is grown both with and without irrigation, though over the years the proportion as well as total area planted of irrigated vs. non-irrigated rice has increased. Furthermore, each kilogram of rice requires between 3000 and 5000 litres of water, twice as much as corn/maize, which is reflected in that agriculture accounts for 80% of total water demand in the

Philippines. This has important implications for climate change adaptation and the PhilCCAP program given potential changes in water availability in the future.

The above observations suggest that climate hazard indicators could be based on the start of the rainfall/planting season as well as water availability and extreme temperatures/rainfall at different periods of the cropping cycle. Though it should be noted that the potential application of any particular climate hazard indicator will likely be dependent on the localised climate, altitude (particularly affecting temperature), as well as access to water storage and irrigation facilities.

3.1 Seasonal indicators

Hydrometeorological hazards related to the rice crop are generally dependent on their timing with respect to the crop growth cycle, which is in turn dependent on sowing date. Sowing dates (the time when either fields are directly wet seeded or seedlings are sown in a nursery[2]) are not prescribed and are usually dependent on the arrival of the rains and sufficient moisture for seed germination and crop growth. A second consideration, particularly for rainfed cultivation, is the end and/or length of the rainfall season. The rains must continue to provide adequate moisture throughout the cropping cycle if rainfed cultivation is to be successful. In the Cagayan valley there may be a second rice crop but this is normally an irrigated crop during the following dry season. Therefore the starting point for the following analysis is to determine planting dates for the first crop, the end of the rainfall season and the consequent duration.

3.1.1 Start, end and duration of the season

One suitable method for determining sowing da1tes is that suggested by Yoshida, 1981; sowing occurs when 200mm of cumulative rain falls in 30 days after 1 April. Sowing dates may be calculated based on this criterion, though under climate change this may change due to increased temperatures and evaporation, resulting in less retained soil moisture. This problem can be circumvented by applying a second criterion based on estimated potential evapotranspiration (PET) e.g. sowing occurs when the ratio of Precipitation (P) to PET is greater than a set threshold. In practice both of these criteria can yield false starts when 1-2 days of excessive rainfall occur in advance of the start of the main rainfall season and to overcome this it was assumed that planting did not occur unless there were more wet days (> 0 rainfall) than dry days in the same 30 day period. In summary the two criteria for planting dates are:

1. when more than 200 mm has fallen in 30 days, after 1 April AND there are more wet than dry days in those 30 days;
2. when P/PET > 0.5 (averaged over the previous 30 days) AND there are more wet than dry days in those 30 days.

In practise there is a third criteria based on temperature as rice will not germinate in temperatures below 10-12°C. A temperature test was included (sowing dates could only occur when mean temperatures for the following 30 days were above 12°C) but was never an issue as all stations used in this analysis had mean temperatures above the threshold all year. It could however be a factor for locations at higher altitude in the Cagayan valley.

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[2] This does not apply to dry seeding sowing dates, though the development of the subsequent crop depends on similar criteria.

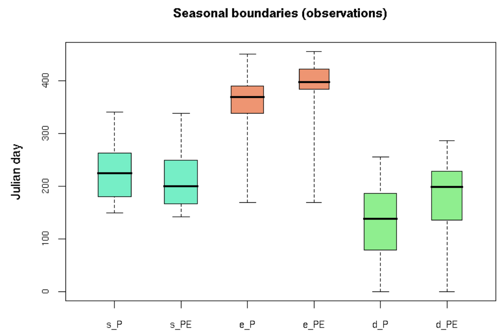
Given the need to extend the analysis to support climate change work under PhilCCAP and that climate change downscalings are only available for precipitation and temperature (initially at least), PET had to be calculated using only rainfall and temperature. We therefore used the Thornthwaite method, which whilst known to under predict PET in arid environments, is not expected to pose a problem in the Philippines. Furthermore we used the method proposed by Pereira and Pruitt, 2004 which corrects for some of these deficiencies as well as providing PET estimates at the daily timeframe. The above criteria assume that farmers do not have access to water resources to muddy fields or that they do not prepare before the rains (even if water is available). They are therefore not valid everywhere and should be treated as approximations for actual planting dates.

Similarly the above definitions can be modified to decide when the main rainfall season has ended. The end of the rainfall season can have important implications for water availability during the cultivation of a second rice crop such as is often grown during the dry season in the Philippines. If the rains end early then there may be a period of excessive drying during the 2nd cropping season, which although irrigated may place increased pressure on available water resources. In the case of rainfed rice the end and consequent length of the rainfall season is important as rainfall is required to be long enough to provide water during the whole cropping cycle (certainly till beyond the sensitive flowering period). We therefore calculate the end of the season similarly to the start of the season, except that we replace the dry/wet day requirement with a consistency check. The criteria for determining the end of the season are therefore:

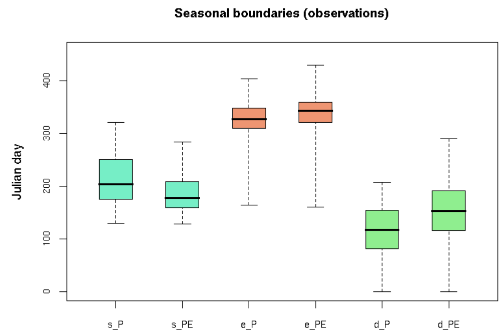
1. When less than 100 mm falls in the following 30 days, after the start of the season AND this criteria is consistently met on each of the following 30 days;
2. When P/PET < 0.5 (averaged over the following 30 days) AND this criteria is consistently met on each of the following 30 days;
3. Both of the above are not calculated if missing data are encountered in the calculation.

Again a temperature factor was included so that the season is assumed to have ended if mean temperature dropped below 12C but this was not a factor at the 3 stations discussed here. Together these definitions allow for the calculation of the start, end and duration of the rainfall season based on both rainfall-only criteria, which are valid in the current climate, and rainfall-PET criteria which are expected to be more representative in a future climate with increased temperatures and evapotranspiration.

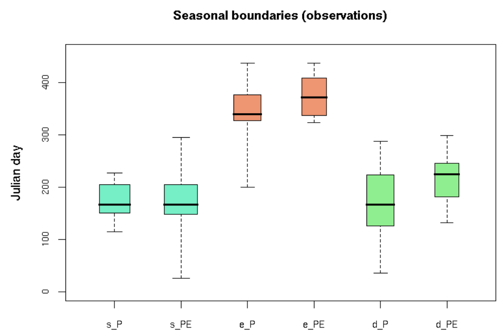
Figure 3 presents the range of values calculated for the start, end and duration of the rainfall season at Aparri, Tuguegarao and Isabela stations utilising the rainfall only (P) and rainfall and PET (PE) criteria. All 3 stations indicate a wide range of start days for the season, roughly centred on Julian day 200, with little difference between the P and PE criteria. Similar observations can be made for the end and duration of the rainfall season at all three stations, except that the season appears to on average end earlier and be of a shorter duration at Tuguegarao.



(a) Aparri



(b) Tuguegarao



(c) Isabela

Figure 3: Seasonal boundaries calculated for the Aparri (a), Tuguegarao (b) and Isabela (c) stations: start of season based on rainfall (s_P), start of season based on rainfall and PET (s_PE), end of season based on rainfall (e_P), end of season based on rainfall and PET (e_PE), duration of season based on rainfall (d_P) and end of season based on rainfall and PET (d_PE). Boxplots indicate the range (dotted extension), central 50% (boxes) and median (thick line) values.

3.1.2 Potential net soil water before, during and after the season

Given the above measured start to the season (assumed to be the sowing date) it is then possible to estimate the net atmospheric transfer of water to the soils as water from rainfall (P) minus water lost through evapotranspiration, assuming that water is always available for evapotranspiration. According to FAO guidelines (FAO, 1998) this first involves calculating PET (as detailed above), which gives the potential losses due to climatic conditions, and multiplying it by a constant (k_c) representing the dominant vegetation type (and hence losses through transpiration). During the period when crops are being grown this is a crop-specific coefficient which depends on the period of the cropping cycle (see below), whereas during other times k_c can be assumed to be representative of a short grass variety with a typical value of 0.2. During the season we assumed a value of 1.0, which is typical of the growing rice crop (see below). The daily potential net water transfer (PNW) to the soil surface therefore becomes:

$$PNW = P - k_c * PET \qquad \text{(equation 1)}$$

It is important to understand that this quantity is not the real net transfer of water as it assumes that there is always water for evapotranspiration, which in practise depends on the runoff and water holding capacity of soils (which may dry out and hence reduce evapotranspiration). However, the purpose here is to characterise the climate hazard with respect to it's potential impact on soil water, without complex modelling of soils and their properties. In this respect PNW can be considered a 'drought' index for the periods before, during and after the rainfall season. This index will be used to characterise potential changes in the climate hazard affecting water availability during these periods in a future climate e.g. it may be important before planting when water is required for land preparation (ACIAR, 2007; ADPC, 2007). In the following analysis the daily sums of PNW for before, during and after the rainfall season are given the respective notations: "wbb", "wbd" and "wba" (note: these indicators are not calculated if missing data is present). A modified version of PNW is used in the following section to characterise the drought hazard during specific crop growth periods.

3.2 Crop specific indicators

Given the calculated sowing dates in section 3.1.1, the cropping calendar can be divided into the three main growth stages (vegetative, reproductive and ripening) the duration of which depends on the particular varietal, examples of which are shown in Figure 4. The IR64 varietal is used extensively in the Cagayan valley and the following indices are based on the growth phases of this varietal (vegetative - 45 days, reproductive – 35 days, ripening – 30 days).

