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From Climate Data to Actionable Climate Knowledge: DOST-PAGASA Experience Providing Climate Services to Smallholder Farmers in Calapan, Oriental Mindoro

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Communicating weather and climate information for farm decision-making remains a challenge for hydro-meteorological agencies, including the Philippine agency DOST-PAGASA. Through stakeholder engagements with smallholder farmers in Calapan, Oriental Mindoro, three possible root causes were identified: a lack of awareness and accessibility to information, the misinterpretation of probabilistic seasonal forecast and drought categories, and an inadequate understanding of local climate change implications. In this paper, we describe a series of steps to address these barriers. To improve awareness of information we implemented simplified scientific climate knowledge presented through a KlimAgrikultura workshop and conducted crop risk matching to identify relevant climate products. The understanding of seasonal climate forecasts was addressed by simplified tools to analyze seasonal impacts of ENSO on rainfall which helped end-users visualize and examine the relevance of monthly forecasts relative to the baseline historical rainfall distribution for each ENSO phase. The complex issue of climate change was addressed through localized historical and projected climate information which provided Calapan rice farmers with foresight on future threats of drought and extreme rainfall. We conclude by reflecting on advice from the World Meteorological Organization on effective Climate Services, and how the work described in this paper meets these recommendations.

Keywords: Climate services, capacity-building, climate change, ENSO, KlimAgrikultura

Abbreviations: CFS—Climate Field School, PAGASA—Philippine Atmospheric, Geophysical and Astronomical Services Administration, DOST—Department of Science and Technology, AEW—agricultural extension workers, LFT—local farm technicians, PIDS—Philippine Institute for Development Studies, LGU—local government unit, ITCZ—intertropical convergence zone, LPA—low pressure areas, TC—tropical cyclones, ENSO—*El Niño* Southern Oscillation

INTRODUCTION

Philippine rice farmers, especially smallholders, are vulnerable to fluctuations in climate and weather extremes (Morishima and Akasaka 2008; Roberts et al. 2009; Dawe et al. 2009; Zubair 2002; Naylor et al. 2001; Buan et al. 1996; Lansigan et al. 2000; Vaghefi et al. 2011; Mathauda et al. 2000; Harvey et al. 2018). According to Palombi and Sessa (2013), Climate Smart Farming requires information on new farming practices to be able to adapt to future climatic conditions and information on the future climate in the form of weather forecasts, seasonal forecasts and longer-term climate trends. The Philippine Atmospheric, Geophysical and Astronomical Services Administration of the Department of Science and Technology (DOST-PAGASA) is mandated to provide climate information to all sectors of the Philippine economy, including agriculture. Over the years, several capacity-building programs and projects have been implemented. Among the earliest and most successful programs is the Climate Field School (CFS) in Dumangas, Iloilo, which was reported by the participants to have been the catalyst for the improvement in the local rice production (Golez 2012). The success of the CFS set the groundwork for other subsequent programs catering to various issues, including building community resilience to weather and climate hazards, and strengthening disaster risk reduction for agriculture and food security using livelihood and adaptation practices.

DOST-PAGASA is a partner in the ACIAR project, "Action ready climate knowledge to improve disaster risk management for smallholder farmers in the Philippines" (hereafter, ACIAR project). In collaboration with the University of the Philippines – Los Baños (UPLB), the Philippine Institute for Development Studies (PIDS) and the Department of Agriculture through the Agricultural Training Institute, DOST-PAGASA has worked with rice farmers in Calapan to assess and improve their use of weather and climate information for decision-making. The agricultural extension workers (AEWs) and local farm technicians (LFTs) are important targets of this project as they are government personnel who provide guidance to agricultural decision-makers (farmers) in developing appropriate responses to the impacts of weather hazards and establishing necessary measures to adapt to climate change.

Climate services transform climate data into information for decision-makers (Tall 2013). The communication of climate information to end-users is an ongoing challenge for climate services across the globe (WMO 2019), with a recognition of specific challenges of understanding and meeting the needs of resource-poor farmers and their advisers (Palombi and Sessa 2013). There are many barriers to the use of climate information. For example, poor internet and mobile phone coverage is a limitation for smallholder farmers. Other barriers commonly raised include a lack of local weather stations and the fact that predicting the future weather and climate is far from perfect. Fortunately, there is a range of projects in the Philippines to improve the connectivity for smallholder farmers, to increase the number of weather stations and to improve the skill of prediction. Weather forecasts and warnings in the Philippines and around the world have steadily improved in recent decades due to improvements in weather models, computing power and data to initialize the models (Bauer et al. 2015). It is important that smallholder farmers and extension workers are able to access these advances for their livelihoods and, in the case of cyclone warnings, for their lives. Unfortunately, the accuracy of the forecasts at a seasonal time scale is much lower. The lower signal to noise ratio of seasonal climate forecasts means that they are best represented as shifts in probabilities and this presents a communication challenge.

In this paper we focus on steps to address specific barriers identified through recent stakeholder engagements held by DOST-PAGASA. First, and most commonly raised, is the gap between the climate information used by smallholder farmers and what is currently available from DOST-PAGASA. Second, is the difficulty in interpreting probabilistic seasonal climate forecasts. This is in part due to confusion about the terms used in categorizing rainfall in related DOST-PAGASA products and in part the erroneous presumption that declaring an *El Niño* event is the same as declaring a drought rather than an increased chance of drought. Lastly, a lack of awareness of and clarity about the implication of climate change for the livelihoods of the smallholder farmers. This paper addresses progress towards these issues for the smallholder farmers in Calapan, Oriental Mindoro. We conclude with general reflections about hydro-meteorological services for smallholder farmers.

