PHILIPP AGRIC SCIENTIST
Vol. 103 Special Issue, 1-10
December 2020

ISSN 0031-7454

Making Climate Science More Useful for Decision-Making: A Synthesis of Multidisciplinary Perspectives from Case Studies with Smallholder Farmers in the Philippines

Peter Hayman[1,*], Juan M. Pulhin[2,3], Canesio D. Predo[4] and Bronya Cooper[1]

[1]South Australian Research and Development Institute, Adelaide
[2]Interdisciplinary Studies Center for Integrated Natural Resources and Environment Management, University of the Philippines Los Baños
[3]Department of Social Forestry and Forest Governance, College of Forestry and Natural Resources, University of the Philippines Los Baños
[4]Institute of Renewable Natural Resources, College of Forestry and Natural Resources, University of the Philippines Los Baños

[*]Author for correspondence; e-mail: Peter.Hayman@sa.gov.au

There is a compelling case to make advances in climate science useful for one of the most exposed and vulnerable communities, the Philippine smallholder farmer. The Philippine government's investment in the modernization of PAGASA is consistent with a substantial international effort in weather and climate science. However, these improvements are only of value if they can be communicated and used in decision-making. Collectively the 12 papers in this special issue offer insights into the process of creating value from PAGASA information for smallholder farmers. These 12 papers are drawn from case studies in two contrasting farming systems: high-value vegetable production in Benguet, and the corn and rice production in Mindoro. The papers have a common focus on the use of weather and climate information for smallholder farmers, but they apply various methods from the social sciences (social network analysis, key informant interviews, gender analysis) and applied economics (risk matrices, simulation model, decision analysis, and value of information). The resulting insights are cross-disciplinary, consisting of a research team of Philippine and Australian colleagues, cross-national. We conclude this synthesis paper by drawing together what was learned in specific contexts and what this might offer other applied researchers in the Philippines, Australia and globally as they seek to make the advances in climate science useful to decision makers.

Keywords: Climate risk, Philippine agriculture, decision-making

Abbreviations: ACIAR—Australian Center for International Agricultural Research, DOST—Department of Science and Technology, PAGASA—Philippine Atmospheric, Geophysical and Astronomical Services Administration, ENSO—*El Niño* Southern Oscillation, MAO—Municipal Agricultural Office, DSSAT—Decision Support System for Agro-technology Transfer, W&C—weather and climate, WMO—World Meteorological Organization

INTRODUCTION

The Ongoing Challenge of Applying Climate Science to Agriculture

"How can the skills developed in operational, experimental and theoretical aspects of agricultural meteorology be more effectively integrated and deployed to make production systems of agriculture more reliable, more efficient and above all more equitable in the world at large?" Monteith (1993).

"The use of climate information and knowledge is currently sub-optimal, hence the most vulnerable in our society are not benefiting from recent scientific and technological advancements." Allis et al. (2019).

The papers in this special issue address the challenges facing one of the most exposed and vulnerable communities to climate risk on the planet, the Philippine smallholder farmer. According to the Global Climate Risk Index (2020), published by German watch, in 2018 the Philippines ranked second among the countries most affected by climate change based on direct losses and fatalities from extreme weather events. Using the same index (Eckstein et al. 2019), it ranked fourth among the 10 countries most affected from 1999 to 2018 (annual averages). Studies on the observed and projected impacts of increasing temperature and variable rainfall patterns have consistently suggested the same adverse impacts of climate change on the country's agricultural productivity, making the poorest farmers more vulnerable mainly due to limited capital assets (Lansigan and Tibig 2017).

The 12 papers in this issue were written by a diverse range of authors representing at least three broad disciplines namely, climate science, social science, and applied economics. This diversity of perspectives is focused on two contrasting farming systems and regions: extensive rice and corn production in Oriental Mindoro, and intensive vegetable production in Benguet, 260 km north of Manila (Fig 1a and 1b). The overall coherence for the special issue is derived from addressing the one question of how to make advances in agricultural meteorology and climate science useful for action on smallholder farms. The partners were drawn together through a four-year project (2016-2020) funded by the Australian Government through the Australian Center for International Agricultural Research (ACIAR) titled, "*Action ready climate knowledge to improve disaster risk management for smallholder farmers in the Philippines.*" The project aimed to study and improve the flow of information between PAGASA, and key decision makers involved in managing climate and weather risk of smallholder farmers. The objective was to enhance the relevance of climate and weather information for extension and advisory services by improving local information and policy.