Figure 4: Growth phases for 2 popular rice varietals. *Source IRRI.*

Often a second crop is grown after the first crop has been harvested and the following indicators were calculated for this second crop, assuming there was a 30 day fallow period between crops i.e. the growth phases for crop 2 were assumed to start 140 (110 + 30) days after the sowing dates determined earlier.

3.2.1 Drought

Droughts are often associated with El-Niño occurrences in the Pacific, which may be forecast ex-ante (ACIAR, 2007). According to the DA drought damage matrix (appendix A) the greatest risk of yield loss is faced during the panicle initiation, booting and flowering stages, which occur between reproduction and maturation. Accounting for water deficits to relate to the drought-yield matrices in Appendix A is a demanding problem. It is dependent on PET but also irrigation when available and soil drainage. Even so, simple water balance calculations may be useful for understanding how climate hazards that impact the rice crop may change in the future. As detailed above this can work for defining the beginning of the

(1^{st} crop) season because this is mostly dependent on rainfall (there is little irrigation available after the long dry season). Though this changes throughout crop development, a simple index as given in equation 1 and modified for the different growth stages can be used to imply the effect of the climate hazard on soil water and hence give an indication if the climate is favourable or not. Appropriate values for k_c for the different growth stages are given by FAO[3] as 1.05 (vegetative), 1.2 (reproductive) and 0.9 (ripening). Integrating equation 1 for the different periods of crop growth gives an indication of whether rainfall alone is enough to sustain water demand of the crop and overlying atmosphere. The indicators are named "wb1", "wb2" and "wb3". However these simple indices do not include losses due to runoff, percolation and seepage and therefore it should be remembered that they will underestimate the atmospheric water requirements of the rainfed crop.

Doorenbos and Kassam (1979) provide a method for estimating fractional yield changes from the fraction of actual vs. required evapotranspiration:

$$1 - \mathrm{Ya} = k_y * (1 - E_r) \qquad \text{(equation 2)}$$

Where Ya is the fraction of maximal yield, E_r is the ratio of actual to required evapotranspiration and k_y is a crop (and growth stage) specific coefficient. Here we use k_y values of 1.4, 3.0, 0.4 for the vegetative, reproductive and ripening stages respectively. If we assume that all water required for evapotranspiration is provided by rainfall then E_r can be approximated as $P/(k_c PET)$. If E_r is greater than 1 then moisture requirements are satisfied and maximal yields are attained, whereas there is a decrease in yields if $0.5 < E_r < 1$ (the equation is only valid for $E_r > 0.5$).

These indices are calculated in a similar manner to the methods used to characterise the climate hazard in the FAO CROPWAT software, except that here because of data limitations we use a different method to calculate PET and neglect the full soil water balance equations.

3.2.2 Increasing/excessive temperatures

As noted previously in discussions with IRRI and PhilRice, daily maximum temperatures in excess of 35°C are detrimental to crop development and may result in decreases in yield especially during the reproductive stage[4]. Therefore an indicator which simply measures the frequency with which daily maximum temperatures exceed 35°C is calculated for the 3 crop growth stages ("Tmax1", "Tmax2", "Tmax3"). IRRI have also noted that increasing daily minimum temperatures reduce rice yields (Peng *et al.*, 2004), hence a second temperature index was calculated as the average minimum temperature during each crop growth stage ("Tmin1", "Tmin2", "Tmin3").

3.2.3 Flooding

Flood damage can occur at all stages of the rice growth cycle and depends of the presence of muddy or clear water, whether the crop is completely submerged and the number of days of inundation (see appendix A). Greatest sensitivity/vulnerability is during the panicle initiation/booting stage when completely submerged, though the flowering stage is particularly sensitive to muddy water flooding. Besides affecting the growth and cultivation of rice, flooding may also cause problems for farm management (e.g. getting into fields during harvesting), post-production activities – as much as 50% of the rice in Region II is

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[3] http://www.fao.org/docrep/X0490E/x0490e0b.htm#tabulated%20kc%20values
[4] http://www.knowledgebank.irri.org/oryza2000/Oryza_User_Manual/3_-_Crop_growth_and_development/3.2.8.htm

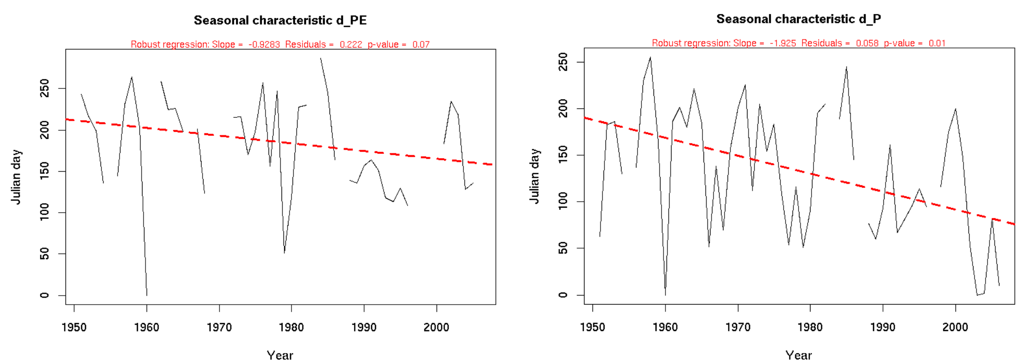
dried in the open air (PCARRD, 2001), as well as damage to irrigation, transportation and storage infrastructure (UNDP, 2004). However, flooding is a complex phenomenon and requires modelling the interaction of rainfall with site specific attributes such as soils, drainage channels and slopes. This is beyond the objectives of the present study and so the maximum daily rainfall within each of the 3 crop growth periods (“Pmax1”, “Pmax2”, “Pmax3”) is calculated as a proxy indicator. Whilst this indicator does not directly provide information on the hazard (flooding) it can indicate if the hazard is likely to be a problem

4 Analysis of current trends in the derived indicators

Given the derivation of the indicators in the previous section and that one of the major objectives of this study is to determine potential hazards to rice production in a future climate, it is logical to ask if there have been any noticeable changes in climate hazards affecting rice production in the recent past. This is very important to determine as some aspects of climate change are expected to already be occurring (e.g. increases in temperature in many places around the world) whereas other aspects (e.g. changes in rainfall) may only be detectable at a later date. Therefore examining the data for recent changes can lend weight to adaptation policies that may need to be followed now, rather than later. In the following analysis all trends were calculated using a robust regression which is less sensitive to outliers and problems with heteroskedastic timeseries.

4.1 Start, end and duration of the season

Changes in the seasonal boundaries were detected at Aparri station utilising both rainfall only (P) and rainfall/PET (PE) criteria. In the former case the main change was that the end of the season has been tending to be earlier but in the latter (PE) case the start of the season has been tending later. Both criteria resulted in a decreasing length of the rainfall season as demonstrated in Figure 5



(a) (b)

Figure 5: Changes in the duration of the rainfall season at Aparri, a) PE, b) P

Further south at Tuguegarao the main change during the 50 years of reported observations is that, based on the PE criteria, the rainfall season has been tending to be longer (figure 6). This is the result of non-significant trends for an earlier start and later end to the season. Whilst this result is at odds with the changes noted for Aparri, the two stations are some distance apart and likely influenced by different synoptic weather patterns (Aparri is coastal whereas Tuguegarao is inland). Unfortunately the shorter timeseries for Isabela station combined with more missing data meant that the seasonal boundary indices (and all other indicators) could only be calculated for approx 10 years which is insufficient for determining trends and so no robust trends could be calculated for this station.

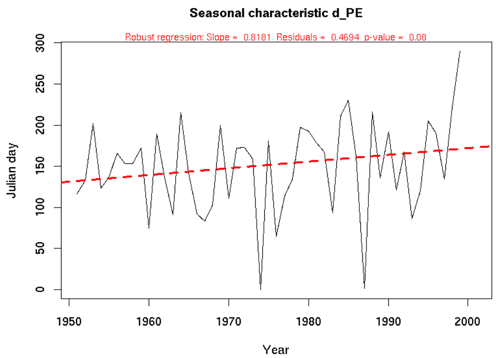


Figure 6: Changes in the duration of the rainfall season at Tuguegarao (P/PET > 0.5).

4.2 <u>Potential net soil water before, during and after the season</u>

There were no detectable changes in PNW before, during and after the season at Tuguegarao station and the timeseries was too short at Isabela. However in line with the decreases in seasonal duration mentioned earlier, there was a detectable decrease in the amount of PNW during the rainfall season at Aparri.

4.3 <u>Crop specific indicators</u>

Four crop specific indicators were calculated for 2 cropping calendars (assuming a 30 day fallow period between each) at each of the 3 stations, though data for Isabela is not shown due to the problem of excessive missing data mentioned earlier. These climate hazard indicators are shown for each station and cropping calendar in Table 2. Given that these indicators exist for both the P and PE criteria for the start of the season and that the PE definition is believed to be more robust to potential changes in temperature, only indicators based on the PE definition are shown in the table.

Station	Change in crop indicators					
	Crop 1			Crop 2		
	Vegetative	Reproductive	Ripening	Vegetative	Reproductive	Ripening
Aparri						
Tmax	0	0	0	0	0	0
Tmin	**-**	**-**	**-**	0	**+**	+
Pmax	+	-	**-**	**-**	**-**	+
Wb	+	-	**-**	**-**	**-**	-
Tuguegarao						
Tmax	**-**	**-**	-	0	0	**-**
Tmin	0	**-**	-	+	0	-
Pmax	-	-	-	0	+	+
Wb	-	-	+	0	**+**	**+**

Table 2: Change in each crop indicator (+/- trends for the approximate period 1950-2000). Trends marked in bold are significant at the 90% confidence level.