Calapan as the Study Site

The area around Calapan City is a major rice producing hub in the MIMAROPA region (Sarian 2018; Alcayde 2019; Calapan Gov't 2019). The Calapan local government unit (LGU) has been proactive in improving the overall crop production of the city through intensive programs promoting rice production and subsidies, urban gardening, organic fertilizer production and farm mechanization (Alcayde 2019), making it an ideal project site.

The annual climate cycle of Calapan City has no pronounced maximum rain period and has a dry season usually from the start of the year. Local farming activities in Calapan City are vulnerable to the hydro-meteorological hazards created by the onset of the northeast and southwest monsoons (called *Amihan* and *Habagat*, respectively), the intertropical convergence zone (ITCZ), easterlies, cold fronts, low pressure areas (LPA) and tropical cyclones (TC). Hydro-meteorological events can occur simultaneously, causing cascading impacts from one extreme event to another. A hazard often triggers a subset of hazards consisting of primary and secondary hazards. A meteorological event, such as a tropical cyclone, can bring a primary hazard such as strong winds and heavy rainfall, as well as trigger secondary hazards like storm surges, floods and landslides. Farmers and their advisers are interested to know the risk of impacts on their livelihoods and agricultural production. For example, typhoons result in heavy rains, causing the inundation and flooding of farmlands and at the same time the lodging of mature crops due to strong winds.

METHODOLOGY

Climate Analysis: Data Acquisition and Analysis

The rainfall record for Calapan spans from 1951–2019. This relatively long-term dataset allows for a reliable analysis of historical values and provides a baseline for seasonal climate forecasts and climate change projections. However, due to some missing data, we filled in missing values for Calapan to make a continuous time series dataset. Any residual missing values were filled using an APHRODITE gridded dataset (Yatagai et al. 2018) extracted at (121.190°E, 13.410°N). The small number of days filled will not have a significant impact on the results. Indices of extremes were calculated using the Climpact2 v1.2.7 software (ET-SCI 2016). Climpact2 is the most recent code used to calculate the indices established by the Expert Team on Climate Change Detection and Indices (ETCCDI) and Expert Team on Sector-specific Climate Indices (ET-SCI). It is available from https://github.com/ARCCSS-extremes/climpact2 and https://climpact-sci.org/.

The impact of the *El Niño* Southern Oscillation (ENSO) on Calapan rainfall was based on the Oceanic Niño Index (ONI) obtained from the National Weather Service Climate Prediction Center, 2020 (ERSST.v5 SST anomalies). The ONI is one of the measures of ENSO and is calculated as the average sea surface temperature anomalies in the Niño 3.4 region (5°N–5°S, 120°–170°W), where a +0.5°C and -0.5°C for at least five consecutive seasons are considered *El Niño* and *La Niña*, respectively.

Internationally, seasonal rainfall forecasts are generally communicated using one of two methods: quantiles or a percent of the average. Quantiles are produced by splitting the full rainfall distribution into equal parts, such as above and below median (two equal parts) used by the Australian Bureau of Meteorology (Climate Outlooks 2020) or terciles used by the UK (Global 2020) Japan Meteorological Agency (Seasonal Forecasts 2020). Alternatively, forecasts can be given as a percent of the average, often expressed in categories which is the most common format used by PAGASA. The categories used by PAGASA are Way Below Normal (forecast rainfall is less than 40% of the average), Below Normal (40–80% of the average), Normal (80–120% of the average), Above Normal (120–160% of the average) and sometimes Way Above Normal (more than 160% of the average) (Rainfall 2020). The forecast is given as a map of the Philippines highlighted to show the most probable category in each region.

To assist in interpreting these categorical seasonal rainfall forecasts, a Microsoft Excel spreadsheet was created to allow users to enter monthly historical rainfall (ACIAR 2019). This gives a historical perspective on the distribution across categories (climatology), and can be compared with a forecast to see whether the forecast offers any new information.

To provide localized climate change information, downscaled (25 km) projections (DOST-PAGASA 2018; Daron et al. 2018; Villafuerte et al. 2019) of rainfall and daily temperature values for Calapan (121.19°E, 13.41°N) were extracted for RCP4.5 (moderate) and RCP8.5 (high) emission scenarios. The Regional Climate Models (RCMs) require bias correction using quantile mapping (Perez et.al. 2017) to offset the distributional and spatial biases in precipitation outputs (Cannon et al. 2015). Bias correction of the RCM data provides a more accurate estimate of climate change projection (Yang et al. 1999) by considering the shape of the RCM rainfall and temperature frequency distribution and the trend between historical and future climates. RCM historical data were "trained" with the observed climate data to improve the accuracy of the estimate while maintaining the trend (Hempel et al. 2013; Yang et al. 1999). The daily corrections computed in the hindcast data were applied to the RCM future data to bias-correct the future projections. The parameters were computed and compared for the years 2036–2065 centered at 2050 and 1971–2000 as baseline to determine the changes of seasonal rainfall and temperature. To present the range of possible future changes, the multi-model median of the seven (7) RCP4.5 and eleven (11) RCP8.5 ensemble members were calculated, along with the 10th (lower bound) and 90th (upper bound) percentiles, and then presented using the Climate Information Risk Analysis Matrix (CLIRAM) tool (Daron et al. 2018).