Although the work is embedded in the Philippine context, authors have drawn from international studies and aimed to contribute to the broader agenda of making climate science useful to agriculture, especially to resource-poor smallholders. The challenge of implementing knowledge from climate science was captured in the quotes at the start of this section. The second quote from the World Meteorological Organization was a clear statement or re-statement of the challenge outlined by Monteith three decades earlier in the first quote. Both quotes draw attention to the use of climate information and knowledge in ways that assist the most vulnerable.

Three assumptions underlying Monteith's question are pertinent to this synthesis paper. First, an assumption that the practice and theory of meteorological and climate science entail ways of thinking and generating knowledge about the natural world that are useful for agriculture. Second, rather than call for more meteorological and climate science (Monteith's area of expertise), he called for effective integration and deployment in agricultural systems of what was already known. Third is the assumption that the deployment of information into social systems is not neutral, hence monitoring, planning, and effort are required to ensure not only efficiency but also equity.

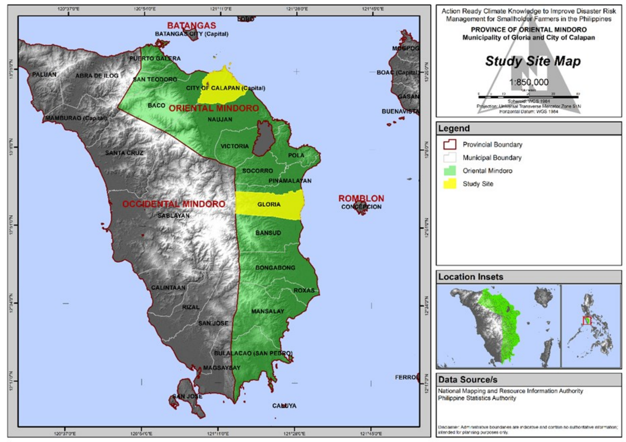

Fig. 1a. Map of Mindoro (photo by Diona et al.).

Fig. 1b. Map of Benguet (photo by Tabuga et al.).

Although ubiquitous in the current age, most recognizable aspects of meteorology and climate science are relatively recent as they depend on technology and advances that have occurred during and immediately after WWII (Bauer et al. 2015). Indeed, as a meteorologist, Monteith's colleague Howard Penman worked on the applied question of soil moisture across Europe for the trafficability of military tanks. For eons, the demand for weather and climate from agriculture preceded the supply from climate science. Agriculturists have always wondered, learned, and theorized about the weather. The cycle of seasons and indicators of weather are deeply understood and ingrained in agrarian societies. The critical question is what does modern meteorological and climate science have to offer agriculture, especially farming systems that have been developed over many generations of trial and error?

The evidence and projections from anthropogenic climate change both locally in the Philippines and across the globe have increased the urgency of Monteith's challenge. Not only in the exponential increase in the amount and complexity of information from climate science, the timeframes of warnings, short-term weather forecasts, seasonal outlooks, and climate change projections raise the difficulties of implementation to agricultural systems. The notion of equity is also increased, especially for communities of smallholder farmers who have a small environmental and emission footprint yet seem to be bearing the brunt of the changing climate.

Overview of Papers for the Special Issue

Contribution from Climate Science

The first contribution to this special issue comes from DOST-PAGASA. Writing from the perspective of the mandated source of climate information in the Philippines, the authors describe some of the challenges of communicating climate information to smallholder farmers and their advisers in Calapan, Mindoro. These challenges are placed in the broader context of shifting from climate data to action-ready knowledge, a shift from being a wholesaler of information, to a partner in the provision of climate services. These challenges are foundational to all papers in the special issue and the underlying ACIAR project.