Table 2 indicates several notable changes in these climate indicators during the 1950-2000 period. Whilst the frequency of maximum temperatures greater than 35°C (Tmax) has not significantly changed at Aparri station (perhaps in part because the climate is milder, coastal and more regulated by the surrounding ocean), they have mostly declined inland at Tuguegarao, particularly early in the first cropping (wet) season. Similarly mean minimum temperatures (Tmin) mostly indicate a decrease during the first cropping season, particularly at Aparri station. The results for Tuguegarao are somewhat at odds with the results reported by Manton *et al.* (2001) who note that cold nights have been decreasing. These results are for annual extremes which may mask some of the sub-seasonal changes found here, with other seasonal changes dominating at the annual timescale. Another possibility is that the trends noted in the start of the season move the cropping cycle to a period with on average lower temperatures.

Significant changes in maximum daily rainfall (Pmax) at Aparri station are mostly negative towards the end of the 1st and beginning of the 2nd cropping season. This is beneficial for harvesting activities at the end of the 1st cropping season and is consistent with reduced extreme rainfall reported in Manton *et al.* (2001). Changes in potential net water to the soil (Wb) indicate decreased availability at the end of the 1st and during the 2nd cropping season at Aparri. At Tuguegarao the situation is different with indications of increased water availability at the end of the 2nd cropping season, which could help to alleviate the pressure on irrigation systems.

5 Scenarios of climate change

One of the biggest challenges facing the PhilCCAP program is acquiring downscaled scenarios of climate change at spatial scales which can be used in an agricultural impact assessment of potential future changes. In this section we derive a range of future scenarios and calculate the same climate hazard indicators detailed previously in order to assess what changes may be expected in these indicators under a global warming scenario.

5.1 Downscaling

Empirically downscaled climate change scenarios of rainfall and temperature from 7 GCMs (all used as part of the IPCC AR4 assessment) were created (for the 2046-2065 period) for the 3 stations (Aparri, Tuguegarao and Isabela) with long enough records (minimum 10 years). Daily data were taken from PCDMI data archive for the 7 GCMs (see table 3 for details), which had been run under an assumed A2 SRES emissions scenario. It was decided to concentrate on spanning a range of GCMs, in preference to a range of scenarios, as scenarios mostly diverge globally after 2050. Whilst this is regionally a rough approximation it is expected to cover the greater portion of the total uncertainty spanned by a range of GCMs and emission scenarios.

The statistical downscaling method is outlined in Hewitson and Crane, 2006 and involves using the projected changes in daily synoptic circulation patterns to project the future climate at a particular location. An example of the data over Africa is shown in Christensen *et al.*, 2007 and these data are used to derive expected changes in the hazard indices outlined previously. Whilst there are certain caveats on this approach (e.g. neglecting rice physiological changes and generalising for all varieties) it can provide a first order assessment of potential hazards in the quickest available time. Under the PhilCCAP program these downscaled rainfall and temperature data could be used to drive more precise crop models, for specific locations where the required supplementary data is available, and so help to refine the projections of changes in crop yield (and further understand the complexities) at a later stage.

Originating Group(s)	Country	CMIP3 ID
Canadian Centre for Climate Modelling & Analysis	Canada	CGCM3.1(T63)
Météo-France / Centre National de Recherches Météorologiques	France	CNRM-CM3
CSIRO Atmospheric Research	Australia	CSIRO-Mk3.0
Max Planck Institute for Meteorology	Germany	ECHAM5/MPI-OM
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory	USA	GFDL-CM2.1
NASA / Goddard Institute for Space Studies	USA	GISS-ER
Institut Pierre Simon Laplace	France	IPSL-CM4

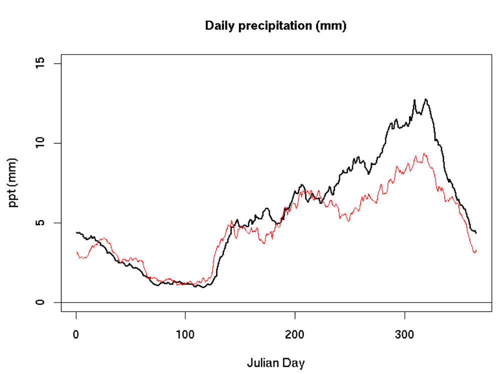
Table 3: The 7 GCMs used to downscale the projected future climate of 2046-2065. Further details are available at http://www-pcmdi.llnl.gov/ipcc/model_documentation/ipcc_model_documentation.php

5.2 Downscaled future climates

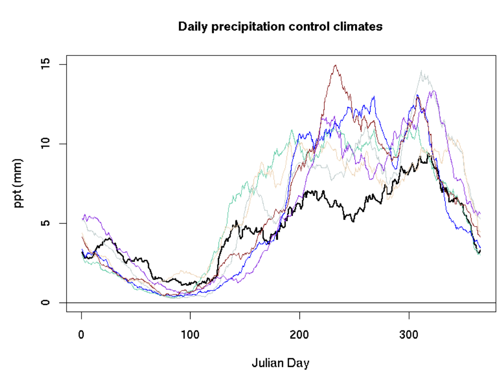
All 7 GCMs were available at a daily timestep for the common 1980-2000 and 2046-2065 periods. However, as the GCMs used in this study all had different annual calendars (some have 360 day years, others 365 day years every year and others include leap years) the first step was to shift all calendars to a common 365 day format. Climate hazards were then calculated based on this calendar and averaged for each of the 20 year periods for each individual GCM. The following sections demonstrate how the seasonality of rainfall, temperature and PET are first simulated in the GCM control climates and how they may be expected to change in the future climate.

5.2.1 Changes in rainfall

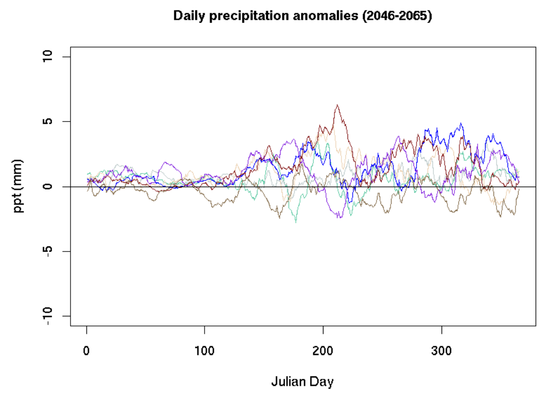
Figure 7 demonstrates the ability of the downscaling technique to simulate the observed climate and the future anomalies for the 2046-2065 period at Aparri. Figure 7a compares the observed rainfall (black line) with that simulated using NCEP reanalysis (observed atmospheric fields) in red. This is an ideal situation where the atmospheric fields are from the observed climate - even so it can be seen that downscaling NCEP underestimates rainfall during the peak season. Figure 7b compares the NCEP downscaled rainfall (black line) with the control climates of the 7 GCMs for the 1980-2000 period – all the control climates simulate more rainfall during the peak of the season, which is closer to the observations given the NCEP downscaled negative bias shown in Figure 7a. The future change in rainfall presented in Figure 7c indicates that most GCMs simulate increases in rainfall for most of the year – even so there is usually 1-2 GCMs simulating a negative change at any particular time of year. Equivalent comparisons for the Tuguegarao and Isabela stations can be found in Appendix B.



(a)



(b)

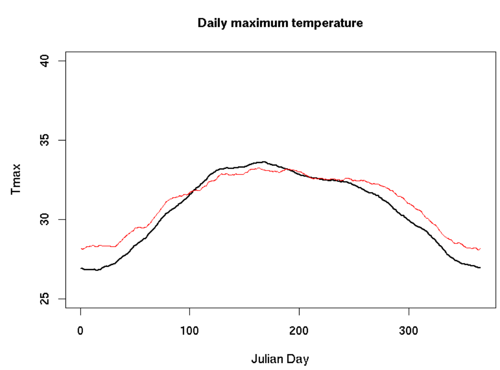


(c)

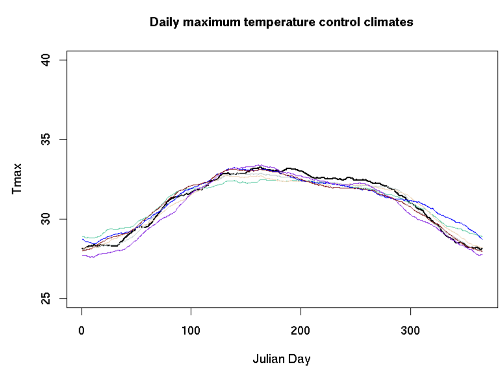
Figure 7: Aparri; (a) comparison of observed (black) and NCEP downscaled (red) rainfall. (b) comparison of NCEP downscaled (black) and control (1980-2000) climates for 7 GCMs. (c) future anomalies for the period 2046-2065. 10-day running filter applied to the data.