Stakeholder Engagement

Several stakeholder engagements were initiated to assess and pave the way for the development of a system to fill-in the gap in the communication of weather and climate information to smallholder farmers. First, the ACIAR team made up of researchers from UPLB and Mindoro State College of Agriculture and Technology (MinsCAT) determined the information needs of climate-sensitive farming activities for rice and corn, along with common practiced adaptation measures for high-impact hazards. This was done by conducting focus group discussions, key informant interviews, and questionnaires to gather general information on local farms (e.g., farm size, production system, and cropping calendar) and economic -relevant details on specific farm activities performed in Oriental Mindoro (input cost, labor cost, and average yield) (ACIAR 2019). As follow up, a climate forum was conducted during the ACIAR project launch in Calapan City, for an audience consisting mostly of smallholder rice farmers, AEWs, and LFTs (ACIAR 2019). This was an opportunity to introduce DOST-PAGASA products and services and provide information on ENSO, climate projections, and weather and climate outlooks for the region.

To further identify barriers and gaps in communication on weather and climate information of different product categories (warnings, forecasts, seasonal climate forecasts), a national stakeholder workshop hosted by PAGASA and a local stakeholder workshop held in Calapan were attended by national agricultural-concerned agency representatives, provincial agricultural agencies, Disaster Risk Reduction and Management (DRRM) agencies and project partners. These initiatives were able to identify and further clarify the two main concerns of participants: 1) the lack of information accessibility and 2) the language used in information delivery.

Communication and Capacity-Building Through the KlimAgrikultura Workshop

KlimAgrikultura is a training module designed by the Agricultural Training Institute conceptualized under the ACIAR project developed for smallholder farmers in the pilot areas (ACIAR 2019). The first KlimAgrikultura workshop was conducted in Baguio City for the vegetable farmers in Benguet. Learnings from the activity served as a basis for fine-tuning the presentation materials to improve comprehension and uptake. The feedback from the participants in Benguet and Calapan contributed to further development of KlimAgrikultura. The main responsibility for PAGASA was to provide laymanized weather and climate information.

Weather events were categorized into four classifications: (1) high pressure area (HPA); (2) thunderstorms; (3) large-scale rain-bearing events (monsoons, ITCZ, easterlies, cold fronts, LPA); and (4) tropical cyclones. Following the Hazard Domino Effect, these events were matched to corresponding hazards (primary and secondary hazards) and then to farming risks. The KlimAgrikultura workshop participants used a crop-climate calendar to identify and prioritize the weather and climate risks. Based on the outcome of the risk and hazard matching, the relevant DOST-PAGASA products and services were identified. A description of the products and services was followed by a discussion on how they could be used for farm management. To further improve the learning experience, simulation activities were conducted on the identification and utilization of DOST-PAGASA information needed to address certain weather or climate scenarios.

Warnings and short-term weather forecasts are much more accurate and hence easier to understand than seasonal climate forecasts. PAGASA's monthly and seasonal forecasts are expressed in terms of mean absolute values, anomalies (for temperature maximum, minimum and mean) and percent of normal rainfall (categorized to below, near and above normal) with corresponding probability. The six-month forecast probabilities are presented in tercile pie charts. The pie charts presented during the KlimAgrikultura workshop showed the general likelihood of below normal, near normal (average) or above normal rainfall during different climate episodes. During *El Niño* conditions, the "dry" category is largest while during *La Niña* conditions, the "wet" category is largest. The proportions in each rainfall category will depend on the strength of the *El Niño* or *La Niña* event and will also differ from location to location and season to season. All years will have an equal likely probability of each tercile being below normal, above normal or normal. A neutral year tends to be close to the 'all years' proportions.

Information on the projected future climate for the municipality of Calapan, Oriental Mindoro was provided to the participants after a brief lecture on climate change, the global and local climate scenario, and their impacts. The projection values presented were the seasonal percent rainfall change and seasonal temperature change for the mid-21st century (2036–2065) under the RCP4.5 and RCP8.5 scenarios. The CLIRAM tool (Daron et al. 2008) presents climate information in terms of the median, lower bound, and upper bound. The farmers were encouraged to identify relevant adaptation measures for their individual farm areas.

RESULTS

As shown in Table 1, there are three broad communication challenges addressed in this paper. First, the awareness of what weather and climate information is available for smallholder rice farmers in Calapan, second, interpretation of seasonal climate forecasts, and third, the need for localized information on trends and projections in climate change.

Table 1. Communication challenges identified by stakeholders and steps taken to reduce these barriers.

Issue Identified by Stakeholder Engagement	Steps Taken to Reduce the Barriers
Awareness of Information	Matching weather and climate risks of farmers in Calapan to DOST-PAGASA information.
There is a gap between the level of climate information that smallholder farmers and their advisers are using and what is currently available.	Production of simplified scientific climate knowledge in KlimAgrikultura.
Understanding Seasonal Climate Forecasts	
One of the reasons smallholder farmers and their advisers have difficulty interpreting seasonal forecasts is due to confusion over the terms “well below normal”, “below normal”, “near normal” and “above normal”. A second and related reason is a view that El Niño means drought rather than a change in the likelihood of categories.	The development of a spreadsheet to examine the historical frequency and occurrence of different categories and how they change for different seasons of the year. This spreadsheet is used to analyze the impact of ENSO on rainfall for different seasons at Calapan.
Localizing Climate Change	Detection and analysis of changes in climate extremes for Calapan.
Smallholder farmers and their advisers are aware of climate change but not sure what it means for their location.	Downscaled climate change projections for Calapan and discussion of adaptation to the current and future climates.