Cinco et al. address three specific examples. The first was the production and testing of simplified scientific climate knowledge in an information package "KlimAgrikultura". This information package was developed with the Agricultural Training Institute of the Philippine Department of Agriculture. An important part of the KlimAgrikultura workshop is the matching of weather and climate risks of farmers to PAGASA information. This exercise indicated that rice farmers and their advisers in Calapan were only aware of a subset of available PAGASA information.

The second was the development of a spreadsheet that can be applied to any historical set of monthly rainfall observations to explain the categories used in PAGASA seasonal forecasts (e.g., Well below Normal, Below Normal, Near Normal, etc.). This enabled users to understand a time series of different categories and to see how they change for different seasons of the year. The spreadsheet is used to analyze the impact of *El Niño* Southern Oscillation (ENSO) on rainfall for different seasons in Calapan.

The third and final problem addressed is that communities are aware that the climate is changing and will change in the future, but they are not sure what it means for their location. Station data from Calapan are used for the analysis of trends in extreme rainfall and are the source for downscaled bias-corrected projections of future changes. An important aspect of the KlimAgrikultura workshop for extension advisory services is as a demonstration of the usefulness of communicating climate and weather information in farmer's terms.

Contribution from Social Science

Six of the 12 papers are based on social sciences. The first paper in this section, from Ruzol and colleagues from UPLB, used social network analysis to investigate the weather and climate information networks of rice and corn farmers in Oriental Mindoro. An underlying premise for this work is that decisions are seldom made in isolation but come from interaction with neighbors, outside experts, and past experience. It follows that mapping flows of ideas and information through social networks provide both an understanding of current flows of information and guides more strategic and effective communication plans or programs in the future.

A rapid ethnographic assessment was conducted to gauge the type of weather and climate information accessed by smallholder farmers. The assessment included a cultural domain analysis to investigate how farmers think and talk about weather and climate. This highlighted distinctions between information about warnings of disasters such as typhoons, everyday weather, and climate forecasting. The social network analysis was preceded by an initial site visit to visualize the landscape, interview key informants, and determine the network boundary. An important finding from this process was a "hidden farmer population" of laborers and tenants who did not appear on the master list of the Municipal Agriculture Office (MAO) because their residence was different from where they farmed. Given the incompleteness of the census, snowball sampling (using participants to recommend further participants) was an effective way to find these isolated nodes or hidden actors in the barangay.

The second social science paper came from Tabuga and colleagues from the Philippine Institute of Development Studies. Using a census approach to social networks in three upland farm communities in the province of Benguet, the researchers set out to find insights about how information and education campaigns may be designed to effectively reach farmers located in remote and mountainous areas. Regression analysis showed that in this mountainous environment, social interaction depended on geographic location such as living near a village, government hall, church or market. Unsurprisingly, belonging to a large family clan increases interaction. The most affluent families were not necessarily the most central actors, the authors speculate that these families may have less need or interest in social interaction.

A significant contribution of this study is the use of social network mapping to examine the role of agricultural extension workers in communicating the weather and climate information. The authors note that there will never be enough resources for extension workers to have direct contact with all the smallholders. Identifying central actors is important for both the efficiency and effectiveness of information dissemination and education campaigns. The challenge is how to identify and encourage these central actors to become disseminators of weather and climate information within their networks. At the same time, it is important to identify actors who are not well-integrated into the social systems and find ways to ensure that they are not left behind.

The third social science paper by Losloslo et al. surveyed 200 smallholder maize farmers in Oriental Mindoro. The study found relatively high use of weather and climate information for operational and tactical decisions. An interesting observation was that a relatively small proportion of maize farmers still relied on traditional forecasting methods, but even among them there were some questions about the continuing reliability of these forecasts. An explanation offered by participants was that increased climate variability has led to a decline in the perceived accuracy of indigenous and local knowledge of forecasting. The authors recommended that beneficial information from traditional knowledge should not be ignored, but incorporated into farm decision-making.