5.2.2 Changes in temperature

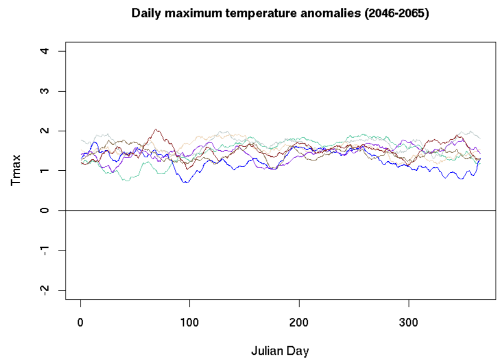
Figure 8 demonstrates the ability of the downscaling technique to simulate observed daily maximum temperatures and anomalies for the 2046-2065 period at Aparri (the discussion with respect to daily minimum temperatures is qualitatively similar and so not presented here). Figure 8a compares the observed maximum temperatures (black line) with that simulated using NCEP reanalysis (observed atmospheric fields) in red. It can be seen that downscaling NCEP underestimates maximum temperatures at their peak values and overestimates them during cooler periods. Figure 8b compares the NCEP downscaled temperature (black line) with the control climates of the 7 GCMs for the 1980-2000 period – the NCEP downscaled temperature is mostly within the range of GCM control climates indicating that the GCM control climates are not significantly biased, except for perhaps similar biases as NCEP noted above. The future change in maximum temperature is presented in Figure 8c and indicates that all GCMs simulate an increase in maximum temperature for all of the year. Equivalent comparisons for the Tuguegarao and Isabela stations can be found in Appendix B.



(a)



(b)

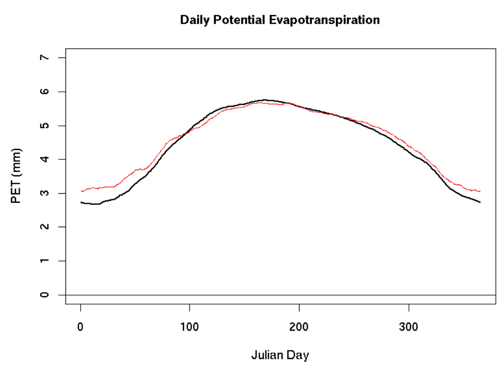


(c)

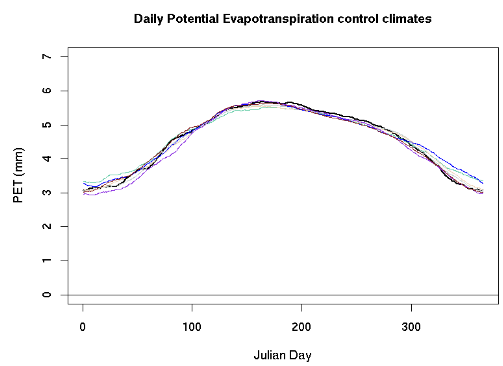
Figure 8: Aparri; (a) comparison of observed (black) and NCEP downscaled (red) daily maximum temperature. (b) comparison of NCEP downscaled (black) and control (1980-2000) climates for 7 GCMs. (c) future anomalies for the period 2046-2065. 10-day running filter applied to the data.

5.2.3 Changes in PET

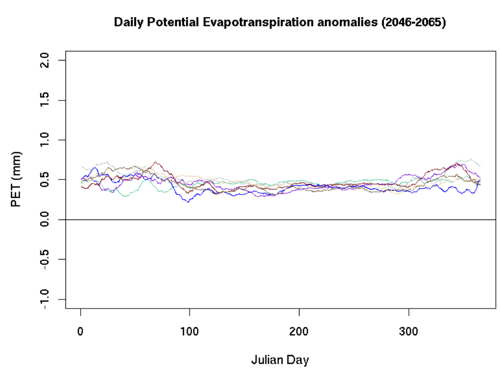
Figure 9 demonstrates exactly the same comparisons as figures 7 & 8 except in this case for calculated values of PET. The similarities and differences are the same as those noted for maximum temperatures. The equivalent figures for Tuguegarao and Isabela can be found in Appendix B.



(a)



(b)



(c)

Figure 9: Aparri; (a) comparison of observed (black) and NCEP downscaled (red) daily PET. (b) comparison of NCEP downscaled (black) and control (1980-2000) climates for 7 GCMs. (c) future anomalies for the period 2046-2065. 10-day running filter applied to the data.

5.3 Projected changes in climate hazards

The following presents projected changes in the climate hazards calculated earlier for the observed climate and now calculated using the downscaled climate scenarios. It should be noted that maximum evapotranspiration is dependent on both PET and the crop coefficient k_c, which depends on the stage of crop development and may change under climate change if changes in plant transpiration are significant due to increased CO_2 levels. Therefore the indicators calculated from equations 1 and 2 are to be used as a guide only.

5.3.1 Changes in seasonal boundaries and potential net water

Figure 10 presents the calculated changes in seasonal boundaries and potential net water to the soil for the 3 stations for which sufficient data were available. The changes are given as a range of mean changes for the 7 GCMs. Seasonal boundaries at each of the 3 stations are simulated to change in a similar manner and are characterized by the following observations:

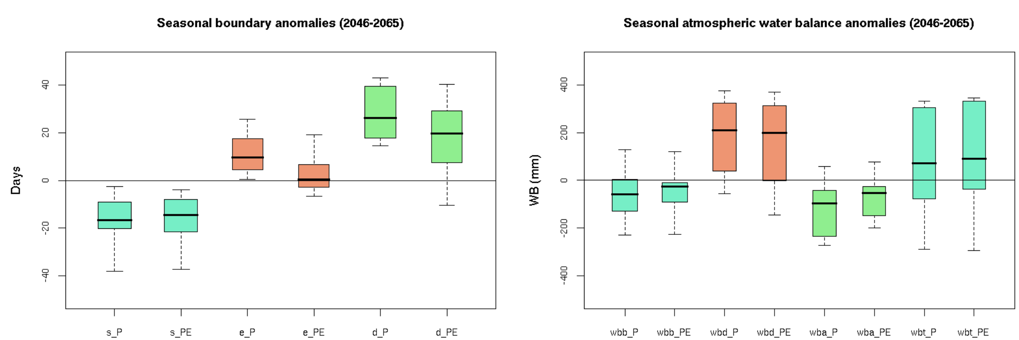
1. Differences between assuming rainfall-only or rainfall-PET criteria are small and mostly within the range of the 7 GCMs – this implies that rainfall is the dominant variable;
2. The start of the season is simulated to occur earlier at all 3 stations;
3. Changes in the end of the season are not simulated consistently early or later across the range of models;
4. The majority of simulations suggest a longer rainfall season at all three stations.

Potential net water to the soil at different periods in the annual cycle indicate the following:

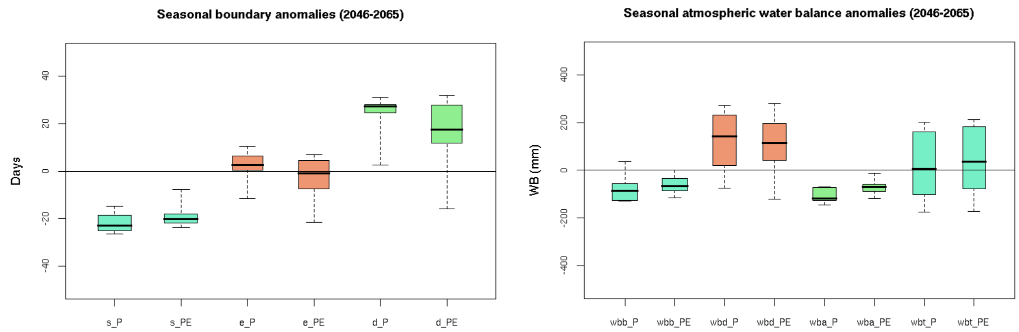
1. Most GCMs simulate less potential net water to the soil before and after the rainfall season at all three stations;
2. Most GCMs simulate an increase in potential net water to the soil during the rainfall season;
3. Total change in potential net water (during the annual cycle) is simulated both positive and negatively with a tendency to be more consistently positive in the north (Aparri) and more consistently negative in the south (Isabela).

Altogether these changes suggest a wetter and longer wet season, interspersed with a drier dry season.