Matching of Weather and Climate Risks of Rice Production to DOST-PAGASA Information

Matching crop risks and associated weather/climate hazards provides a two-way communication between climate scientists and end-users. Tables 2 and 3 relate the weather and climate events and their corresponding hazards to the relevant DOST-PAGASA products. One product may be applicable to more than one hydrometeorological event (the rainfall warning system), some products are intended for specific hydrometeorological events (tropical cyclones), while others are for general event-induced hazards (flooding, landslides). Possible adaptation options for the mitigation of the identified risks, as identified by the farmers, are also listed.

Responses of Rice Farmers to Climate Hazards

Smallholder farmers implement a variety of strategies to manage weather and climate risks to their agricultural activities. Strategies include managing farm inputs, diversifying crop varieties and implementing suitable farming techniques. The following section outlines some of the discussion on how farmers manage strong winds, floods and high temperatures, with a particular reference to the relevant PAGASA information.

Farm Operation Management for Strong Wind Hazard

In recent years, strong winds have caused extensive damage to rice production in Calapan City. Thunderstorms, monsoons, the ITCZ, easterlies, and LPAs are among the weather events that are usually associated with strong winds. This hazard often causes a delay in important farming activities, particularly planting and the spraying of pesticides and/or fungicides. The daily and ten-day weather forecasts are useful DOST-PAGASA products to help farmers anticipate the occurrence of events that induce severe winds. Tropical cyclones often cause strong winds capable of lodging crops that are already in the flowering to maturity stages. In this situation, the most practical adaptation measure preferred by farmers is early harvesting. Farmers can decide the appropriate actions based on the risk calculated from the following DOST-PAGASA products: Tropical Cyclone Advisory (TCA), Severe Weather Bulletin (SWB), Tropical Cyclone Warning for Agriculture (TCWA), and weather forecasts (DOST-PAGASA 2020). The SWB is a specialized product for farmers and fishermen and is written in the Filipino language.

Farm Operation Management for Flooding Hazard

Flood hazards pose a number of risks to rice farms due to heavy rainfall bearing events, such as thunderstorms. Farmers could use the Daily Weather Forecast and the Heavy Rainfall Alert/Advisory issued by the Southern Luzon DOST-PAGASA Regional Services Division (SL-PRSD) for Calapan City (DOST-PAGASA 2020) to determine whether they should consider taking appropriate early action (open drainage canals, delay fertilization applications, early harvesting). Flash floods are induced by thunderstorms in naturally susceptible areas if the rainfall intensity is sufficiently strong. Common crop risks from this hazard are seed immersion and seed washout (in the early crop stage), or submergence of plants (in the flowering or maturing crop stages). Through the Thunderstorm Alert System (TAS), DOST-PAGASA provides guidance to the general public

Table 2. DOST-PAGASA information risk matching with corresponding weather-related crop risks (short-term).

EVENTS	WEATHER HAZARD	CROP RISK	PAGASA PRODUCTS		ACTIONS TO BE TAKEN
			Warning/Advisories	Weather Forecast	
High Pressure Area (HPA)	Hotter temperature	Soil hardened due to inadequate water		Weather forecast	Adjust cropping calendar
		Wilting, decrease in yield		Regional weather forecast	Continue with the farm
		Presence of pests and fungal infection		10-day Weather outlook for farm operation	Farm irrugation
		Poor crop quality		Heat index forecast	Delay crop planting
Thunderstorm	Flash floods	Immersion of seeds	Thunderstorm Alert System	Weather forecast	Monitoring of weather
		Submergence of plants		Regional weather forecast	
		Seeds washout			
Southwest monsoon (Habagat)	Flooding	Seeds washout	Thunderstorm Alert System	Weather forecast	Open drainage canal
Northern monsoon (Amihan)		Immersion of seeds	Rainfall Warning System	Regional weather forecast	Delay fertilizer application
Intertropical Convergence Zone (ITCZ)		Poor germination	Flood advisories	Farm weather forecast	Adjust cropping calendar
Low Pressure Area (LPA)		Falling of flowers	Flood bulletin	10-day Weather outlook for farm operation	Early harvesting
Easteries		Submergence of plants	Weather advisory	10-day Probability forecast	Construction of drainage canal
Cold front		Unfilled grains		10-day Agri-weather information	Monitoring of weather
Tropical Cyclone (TC)		Presence of gas			
		Falling of flowers			
		Lodging of plants			
		Decrease in yield			
		Presence of insects and infection			
	Strong winds	Pollen blown away	Tropical Cyclone Advisory	Weather forecast	Early harvesting
		Rapid dryness of soil	Severe Weather Bulletin	Farm weather forecast	Trellising
		Uneven distribution of seeds	Tropical Cyclone Warning for Agriculture/Shipping	Regional weather forecast	
		Delay farm activities	Storm Surge Warning		
		Damage to plant/leaves	Gale Warning Information		
		Lodging of plants			
		Decrease in yield			

on the likelihood of thunderstorm occurrence based on three levels: (1) Information; (2) Watch; and (3) Advisory (DOST-PAGASA 2020).

Monsoons, ITCZ, easterlies, LPA, and TCs are also common sources of flood hazard. During these events, farmers could be guided in mitigating flood risks through the rainfall intensity forecast provided in the Daily Weather Forecasts, Ten-Day Weather Forecasts, Weather and Flood Advisories, and Rainfall Warning System (RWS) (DOST-PAGASA 2020). To mitigate the risk of flooding during the occurrence of any of the aforementioned systems, farmers could refer to the RWS information provided by DOST-PAGASA through the SL-PRSD. The RWS uses three color level warnings for the Heavy Rainfall Warning System: (1) Yellow; (2) Orange; and (3) Red. The warning levels require increasing awareness and actionable response from both farmers and LGUs to minimize the damages brought about by the heavy rainfall.