Other factors that influenced the uptake of climate and weather information were the nature of the cropping system and the ownership status. Regression analysis indicated that intercropping was associated with the increased use of weather and climate information. A possible explanation is that bananas are used as a perimeter crop and like maize, bananas are highly prone to damage brought by torrential rain, strong winds, and typhoons. The uptake of weather and climate information was also high where respondents were the landowners or working on land owned by relatives. The authors make the important point that information was not always the limiting factor, as access to farm inputs could also limit decisions.

In the fourth social science paper, Launio and colleagues from Benguet State University also used surveys and key informant interviews to study local knowledge on climate hazards and the use of weather and climate information in the cool highland region of Benguet. The authors point out that most studies on climate risk management in the Philippines have been conducted in coastal and riverine regions. Smallholders in the highlands are prone to typhoons and flooding like much of tropical agriculture, but are also exposed to frost, hailstorms and landslides. Most of the respondents and informants in this study are members of the indigenous people of Benguet Kankana-ey and Ibaloi. The local farmers have maintained a rich local knowledge of climate-related risks. They also have traditional weather and climate indicators for all seasons of the year.

Seasonal calendars were used to identify the perceived changes in the timing of the rainy season, typhoons, thunderstorms, and frost. Similarly, a calendar was used to catalogue the traditional indicators which varied from atmospheric phenomena such as bluish clouds indicating drought to the appearance of insects or migratory birds. The authors suggested that future research should study this local knowledge and compare it with long-term records and PAGASA forecasts. They also recommend more research and development on frost management and the promotion of the 10-day rainfall forecast and monthly climate forecast.

A second paper by Launio et al. took an opportunity to study coping mechanisms from a specific extreme event that occurred in the Benguet case study region during the project. On September 15, 2018, Super Typhoon *Mangkhut* (known locally as Typhoon *Ompong*) hit the Philippines with sustained wind speeds of more than 205 km/h and gusts of 255 km/h. The typhoon was preceded by almost month-long, non-stop monsoon rains that had already affected Benguet province. Participants were asked how they heard that Super Typhoon *Mangkhut* was going to hit the province, and what changes or actions they implemented as a response.

Most of the farm households heeded the early warning of the typhoon occurrence by securing their farm and house, storing food, and harvesting harvestable standing crops or transporting harvested crops to the local trading area before the event. After the event, re-planting and marketing of the remaining crop were the only option. Community cooperation was found to be automatic in terms of cleaning and repair of roads and water sources. Most farmers recovered their losses in six to eight months, but the average was 13 months from the typhoon occurrence. The study recommends to PAGASA, Local Government Units and Agricultural extension services the need to strengthen forecasts and forecast dissemination of continuous heavy rainfall, increased local R&D on erosion and road landslide forecasting, ensuring the availability of ready-to-plant seeds and seedlings after extreme weather events, and capitalizing on the traditional "*adduyon*" for disaster management.

The final paper in social sciences section by Gata et al. examines the question of gender in weather and climate risk. The authors provide a useful overview of the expanding literature on gender and climate in agriculture. A common finding is that it is the women who suffer the most due to limited access and control of agricultural assets and restrictive social and cultural norms on gender roles. In the Philippines, women own few agricultural assets and are less likely to own agricultural lands than men.

The study used the focus group discussions and survey of 337 farmers. Apart from female-headed households, agricultural activities in rice and corn production in the Philippines remain male-dominated. Women's roles seem to be more visible in rice production than corn production, but the operational (weather dependent) and tactical (seasonal climate dependent) decisions are still male dominated. Longer-term strategic decisions about household livelihoods and adaptation to climate change are more evenly shared between genders. Studies such as this provide essential information for policy and development programs, not only to achieve equity but also for effectiveness. Furthermore, gender roles in agriculture are not static and hence, updates will be required. An important challenge for all programs is to be gender-aware rather than viewing gender as a specialty study. As discussed in more detailed in section 3, the social sciences provide a rigorous assessment of sources of knowledge from different actors who all contributed to managing weather and climate risk.