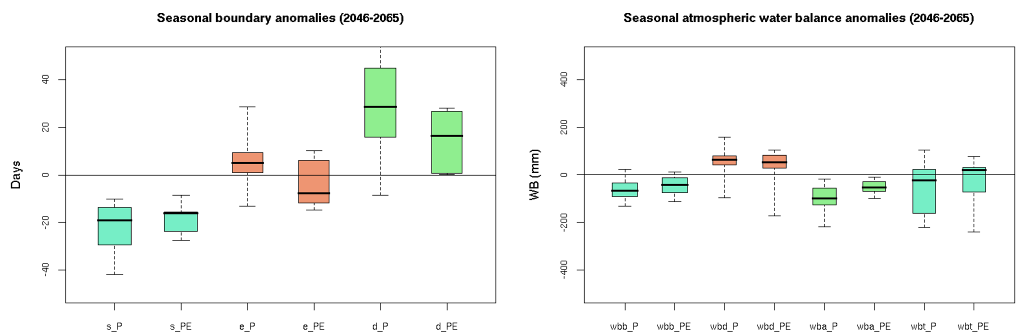
Aparri



Tuguegarao



Isabela

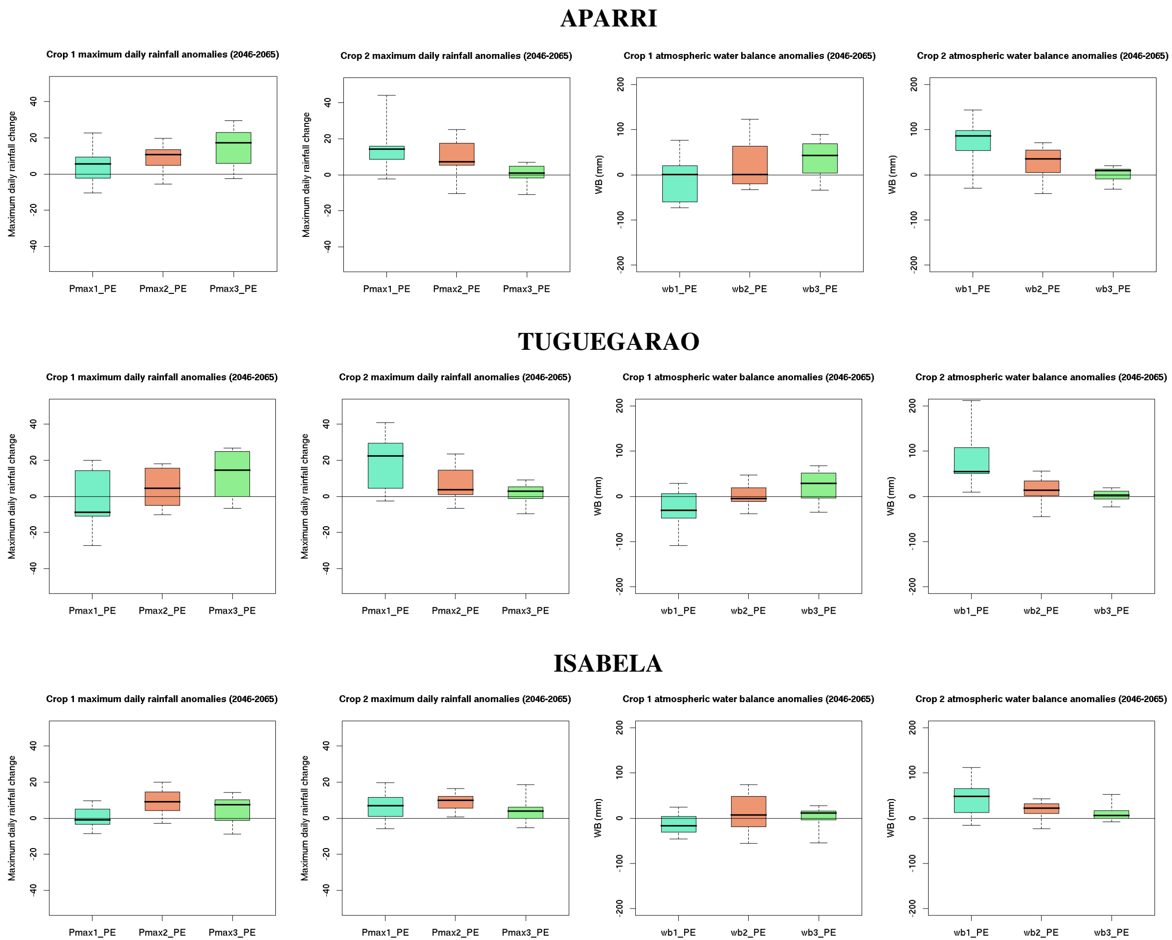


(a) **(b)**

Figure 10: Future anomalies (2046-2065) of (a) seasonal boundaries (start s_*, end e_* and duration d_* of the season), (b) potential net water to the soil surface (before the season wbb_*, during the season wbd_*, after the season wba_* and total for the year wbt_*.

5.3.2 Changes in crop-specific climate hazards

Given that the previous section suggests that determining the start of the season via rainfall only or rainfall-PET criteria does not significantly change the seasonal boundaries, the following crop specific hazard indices are shown only for the rainfall-PET criteria. Figure 11 indicates the downscaled changes (future – control climate) in Pmax and wb for the two consecutive crops. Boxplots indicate the percentile ranges from the 7 GCMs for each of the three crop-growth stages. Maximum daily rainfall is projected to increase at all three stations for most crop growth stages, though the most consistently predicted increases are during ripening of the 1st crop and vegetation of the 2nd crop at Aparri and Tuguegarao. Whilst this could cause problems when trying to dry and harvest the first crop (potentially increasing the likelihood of flooded fields), extra water for growing the second crop could be an advantage if it does not result in excessive flooding.



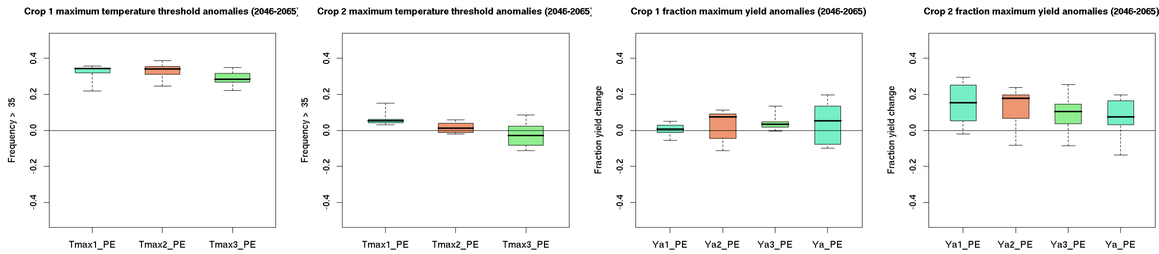
(a) (b) (c) (d)

Figure 11: a & b) crop 1 and crop 2 maximum daily rainfall anomalies, c & d) crop 1 and crop 2 potential net water to soil

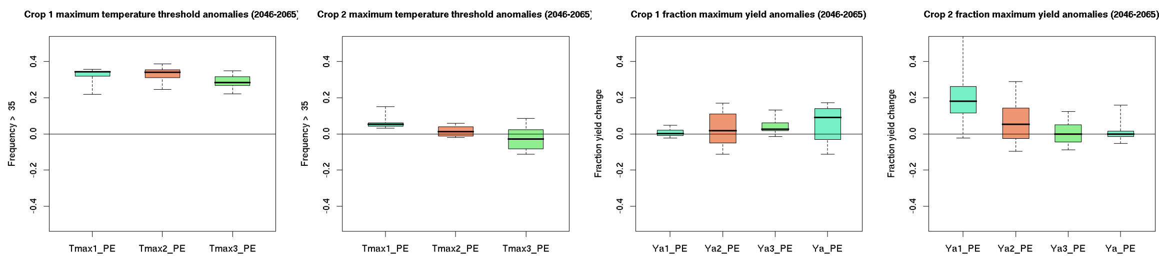
Changes in potential net water to the soil largely reflect changes in Pmax with mostly positive increases at the end of the 1st and beginning of the 2nd cropping cycle. Again this could be beneficial for the growing the second crop if the increased water is harvested and does not result in flooding damage either to the mature 1st crop or the seedlings used for the 2nd crop. Most GCMs simulate a decrease in potential net water to the soil during the vegetative stage of the first crop and this suggests that although the start of the season may come earlier, water available through rainfall immediately after this early planting may not be as much as is available in the current climate. This requires further research but one possibility is that increased evapotranspiration in the future climate results in the availability of less rainfall – this may be a problem if the rainfalls are heavier but less frequent. Given that potential net water decreases between rainy seasons, suggesting drier soils at the start of the following season, this requires further evaluation.

Figure 12 indicates the downscaled changes (future – control climate) in Tmax and Ya for the two consecutive crops. Boxplots indicate the percentile ranges from the 7 GCMs for each of the three crop-growth stages. Tmax anomalies are much greater during growth of the 1st crop, particularly during the sensitive reproductive period, and this may also be linked to an earlier start to the season – Figure 8 clearly indicates that maximum temperatures peak just before the rainy season and that increases in temperature are more or less uniformly spread across the year. Therefore a shift of the 1st crop to the earlier period would likely coincide with peak maximum temperatures and which also increase in the future. This is therefore another potential hazard (besides the increased drying noted earlier) for the earlier planted 1st crop. Increases in Tmax during growth of the 2nd crop are significantly less than during growth of the 1st crop, but are still positive and therefore represent a potential increase in the climate hazard. There is, however, the suggestion that Tmax may decrease during ripening of the second crop at Aparri and Tuguegarao stations.

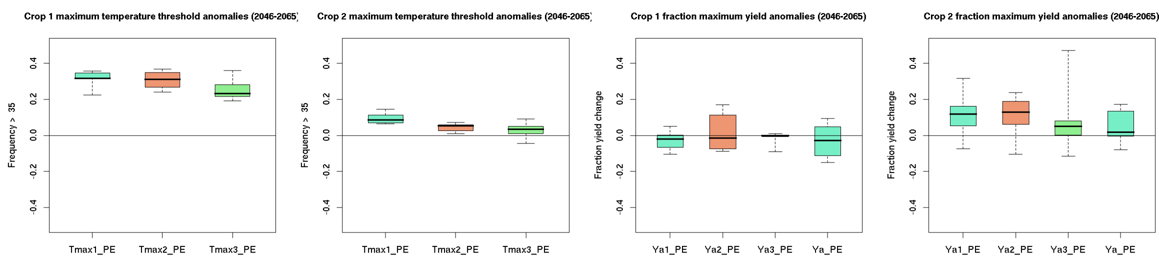
APARRI



TUGUEGARAO



ISABELA



(a) (b) (c) (d)

Figure 12: a & b) crop 1 and crop 2 anomalies of frequency maximum daily temperatures > 35°C, c & d) crop 1 and crop 2 fraction maximum yield anomalies.

The fraction of maximum yield anomalies, which are based only on the ability of rainfall to meet the crop water requirements, do not suggest consistent changes for the first crop. This is likely because under present conditions rainfall sufficiently meets the crop water requirements and given that the projections mostly suggest increases in rainfall, this situation is not likely to change. However, during growth of the 2nd crop the projections suggest an increase in the fraction of maximum yields, likely because crop water requirements are not met in the current climate (2nd croppings are usually irrigated). The projections here suggest that the longer rainfall season could provide more net water to the soil (see figure 11) and hence potentially increase the yield of a rainfed 2nd crop. Whether this change is sufficient to sustain a rainfed 2nd crop at cost-effective yield levels requires further evaluation, though if the extra potentially available water is efficiently harvested this may enable 2nd crops in current climatically marginal environments.