Farm Operation Management for Hot Temperature Hazard

Rice crops are vulnerable to wilting during the dry and hot season. These conditions are commonly due to high radiation from clear skies associated with High Pressure Areas (HPA). The higher temperature and reduced cloud cover lead to enhanced evaporation. During this time, extra irrigation is necessary to provide the water needed for rice production. The DOST-PAGASA products that farmers could refer to for HPA events are the Daily and Ten-Day Forecasts (DOST-PAGASA 2020). These weather

Table 3. DOST-PAGASA information risk matching with corresponding climate-related crop risks (month/season).

Events	Climate Risk/Hazard	Crop Risk	PAGASA Products	Actions to be Taken
	Flooding and Landslide	Poor to zero germination	Monthly Climate Assessment and Outlook	Channeling
Monsoon activity	Above average rainfall condition	Plant submergence	Monthly Rainfall Forecast	Avoid planting on landslide prone area
	Prolonged dry season due to late onset of monsoon rains	Lodging of crops	Seasonal Probability Forecast	Apply sloping agricultural land technology
		Delayed planting		Adjustment of planting calendar
				Open drainage canal
	Increase in Temperature	Rapid dryness of soil	Monthly Temperature Forecast	SMAW H2O Irrigation System/ Shallow Tube Well
	Dry Spell/ Drought	Stunted growth/ Wilting	Monthly/ Seasonal Rainfall Forecast	Pump Irrigation System from open source
El Niño	Decrease number of Tropical cyclone	Decreased/ Loss of yield	Monthly Tropical Cyclone Forecast	Adjust planting calendar
		Increase pest and diseases	*El Niño* Watch/ Alert/ Advisory	Application of pesticides
		Soil nutrient loss	Dry Spell/ Drought Assessment and Outlook	Increase application of fertilizer
			Seasonal Outlook	Crop diversification
			Regional Forecast Quick Look	Plant crop varieties suited to drought
	Flooding and Landslide	Poor germination	Monthly Temperature Forecast	Channeling
	Increase number of tropical cyclones	Pest infestation	Monthly/Seasonal Rainfall Forecast	Plant crop varieties suited to flooding
La Niña	Above normal rainfall condition	Stunted growth/ Wilting	Monthly Tropical Cyclone Forecast	Practice multiple cropping
		Death of plants	*La Niña* Watch/ Alert/ Advisory	Early harvest
			Seasonal Outlook	Adjust planting calendar
			Regional Forecast Quick Look	

forecasts have minimum and maximum temperature ranges that may help the smallholder farmers in their farming activities. The information is also important for personal health and safety. For specific guidance in responding to extreme heat, the farmers could refer to PAGASA's Heat Index Forecast.

Simplified Climate Knowledge through KlimAgrikultura

The work described in this paper contributed to the development of KlimAgrikultura. The modules in the workshop includes the following: 1) identifying farm risks through the development of the crop climate calendar; 2) matching the weather and climate risks to DOST-PAGASA information; and 3) the use of decision analysis tools. Small holder farmers and their advisers have an interest in weather and climate science, but the interest is primarily practical. The desire for practical impacts of weather is addressed through the domino or cascading effect framework that distinguishes between hydrometeorological events such as a tropical cyclones, primary *hazards* such as heavy rainfall and wind and secondary hazards such as flooding. The further steps of identifying the crop risks and actions taken to manage these risks go from what the weather will be (forecast of event) to what the weather will do (impacts and hazards) to what can be done to manage the risk. This is not only empowering for small holder farmers, but it is valuable information for PAGASA. In this way KlimAgrikultura has the potential to encourage co-learning between the providers and the users of climate information.

Improving the Understanding of Seasonal Climate Forecasts

As outlined earlier, seasonal climate forecasts can be expressed as revised chances of climatological quantiles (equally likely categories such as terciles or deciles) or the likelihood of different categories based on the "percent of average". Both of these approaches have strengths and limitations in communication. Although quantiles can be more challenging to understand and interpret as a concept, it is easy to compare the forecast with climatology. For example, a 50% chance of above median rainfall represents no shift from the long-term climatology, whereas a forecast of 70% chance above median indicates a higher chance of the season being wetter than expected. Forecasts communicated as a percent of the average rainfall are more immediately understood. However, because they are unique for each season and location, an end-user can't identify how the forecast shifts the probability from climatology. For example, a forecast that suggests rainfall will be in the Below Normal category might be a statement of the climatological odds (the most likely category from historical records) or there may be information from the forecast. Engagement with end-users in Calapan, Oriental Mindoro indicated one reason for the difficulty in interpreting seasonal forecasts from PAGASA was that the farmers and advisers didn't know exactly what was meant by a Well Below Normal season (ACIAR 2019). By highlighting recent years that were Well Below Normal using the historical rainfall data in the Excel spreadsheet as described in this paper, end-users can more easily imagine the categories.

Figure 1 shows that the proportion of years that fall into the five rainfall categories varies considerably by month. For the 30 years between 1981–2010 (Figure 1, top left), during May there have been roughly equal (six out of 30) cases of rainfall being in any of the five categories of deviation from the long-term average. However, for the same 30 years, March rainfall has been in the Way Below Normal category more than 40% of the time. As a consequence of this skewed distribution, Way Below Normal (rather than Near Normal) is the most likely category for that month. If the forecast for March is Way Below Normal, it may be perceived to be a signal from the forecast system of a drier than expected outlook. However, the long-term climatology shows this to be the most likely category.