Contribution from Applied Economics and Simulation Modelling

The remaining four papers use the tools of applied economics and simulation modeling to examine the use of weather and climate information. The papers by Domingo et al. and Diona et al. follow the use of a framework that has been developed through this ACIAR project and with parallel activity in Australia. This involves crop climate calendars to identify and prioritize the weather and climate risks, verbal climate decision analysis to express the logic of climate-sensitive decisions and Rapid Numerical Climate Decision Analysis to quantify the trade-off involved in climate-sensitive decisions.

Domingo et al. examined the economics of high-value vegetable production in Atok, Benguet Province, to identify the climate and weather risks and estimate the value of information from weather and climate forecasts. Cabbage production suffers from either too little or too much water, and is sensitive to physical damage in typhoons. The use of the crop calendar identified important secondary effects of weather in the spectrum of pests and disease, and the ability to access the crop for operational aspects of sowing, weeding, crop protection, harvest, and importantly transport of a perishable crop from the farm to the market. Hail and frost were noted as risks that caused loss and damage but were not forecast. Importantly, the study identified that these were risks that farmers managed after the event with limited options for prevention. This leads to a situation where forecasts would be of limited value.

Verbal climate decision analysis provides a simple framework to structure the logic of the decision to plant cabbages (higher risk and higher return) or potatoes (lower risk and return). The simple matrix gives four outcomes consisting of the choice to plant potatoes or cabbages and the rainfall over the coming months being below normal or above normal. Selecting cabbages to plant leads to either the best outcome under above normal rainfall or the worst outcome with below normal rainfall. The authors note that by identifying the risks and rewards in various seasonal states and decision alternatives, the decision ultimately depends on factors that include risk aversion, market price projections, financial capacity, and farmer preference. The authors also conducted Rapid Numeric Climate Decision Analysis for the question of crop choice and showed how a forecast had to swing to an extremely high chance of a drier than normal season for the decision to change.

Quantifying the risk and opportunity with a simple measure of profit under different climate states requires extra time and effort, but it draws out specific information on both the biophysical and economic situation. Quantification enables a simple comparison of production risk and price risk, and in the case of vegetable production the price risk can override climate risk. Furthermore, prices are continually changing and depend on supply and demand for different quality grades of vegetables at the La Trinidad Vegetable Trading Post.

Diona et al. review the international and national literature and conclude that although farmers and advisers are aware of seasonal climate forecasts, the use is lower than the potential. They use crop climate calendars and decision analysis to better understand farm decision-making, specifically in addressing weather and climate-related risks of rice and corn farmers in Oriental Mindoro. They used crop climate calendars with focus groups and key informant interviews to identify weather and climate risks, but more importantly to probe possible actions to manage the risk and check that the action would benefit from weather or climate information. A decision identified in the crop climate calendar and taken through to Verbal Climate Decision Analysis was the decision, given a typhoon threat, to harvest or let crops reach full maturity. A cautious farmer would follow the general advisory and harvest. The reward of caution is saving the crop, whereas the regret of caution is that the typhoon misses the farm, meaning it was unnecessary to harvest early. The best outcome is the reward of optimism where the farmer chooses not to harvest early, the typhoon misses the farm and there is no loss and no cost of an early harvest. The action-state-outcome framework provides a discussion focus and raises the point that when facing uncertainty there is an unavoidable chance of regret.

Rapid Numeric Climate Decision Analysis was used to investigate pest and disease risks in rice farming brought about by excess rainfall. Using long-term climatological probabilities, considering a farmer would be marginally worse off in 56% of years with the more disease-resistant variety, the long-term probability-weighted average suggested that the protection in a more wet years covered this extra cost than in a more dry years. The disease-resistant variety is more favorable with the forecast of a higher chance of wetter years than average. An emphatic forecast of 80% chance of being in the most dry tercile switches the choice away from the disease-resistant variety, but the long-term probability-weighted average of the disease-resistant variety is 98% of the non-disease-resistant variety. Most farmers decided to use the disease-resistant variety as insurance under all circumstances.