Although not shown in the above figures, minimum temperatures are projected to increase by between 1 and 2 °C during most stages of crop growth and this will likely have a detrimental effect on yields. Peng *et al.* (2004) observe a 10% decline in rice yields for every increase of 1°C in minimum temperature which suggests a 10-20% decline in yields if this hazard was to increase in the absence of other changes.

6 Summary and recommendations for further work

The focus of this report has been to ally agro-meteorological concepts and fundamental understanding of how climate impacts yields with current state of the art climate change downscaling techniques. Given the limitations of the climate change data (only producing rainfall and temperature estimates) it was necessary to circumvent some recommended practises e.g. using a modified Thornthwaite equation to calculate PET instead of the FAO recommended Penman-Monteith equation. A second factor affecting the analysis was that it should be applicable at all locations where adequate climate data was available, therefore analyses requiring location-specific data on soils, slopes etc. affecting soil runoff and water holding capacity(e.g. site-specific crop modelling) were avoided. The climate data were, however, examined in a similar manner to a crop model to understand how, in the absence of site-specific modifiers, climate hazards affecting crop production may be changing now and in the future. This work therefore sets the scene for further exploration of potential climate impacts on crop production

6.1 Observed vs. long-term change

One of the major policy-relevant questions for climate change adaptation is when to adapt. This is often problematic within the agriculture sector, especially the cereal sub-sector where cropping practices can be changed from one year to the next and so adapt quickly. Whilst climate scenarios for 2050 can give an idea of expected rainfall and temperature at that time in the future, they do not inform at what point in the intermediate period the change to a new level is expected to happen. Therefore some change may already be occurring (e.g. temperature rise) whilst other change (e.g. rainfall) will only happen later.

Comparing observed trends with changes simulated in a future climate is difficult and hampered by a lack of long term data which can be used to derive trends in the current climate. Often this is made more difficult by missing data in the timeseries that are available, as was found for the data at Isabela; although there was a long timeseries for this station missing data meant that indicators were not able to be calculated for many of the years. This however did not preclude the data from being used in the statistical downscaling procedure.

Seasonal boundary changes at Aparri and Tuguegarao were somewhat at odds with each other, which is not surprising as Aparri is coastal and Tuguegarao inland at the bottom of a valley. To some degree such differences could reflect different responses to ENSO (Lyon *et al.*, 2006) though the timeseries at both stations is long enough to mitigate this as a dominant factor. Detected trends at Aparri suggested a trend for reduced duration of the rainfall season, the result of later starts and earlier cessation, whereas at Tuguegarao the duration of the season has been increasing due to a combination of non-significant trends for an earlier start and later cessation. These changes noted at Tuguegarao are consistent with the projected changes in climate for 2046-2065, the most consistent changes of which are expected to be an earlier start to and increased duration of the rainfall season. However, the negative temperature trends calculated for periods of the cropping cycle are somewhat at odds with those expected from climate change and reported elsewhere in the literature (Manton *et al.*, 2001). This is likely because temperature trends calculated here are for small portions of the annual data and are influenced by changes in start dates within the seasonal cycle. They therefore should not be taken as an indication of general cooling but do serve to highlight that temperatures affecting particular cropping stages may differ from the annual average and that adapting (by shifting planting dates) can help ameliorate potential increases.

Overall there is not enough observed data (only 2 stations) to be able to suggest whether the observed changes are consistent with those expected from climate change, especially when given their significantly different surroundings and localised weather the 2 stations can be expected to experience different changes moving into the future. Even so the changes modelled for the future period are consistent across all 3 stations with a general suggestion that rainfall will arrive earlier, potentially retreat later and result in a longer rainfall season. These changes are more consistent (across the range of GCMs) for the stations further north (Aparri and Tuguegarao), whereas Isabela may not be so clearly expected to experience these changes. This highlights that the localised climates within the Cagayan valley may modify the effect of large-scale changes in the climate expected from climate change. This may be particularly relevant for regions at higher altitude and means that it will be dangerous to extrapolate the findings for 3 stations, all of which are found on the valley floor, to the Cagayan valley in general.

Crop specific indicators suggest that in the future climate more water is potentially available from the atmosphere and, consistent with the increased duration of the season, this could benefit a rainfed 2nd crop or help reduce irrigation requirements for a 2nd irrigated crop. However, there are several mitigating factors that need to be taken into account. Firstly, projected increased drying during the dry season may mean that soil water levels are not sufficiently replenished by earlier rains and hence the first crop cannot be planted earlier than at present. A second mitigating factor may be that increases in temperature result in significant yield losses e.g. increases in maximum temperatures occur during the reproductive period. This is likely to be more of a problem on the valley floor and may to some degree be alleviated by cultivation at higher altitude, though as noted previously there is no data to suggest whether similar changes in net water from the atmosphere can be expected. A third factor may be that more water during the rainfall season will result in flooding. Not only does flooding affect crop growth but also harvesting operations e.g. getting equipment into the fields, and post-harvest drying (especially when performed in open outside areas). Given the projected changes in rainfall this is expected to be a bigger problem for harvesting and drying the 1st crop.

Linking the observed and future climates needs to be tackled from a fundamental understanding of how the large-scale climate processes are changing and expected to change in the future. This then allows local and synoptic forcings on the local climate to be disaggregated, generalised for the surrounding environment and ultimately related to climate changes which result from changes in the large-scale climatic environment. Therefore a starting point might be to link changes in atmospheric circulation (as simulated in the NCEP and ERA40 reanalyses) to the observed changes in climate at each station.

6.2 Exploring climate-yield relationships

Whilst this report has attempted to provide some indication of potential climate-yield relationships using simple criteria, this was not possible to do with any rigour without utilising a crop model. Even then there are issues of parameterisations and assumptions that characterise the particular crop model that may be used. In the previous scoping report (Tadross, 2008) it was suggested that statistical relationships may be derived between the climate indicators presented here and observed yields and/or losses. This was not possible in the present study due to time constraints and the noted problems with the observed climate data. However, further studies should pursue this avenue as it allows the impact of changes in climate on crop production to be assessed over broader regions, without complex site-specific crop modelling. It also allows other factors, such as the application of fertiliser, to be factored into the relationships. This approach is currently being undertaken at IRRI (R. Hijmans *pers. comm.*) and so any future investigations could benefit from the work undertaken there. Furthermore it may be possible to relate post-harvest losses to factors such as heavy rains.

One distinct advantage of using a crop model is that it can take account of crop physiological changes in a future climate that will be characterised by increased CO_2 levels. Whilst changes in crop transpiration could be incorporated into the water balance indicators used here (through changing k_c), changes affecting biomass accumulation and hence yield in a future climate need more complex crop modelling. Therefore some effort should be made to understand how these effects on the crop physiology affect crop yields and to what extent they may mitigate the direct impacts of the climate. In this regard it would be useful to develop an understanding of which factors indicate the dominant first order impacts and which are mitigating second order impacts. Some of this work is already being carried out at the University of Los Baños and could take advantage of the capacity already developed there (Lansigan *et al.*, 2007; F. Lansigan *pers. comm.*).

6.3 Further data and modelling

As indicated above, further crop modelling studies can help to understand how the interplay of local conditions (e.g. soils), crop physiology and large-scale climate changes affect rice yields and similarly modelling could also help to understand potential water availability in a future climate. This would involve utilising a hydrological model of the Cagayan basin to understand how runoff, groundwater, dam storage etc. are linked and influence the total available water for irrigation. Whilst such a model was not encountered as part of the previous scoping missions it may yet exist or could be set up in the future (e.g. USGS Geospatial streamflow model). Setting up such a model is complex and would require a significant amount of validation and access to streamflow measurements etc. However, any such model would also require rainfall and PET estimates for the whole basin on a daily basis. As seen in this study such a high density of surface measurements do not exist in the basin, even when the rainfall-only stations are included. However, other datasets that may be used for such an application include the CPC-RFE (from the Climate Prediction Center, U.S.) global estimates of rainfall, which are at a resolution of 0.1°. These data are satellite-based estimates which are often biased in the absence of ground measurements but which uses observations, communicated over the WMO GTS system when available, to anchor the satellite data. PET is also currently estimated by NOAA's Global Data Assimilation System (GDAS) on a daily basis for the whole globe at 1° resolution. Whilst the PET data is at a relatively coarse scale it has been successfully used in combination with the RFE estimates for hydrological studies in India and Africa (J. Verdin *pers. comm.*). Because these data sources are relatively new it is not clear if there are long enough timeseries to allow for a downscaling in a similar manner to that performed for the station observations (which generally requires 10 years of data). This would need to be tested with the available data, but if possible could allow future spatial fields of rainfall and PET to be derived, which if combined with a calibrated streamflow model would allow changes in streamflow to be estimated in a future climate (this would also enable the analysis presented in this report to be extended to other regions in the Cagayan valley). Another and less complex alternative would be to attempt a direct downscaling of measured streamflow. This may be feasible if it can be assumed that the climate – streamflow link was not unduly influenced by dams and water storage in the basin, which is perhaps unlikely.