Figure 1 also shows significant changes to monthly rainfall climatology depending on the ENSO category. During *El Niño*, there are increased chances that rain will be in the lower two categories (Way Below Normal and Below Normal), and decreased chances that rain will be in the higher categories (Way Above Normal and Above Normal). This is in line with general observations of increased chances of reduced rainfall during *El Niño* years in many regions of the Philippines, including

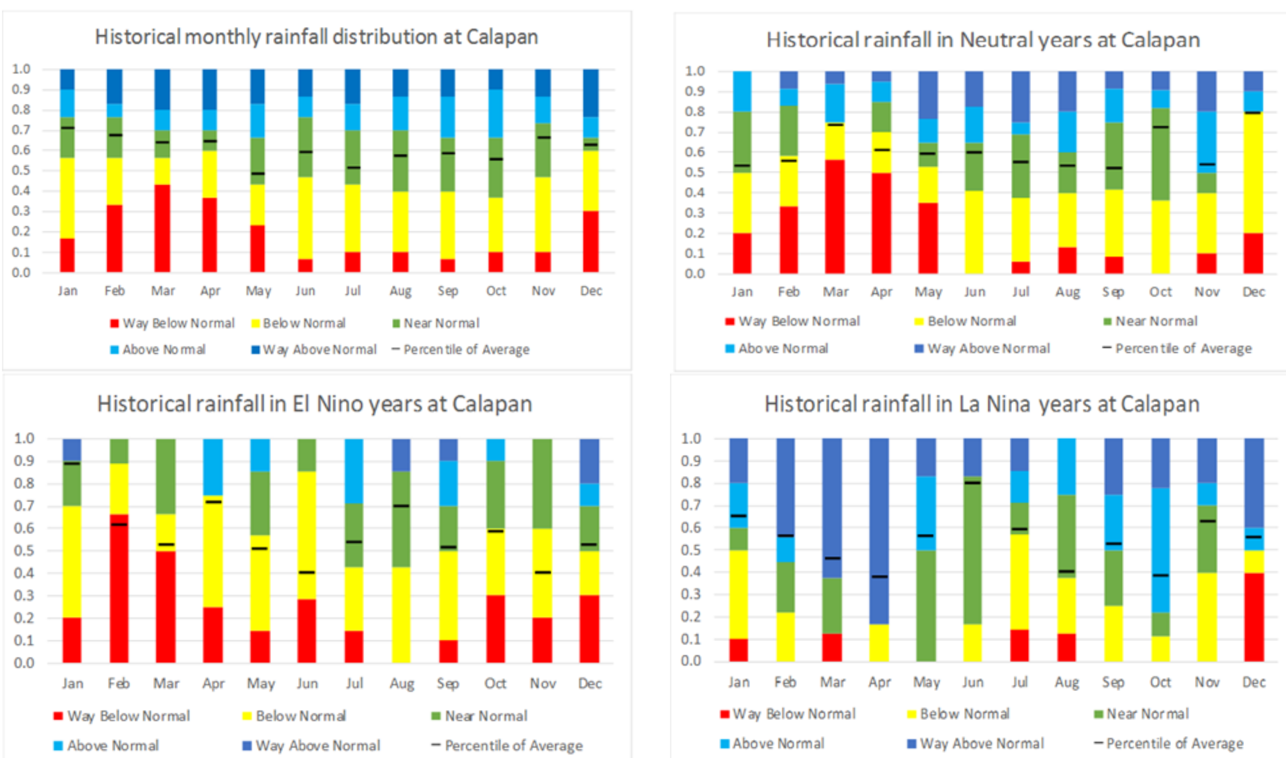

Fig. 1. Monthly stacked bar charts showing the portion (between 0-1 on the y-axis) of years that fall into each rainfall category for all months between 1981–2010 (top left). Historical rainfall for Neutral (top right), *El Niño* (bottom left) and *La Niña* (bottom right) years also shown. Horizontal black bars represent the percentile that relates to the average rainfall for each season.

Table 4. Annual rate and significance of rainfall extreme indices for Calapan for the period 1951–2019; In calculating R95p and R99p, the period 1981–2010 was used as a baseline.

Category	Index	Extreme Index	Description	Units	Slope	*p*-Value
Intensity	RX1day	Maximum 1-day precipitation amount	Monthly maximum 1-day precipitation	mm	0.017	0.010
	RX5day	Maximum 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm	0.030	0.010
	PRCPTOT	Annual total precipitation on wet days	Total wet-day rainfall	mm	0.054	0.010
	SDII	Simple daily intensity index	The ration of annual precipitation to the number of wet days (≥1mm)	mm	0.040	0.010
	R95p	Very wet days	Annual total PRCP when RR > 95th percentile	mm	5.360	0.010
	R99p	Extremely wet days	Annual total PRCP when RR > 99th percentile	mm	2.640	0.050
Frequency	R10mm	Number of very heavy precipitation days	Number of days when PR ≥ 10 mm	days	0.153	0.000
	R20mm	Number of very heavy precipitation days	Number of days when PR ≥ 20 mm	days	0.123	0.030
	CDD	Consecutive dry days	Maximum number of consecutive days when precipitation < 1 mm	days	- 0.050	0.340
	CWD	Consecutive wet days	Maximum number of consecutive days when precipitation > 1 mm	days	0.020	0.280

Mindoro (Hilario et al. 2009). During *La Niña*, there are increased chances of higher rainfall categories, particularly around March and April, and correspondingly decreased chances of lower rainfall categories.