In a second paper Diona et al. examined the value of shorter-term weather forecasts. Discussion through focus groups and key informant interviews identified operational decisions including land preparation, planting, weeding, fertilizer application, harvesting, and drying as being more sensitive to weather than climate forecasts. The study used decision tree analysis to examine the costs and benefits of applying fertilizer to a rice crop and the decision to dry maize kernels. In both cases, the decision tree included to use forecast and Monte Carlo simulations with 1,000 iterations which used to compare the distribution of outcomes "with" and "without" the forecast. This process provides the whole picture of the value of the forecast than a single number. The focus on weather risks is valuable since the skill of weather forecasts is much higher than seasonal climate forecasts. Furthermore, farmers are making more short-term operational decisions than long term climate-related decisions.

In the final paper, Castaneda et al. introduces simulation model to the analysis of climate risk. Crop models used mathematical representations of its growth and yield in response to environmental and management conditions. Castaneda et al. use weather data from Calapan with soil data samples to parameterize the Decision Support System for Agro-technology Transfer (DSSAT) for maize production. Discussion with local experts was used to elicit management options before simulating scenarios of planting dates and fertilizer rates in the wet season and dry season. The climate does not have much variation from year to year and month to month in the wet season. Hence, as expected, the response to fertilizer and planting time is relatively constant. In contrast, the dry season showed a greater variation in response to sowing time and fertilizer rate and the interaction between sowing time and fertilizer. Hence, the interest and value of information is greater in the dry season than the wet season.

As with the Monte Carlo simulation used in the preceding paper by Diona et al., the use of 30 years of weather data in the simulation model generates a series of cumulative distribution functions for each sowing date that can be compared. Not only does the probability distribution provide information for further risk analysis, but relevant for extension workers there is also a rich set of information about on-farm risk management contained in the graph.

Lessons Learned

In the remaining section of the paper we outlined the five lessons learned from this exercise.

Lesson 1: The Benefits of Multiple Perspectives from Different Disciplines

This special issue reflects a flow of ideas between climate application science, agricultural science, and social science on the question of how to make advances in climate science useful to smallholders. Just as the paper from the meteorological agency PAGASA grappled with the challenge of effective communication in the delivery of climate services, the social science papers have the clarity about the different time scales of warnings, short-term weather forecasts, seasonal climate forecasts, and climate change. Initial discussion and some of the pilot activities merged the weather and climate (W&C) information. Separating these led to meaningful insights.

These were gleaned from the perceptions of different audiences, different communication channels, and different responses to cyclone warnings compared to seasonal forecasts and *El Niño* declarations or long-term climate change projections. Reflecting on the interaction of different disciplines, Boles and Newman (1988) observed that the world is a single piece, but that we invent nets to trap it for our inspection. They were not so much critical on disciplines of study, but rather a failure to acknowledge the limits of disciplines, a process they described as mistaking the nets for the reality and in doing so, catching some fish but missing the sea.

Dealing with climate risk in agriculture has been dominated by the discipline nets of agricultural and climate science. These disciplines are deeply rooted in the natural sciences of biology and physics. Both are applied sciences that seek to address questions in society and combine the basic science question of "*why is it so?*" with the applied science question of "*what can we do to improve the situation?*". Demonstrably, the application of applied physics in climate science and applied biology in agriculture has transformed modern life. Just as the applied natural sciences draw on basic science and theory, social scientists draw on foundations of anthropology, economic and social theory to ask, "*why is it so*" and use this base to contribute unique insights into the question of, "*what to do about the situation.*"

Despite some notable exceptions, the social sciences, including economics, have been overlooked or underemphasized in climate applications. Perhaps worse than being excluded is only to engaged as a 'downstream' process. Hartman (2015) reacted to a call for social science to translate and communicate the message of climate science as follows: "*To turn to expert humanities researchers not for the depth of their knowledge concerning values and ethics, or historical trends in human thought and behaviour, but for their ability to translate a highly technical scientific message into the popular idiom is not unlike engaging an accomplished composer to tune your guitar*." In a similar vein, the agricultural economist Bill Malcolm (1994) referred to the "*agricultural scientist way of thinking, which is to build the technical model and add a few dollar signs on the outputs at the end*". If economics is the "study of mankind in the ordinary business of life" (Marshall 1890), it has much more to offer than putting a peso value on forecasts. The same case when it comes to clearly thinking the value of information for decision-making under uncertainty. Perhaps above all is the notion of being comfortable acting with partial understanding and unavoidable scientific uncertainty (Jasanof 2007).