Acknowledgements

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7 Appendix A – Damage (yield loss) matrices

Source: Philippines Department of Agriculture

DROUGHT MATRIX - RICE					
PERIOD OF STRESS					% YIELD LOSS
1	Transplanting	to	Maximum Tillering	(Early Vegetative Stage)	40 - 50
2	Transplanting	to	Panicle Initiation	(Early Vegetative to Reproductive Stage)	60 - 75
3	Transplanting	to	Heading	(Early Vegetative to Reproductive Stage)	65 - 70
4	Max. Tillering	to	Heading	Maximum Vegetative to Reproductive Stage)	45 - 50
5	Panicle Initiation/	to	Maturity	(Reproductive to Maturity Stage)	60 - 100
6	Booting	to	Maturity	(Reproductive to Maturity Stage)	60 - 100
7	Flowering	to	Maturity	(Reproductive to Maturity Stage)	60 - 100
8	Milking Stage	to	Maturity	(Late Reproductive to Maturity Stage)	45 - 60
9	Soft dough/ Hard dough	to to	Maturity Maturity	(Maturity Stage) (Maturity Stage)	10 or less
10	Tranplanting	to	Maturity	(Min. tillering to Maturity Stage)	95 - 100

Period of Reckoning for the Start of Drought		
Type of Field	Soil with High Water Holding Capacity e. g., clay loam	Soil with Low Water Holding Capacity e. g., sandy
Irrigated Paddies	16 days from last trickle of irrigation water	12 days from last trickle of irrigation
Unirrigated/Rainfed	16 days from last day of rain	12 days from last day of rain

TABLE 4: LODGING DAMAGE MATRIX - RICE

GROWTH STAGE	LODGING W/O WATER	LODGING WITH WATER
	< 7 DAYS	> 7 DAYS
	ESTIMATED YIELD LOSS	
Flowering / Milking Stage	45	90
Soft / Hard Dough	25	60
Yellow Ripening	15	35

TABLE 2: DAMAGE MATRIX FOR TYPHOON INDUCED BY STRONG WIND – RICE

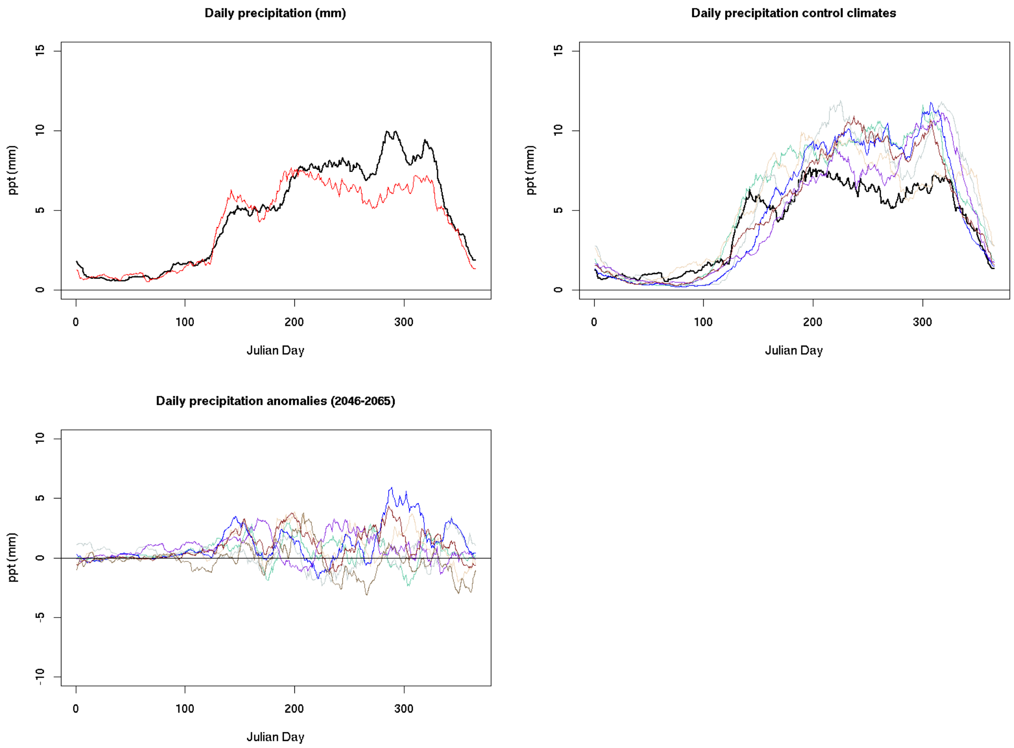
GROWTH STAGE	WIND VELOCITY (KPH)					
	70 - 100		101 - 150		> 150	
	PERIOD OF EXPOSURE (HRS)					
	≤ 12	> 12	≤ 12	> 12	≤ 12	> 12
	ESTIMATED YIELD LOSS (%)					
Booting	< 10 – 15	15 – 20	15 – 25	20 – 30	15 – 30	25 – 35
Flowering	10 – 25	25 – 30	15 – 30	30 – 35	25 – 40	35 – 50
Maturity	< 10 – 15	15 - 20	10 – 20	20 – 25	15 – 25	25 – 30

TABLE 3: FLOOD DAMAGE MATRIX - RICE

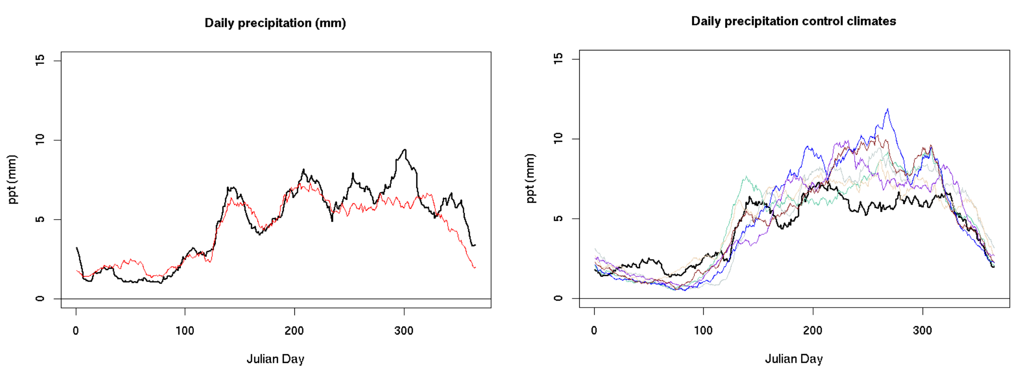
GROWTH STAGE	CLEAR WATER				MUDDY WATER			
	DAYS OF SUBMERGENCE							
	1 - 2	3 - 4	5 – 6	7	1 - 2	3 - 4	5 - 6	7
	Estimated Yield Loss (%)							
Min. Tillering / Max Tillering	10	15 – 20	20 – 30	30 – 50	10 – 20	20 – 30	30 – 50	50 - 100
Panicle Initiation / Booting Stage *Partially inundated*	10	20 – 30	30 – 65	40 – 80	10 – 20	30 – 50	40 – 85	50 - 100
Panicle Initiation / Booting Stage *Completely inundated*	15 – 25	20 – 45	30 – 80	50 – 100	15 – 30	40 – 70	40 – 85	50 - 100
Flowering Stage / Maturity Stage	10 – 15	15 – 25	20 – 30	30 – 70	15 – 30	40 – 70	50 – 90	60 - 100
Ripening Stage	0	10 - 15	15 – 20	15 - 20	5	10 – 20	15 – 30	15 – 30

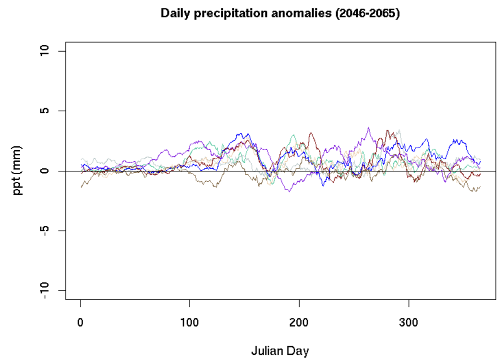
Partly means leaves (9 –15 cm long) remain above water surface
Source : Tsuitsui (197), with long modifications based on experience and opinions of experts

8 Appendix B – Control and future climates at Tuguegarao and Isabela stations

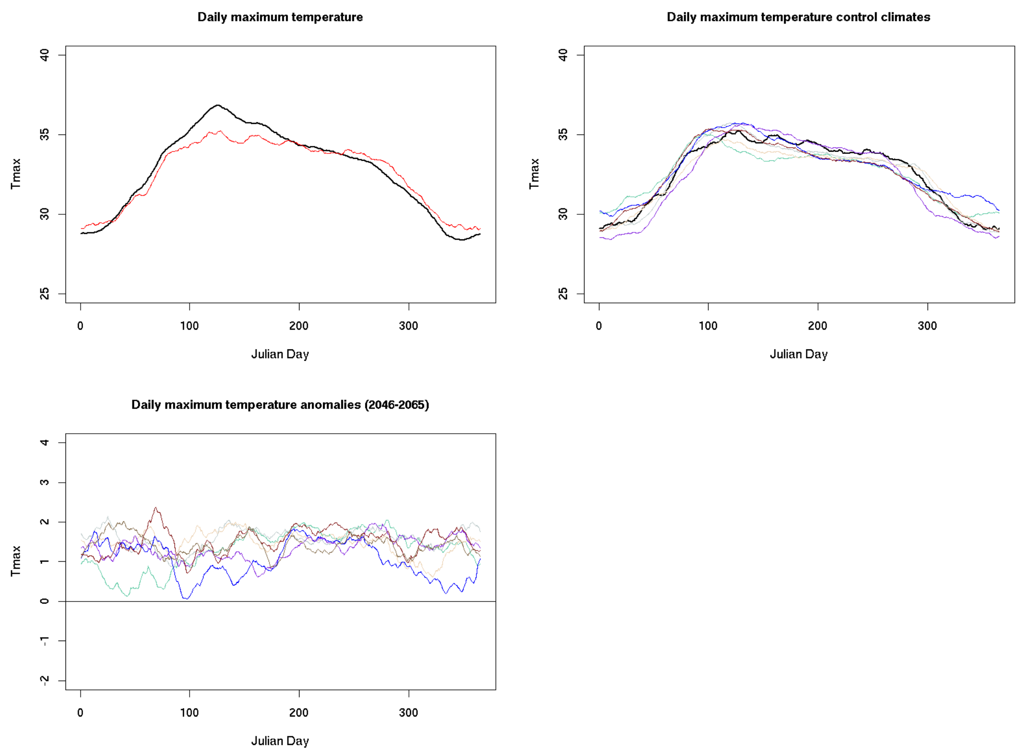


Tuguegarao rainfall; (a) comparison of observed (black) and NCEP downscaled (red) rainfall. (b) comparison of NCEP downscaled (black) and control (1980-2000) climates for 7 GCMs. (c) future anomalies for the period 2046-2065.