Localizing Climate Change by Analyzing Extremes in Calapan

Trends in rainfall for the period 1951–2019 at Calapan were computed with an emphasis on extreme rainfall events. All of the indices of the intensity of rainfall show statistically significant positive trends (Table 4). The relatively high slope values of R95p and R99p indicate a rapid increase in the rainfall intensity annually from both very wet (slope of 53 mm/decade) and extremely wet days (slope of 26.4 mm/decade). These intense rainfall events are mostly associated with TCs and monsoon surges. Although not as steep, the other rainfall intensity index values (Rx1day and SDII) are increasing at statistically significant rates. The increase in monthly

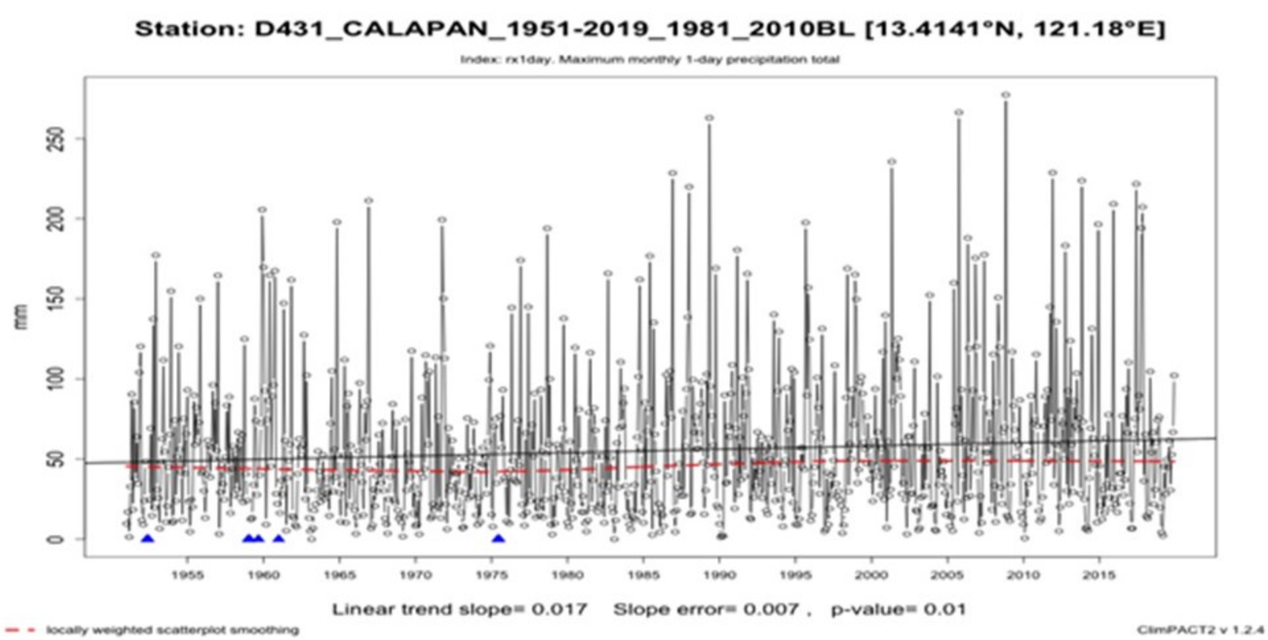

Fig. 2. Highest annual maximum 1-day rainfall (Rx1day) in Calapan for the period 1951–2019.

Table 5. Bias-corrected projected changes in seasonal rainfall and temperature for Calapan centered at mid-21st century (2036–2065) against the baseline period (1971–2000) for emission scenarios RCP4.5 (7 models) and 8.5 (11 models). The intermodal spread is indicated by the median (50th percentile), lower (10th percentile) and upper (90th percentile).

Season; Baseline Values (mean temperature, rainfall)	Scenario	Range	Projected Temperature Change		Projected Rainfall Change	
			Change (°C)	Projected Seasonal Mean Temperature (°C)	Percent (%)	Projected Seasonal Rainfall Amount (mm)
December-January-February (DJF)	Moderate Emission (RCP4.5)	Lower bound	0.90	26.80	-8.40	329.90
		Median	1.10	27.00	10.90	399.50
		Upper bound	1.50	27.30	25.30	451.40
Observed baseline = 25.8°C, 360 mm	High Emission (RCP8.5)	Lower bound	1.10	26.90	-8.70	328.80
		Median	1.40	27.30	0.20	360.80
		Upper bound	1.90	27.80	11.60	401.90
March-April-May (MAM)	Moderate Emission (RCP4.5)	Lower bound	0.90	28.70	-11.30	303.00
		Median	1.10	29.00	1.80	347.60
		Upper bound	1.50	29.30	27.70	436.30
Observed baseline = 27.8°C, 342 mm	High Emission (RCP8.5)	Lower bound	1.20	29.10	-6.00	321.20
		Median	1.60	29.50	4.90	358.50
		Upper bound	2.20	30.00	15.60	394.90
June-July-August (JJA)	Moderate Emission (RCP4.5)	Lower bound	0.20	28.00	-19.00	521.30
		Median	0.80	28.50	-7.30	596.50
		Upper bound	1.60	29.40	5.00	676.20
Observed baseline = 27.8°C, 644 mm	High Emission (RCP8.5)	Lower bound	1.30	29.10	-4.60	614.00
		Median	1.60	29.30	5.10	676.40
		Upper bound	2.20	30.00	16.00	746.50
September-October-November (SON)	Moderate Emission (RCP4.5)	Lower bound	0.90	28.20	-22.70	609.70
		Median	1.10	28.40	-1.70	775.60
		Upper bound	1.80	29.10	18.90	938.20
Observed baseline = 27.3°C, 789 mm	High Emission (RCP8.5)	Lower bound	1.30	28.60	-7.60	729.30
		Median	1.50	28.80	-1.50	777.20
		Upper bound	2.20	29.50	10.50	871.60

Rx1 day values is shown in the time series plot in Figure 2. Variability is apparent in the figure and the maximum rainfall has slightly intensified in recent years. The days with heavy rain and very heavy rain are both increasing by about one day per decade. CDD is slowly declining, while CWD is gradually increasing.