Lesson 2: Acknowledging Different Sources of Knowledge

Fundamental to this special issue is the assumption that information and knowledge from PAGASA have potential value. The high view of knowledge generated by climate science does not require a belittling of local knowledge. All papers in this issue relied heavily on capturing local knowledge for their research. Ruzol and colleagues used rapid ethnographic assessment to catalogue local forecasting methods. Launio et al. provided the useful definitions from FAO, whereby local knowledge is defined as the knowledge in a given community developed over time and that is continuing to develop, and consists of traditional knowledge and indigenous knowledge, where the former implies a static knowledge system of people living in rural areas and the latter is often associated with indigenous people (FAO 2004). An important point is that local knowledge is dynamic and can accommodate aspects of scientific knowledge that become trusted and familiar.

A key term used in disaster risk reduction is 'risk knowledge' which is a hybrid knowledge developed between science and decision makers (Rougier et al. 2013; Wegscheider et al. 2011). This is consistent with the UN Hyogo framework on disaster risk reduction and resilience (UN 2007) and is encouraged by the multi-disciplinary approach outlined in lesson 1.

Lesson 3: The Request for Climate Services is a Non-trivial Challenge for Hydro-meteorological Services such as PAGASA

The Philippine government's investment in the modernization of PAGASA is consistent with a substantial international effort on weather and climate science. Advances are being made in accessing to past and current weather observations along with warnings, short-term weather forecasts, seasonal climate outlooks, based on *El Niño* Southern Oscillation and long-term projections of climate change. However, these improvements are only of value if they can be communicated and used in decision-making. Climate services involve the application of climate information to climate-sensitive decisions. The concept of actionable climate knowledge is a response to what has been termed the "loading dock" view of information provision (Cash et al. 2006).

This request for hydro-meteorological services such as PAGASA to move from information wholesaler to climate services is more than re-branding a series of activities. It is not so much a shift as an additive. Hence, is more than reengineering and re-directing resources. Furthermore, the task of providing reliable information is expanding, not contracting. Hydro-meteorological services such as PAGASA deal with an enormous set of data on past and current temperature, rainfall, wind, soil moisture, and ocean conditions. They also run models that generate an expanding array of warnings, weather forecasts, seasonal forecasts, and climate change projections.

One definition of information is data that is made meaningful through interrogation with questions such as how much and how often (Ackoff 1989; Liew 2007). Since its inception, PAGASA mainly has been in the business of converting data (observations) to information (frequency, long-term averages, variability, and trends). This includes quality checks, storage, retrieval, and data processing. This is an enormous task in a country that is so exposed and sensitive to climate, buffeted by over 20 tropical cyclones a year, strongly influenced by the cycles of *El Niño/La Niña* and facing changes due to anthropogenic warming. A further challenge to any spatial analysis and extrapolation is the geographic complexity of a mountainous tropical archipelago.

Part of the solution to the challenge for PAGASA of coping with a growing task of turning data into climate information and at the same time turning information into actionable knowledge comes from lesson one on partnerships. Cinco and colleagues from PAGASA cite the finding from WMO (2013) that one of the strong indications of success for climate services is the partnership with experts in Agriculture, Health, Planning, Energy, etc. These partnerships should ease the load for PAGASA, but if they are to be truly successful, they will influence the development of PAGASA's meteorological products and services.