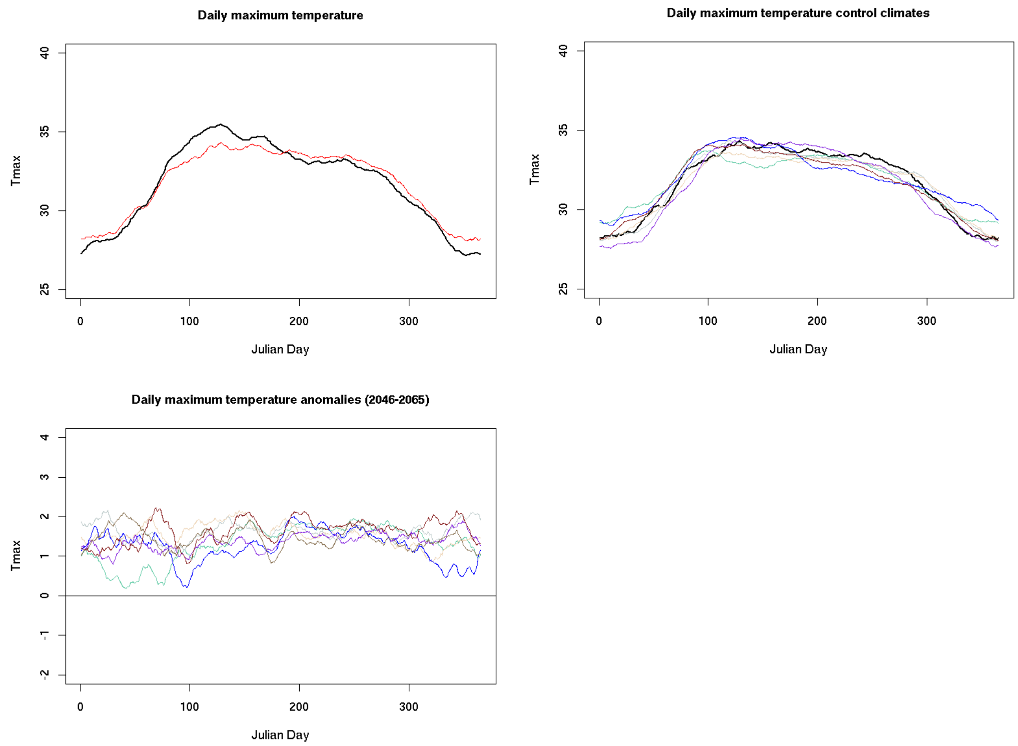




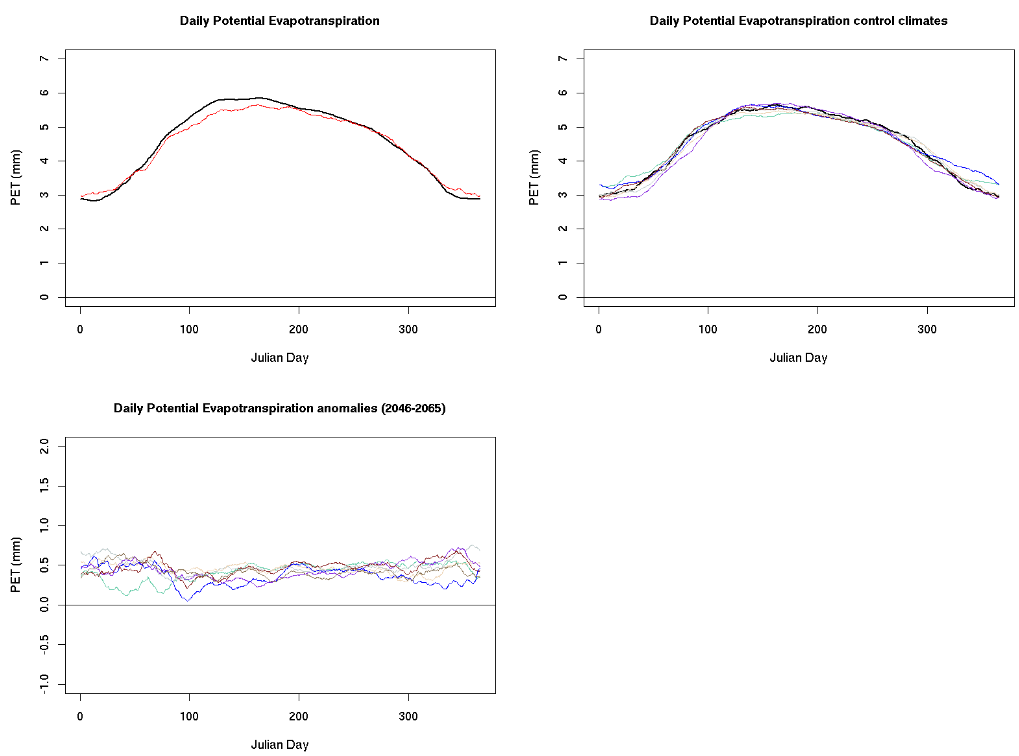
Isabela rainfall; (a) comparison of observed (black) and NCEP downscaled (red) rainfall. (b) comparison of NCEP downscaled (black) and control (1980-2000) climates for 7 GCMs. (c) future anomalies for the period 2046-2065.



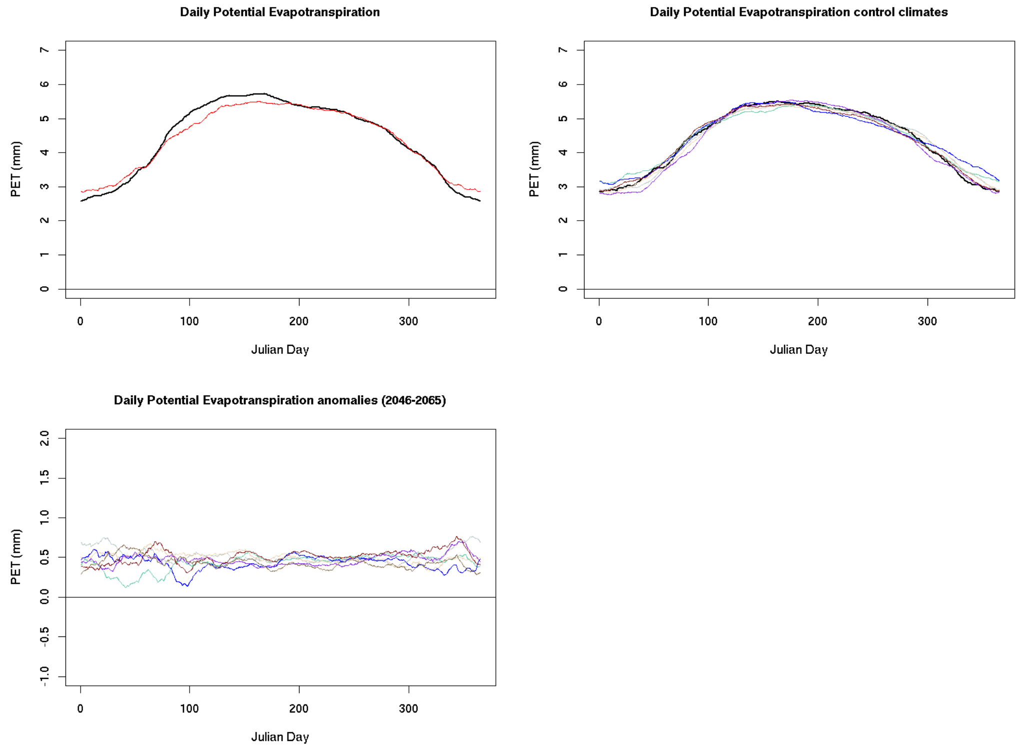
Tuguegarao maximum temperature; (a) comparison of observed (black) and NCEP downscaled (red) daily max temperature. (b) comparison of NCEP downscaled (black) and control (1980-2000) climates for 7 GCMs. (c) future anomalies for the period 2046-2065.



Isabela maximum temperatures; (a) comparison of observed (black) and NCEP downscaled (red) daily max temperature. (b) comparison of NCEP downscaled (black) and control (1980-2000) climates for 7 GCMs. (c) future anomalies for the period 2046-2065.



Tuguegarao PET; (a) comparison of observed (black) and NCEP downscaled (red) daily PET. (b) comparison of NCEP downscaled (black) and control (1980-2000) climates for 7 GCMs. (c) future anomalies for the period 2046-2065.



Isabela PET; (a) comparison of observed (black) and NCEP downscaled (red) daily PET. (b) comparison of NCEP downscaled (black) and control (1980-2000) climates for 7 GCMs. (c) future anomalies for the period 2046-2065.

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