Overall, the direction and magnitude of the trends of the rainfall indices suggest that rainfall over Calapan is becoming more intense and frequent. This implies an increased flood risk due to heavy rain events such as TCs and monsoons.

Downscaled Climate Change Projection in Calapan and Implications for Rice Farming

The median projection of bias corrected, downscaled model projections for Calapan is for warmer temperatures in all months, but wetter conditions from December to May and a drying from June to November. All climate models analyzed projected warming, whereas for all seasons some climate models project drying and some wetting. Table 5 presents the projected seasonal changes of rainfall (in mm and percentage) and temperature (°C and deviation) between the observed historical and the bias-corrected future ensemble climate data.

The worst-case scenario (upper bound) warming approaches 1.8°C under RCP4.5 and 2.2°C under RCP8.5. With a potential increase of temperature from 0.9 to 2.2°C, crop yields are expected to decrease by approximately 10–20% (Bouman et al. 2001). There may not be practical and efficient methods currently available for the adaptation of smallholder rice farms to the projected temperature increases in the mid-21st century. Nonetheless, crop breeding technologies are focused on developing heat-resistant crop varieties (Weiss 2009).

In Calapan, during the usual dry season from December to February, the projected wetter conditions could interfere with harvest and land preparation. Adaptations may be required for the possible occurrence of flooding and other heavy rainfall-induced hazards. During the wet season from June to August, the possible drier conditions pose more risks to the crops with a potential decrease in seasonal rainfall of 19.0% for RCP 4.5 and 4.6% for RCP 8.5. Therefore, adaptation strategies for a possible dry spell and/or drought may be required.

The climate change projections indicate that farmers should plan for more drought during the second half of the year and a consistent 1°C increase in temperature year-round. Adjustment of the cropping calendar to a more suitable season for farming may be required. During *El Niño*, farmers may opt to plant more rice varieties that are resistant to drought (Borines et al. 2008). Planning water conservation and storage strategies, especially in rainfed areas (Ewbank 2016) for irrigation management, will help avoid crop stress during drought or dry spell occurrences. Farmers should also look into incorporating agroforestry in the field (Lasco et al. 2013), as it poses many benefits such as providing an alternative livelihood, food sources and erosion control.

DISCUSSION AND CONCLUSION

In this paper we described the engagement with smallholder rice farmers in Calapan and how we addressed the challenges of developing simplified explanations of weather and climate and the matching of weather and climate information to critical farming risks. While tropical cyclone warnings and short-term weather forecasts are relatively easy to follow, seasonal forecasts and climate change projections are more difficult to understand. We describe steps taken to make the information easier to understand and more action ready.

There are many factors that affect the uptake and use of weather and climate information. Some of the key barriers in limiting the uptake of climate information by smallholder farmers in Calapan were a lack of awareness, access, and understanding of weather and climate information. The steps taken to overcome the hindering factors in this study included: (1) a clear explanation of the basics of weather, climate and climate change and the linking of these concepts to farming; (2) introducing the farm-relevant products and services of DOST-PAGASA and explaining how these are obtained – giving the farmers a better understanding of how to integrate this information into their daily farming activities and adaptation measures; (3) using the crop climate calendar as an effective way to match the necessary products and services from DOST-PAGASA to the corresponding risks; and (4) providing localized climate projection information as basis for farmers to think about risks in the current and future climates.

It was beyond the scope of this study to investigate the success of farmers in integrating their learnings into their respective farm practices. A valuable addition to this study would be an investigation of improvements in the participants' farming activities in terms of measurable indicators, such as increase in yield per period of time and decrease in losses following events of weather and climate hazards. In addition, DOST-PAGASA as the forecast provider, should work with the agrometeorological community towards developing more customized information with user-friendly formats, taking into consideration farmer education and training, as well as their specific information and data requirements.

The Tall (2013) identified five important ingredients for successful climate services: 1) understand the demand side; 2) include sector expertise; 3) co-production of information, 4) communication for the last mile; and 5) assess and reassess. Emphasizing the demand side can be challenging for the National Meteorological and Hydrological Services (NMHS) because the supply of new information is vast. Understanding the demand side in this study was greatly aided through paying attention to the second ingredient of including sector expertise. According to Tall (2013), the extent to which the NMHS partners with the Departments of Agriculture, Health, Planning, Energy, etc., is one of the stronger indications of success. The close partnership between PAGASA and ATI, UPLB, PIDS, MinSCAT and the LGU provided a valuable two-way flow of information. Tall (2013) suggests the co-production should entail the downscaling and localizing of climate information to a specific context. The use of the crop-climate calendar and development of KlimAgrikultura workshops enable the matching of farmer and adviser knowledge with climate science to co-produce action-ready knowledge. While PAGASA has regular meetings with agricultural stakeholders in climate forums, the process of traveling to Calapan and being part of a meeting organized by the LGU with local farmers is one means of reaching the "last mile". These meetings highlight some of the connectivity problems of internet and mobile phones for smallholder farmers which is an ongoing challenge for the "last mile". The final step recommended by Tall (2013) is to assess and reassess. DOST-PAGASA has numerous engagements with agricultural stakeholders; formalizing some of the findings and steps in this study is part of the process of assessing and reassessing and encouraging a learning culture.

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