Lesson 4: The Importance of Being Local

Ostrom (2009) made the point that abstract entities do not fill economies and societies, rather there are people with concrete coordinates of time and space. The findings reported in this special issue come from deep engagement and multiple visits to the two case study sites. Not only to build trust, but also to encouraged a level of reflection and learning about the local context. There are numerous insights into the social networks, the local and traditional knowledge, the cropping calendars, the words and categories for weather and climate, and the decisions and outcomes facing smallholder farmers. There are important differences between vegetable production in the highlands of Benguet, and the rice and corn production in Mindoro.

One example is the study by Launio and colleagues, from Benguet University, on the response and recovery to Tropical Cyclone *Ompong* in September 2018. Despite the event of being more wet than average months, and the city of Baguio receiving almost 800 mm of rain in four days, a major problem faced by smallholder farmers was running out of water for irrigation after the cyclone due to the water infrastructure damage. Although climate risk can be use to represent probability distribution, we sample the distribution one season at a time. It follows that human experience and memory are messy, and livelihoods, especially for vulnerable groups, can be jolted by relatively few events that have a disproportionate local impact.

Lesson 5: The Importance of Being Able to Generalize

A contradicting lesson to the value of paying attention to local events in concrete coordinates of time and space is the importance of being able to generalize. A detailed description of isolated cases and pilot projects is of limited value. Not only the ability to draw general findings necessary for scholarly research, it is also important for development projects. This is captured in the adage for development "the pilot never fails, the pilot never scales" (Rosenboom 2016).

Social network analysis goes to considerable lengths to mathematically map the pattern of social connections in a local context. Indeed, one of the messages from this work is that networks are unique to the history and geography of a region. However, as pointed out by Tabuga et al., social network mapping is valuable, but may not always be feasible. They recommended that the principles can be used to design extension activities focusing on social norms associated with different socio-economic profiles and physical characteristics of an area.

The applied economics papers for this issue draw from decision analysis and valuing information. These techniques require considerable local detail on the decisions available and the biophysical outcomes of those decisions for different states of climate.

Furthermore, specific local farm-level economic information is required to take into account the cost of the decisions and the resulting profit or loss in the outcomes. Although specific in detail, decision analysis offers a general framework to pose clear questions about action-state-outcomes and generate a solution based on the assumptions. The process allows the assumptions to be varied for simple sensitivity or sensibility testing and enables users to quickly recognize insurance type problems (small loss in profit in most years to protect from a major loss in a few years), balanced decisions (downside risk and upside opportunity approximately the same) and risky, but worthwhile investments (upside opportunity greatly outweighs the downside risk).

CONCLUSION

This synthesis paper started with the challenge of implementing climate science effectively and equitably, posed as a question from the eminent scientist John Monteith. This was followed by a quote from the WMO bulletin almost 30 years later, indicating that no simple answer had been found. We should be suspicious of any single definitive answer. Taking Monteith's question as an open challenge invites a series of partial responses. This special issue provides a range of responses from two diverse regions and farming systems in the Philippines. None of the papers claim to provide complete answers, and most evoke further questions. Progress is made as we document our experiences and learnings from both the findings and the methods of others.

Ford, Vanderbilt and Berrang-Ford (2012) warned of an overriding globalized narrative of climate risks that shifts attention from the experiences, understanding, and responses by specific cultures, especially those whose voices are seldom heard. Underlying the work reported in this special issue is a genuine desire to engage with smallholder farming communities, to understand their social networks, how they access weather and climate information, the risks they face and the decisions they make. An example of hearing a local perspective comes from the paper of Launio et al., who detailed lived experiences following Typhoon *Ompong*. When asked about coping after the event, the farming communities referred to "*aduyon*" as the tradition of community cooperation, helping each other to clear and clean roads after the typhoon. This is more than traditional knowledge that needs to be shared, a traditional value with wisdom for the global narrative. It is into this local perspective that the work of the papers of this special issue have their focus. The various messages from these papers amount to a loud voice promoting the provision among various community stakeholders of extension and advisory services that are both clearer and simpler.

This synthesis paper set out to consider how climate science can be more accessible and useful to smallholder farmers. There is good evidence that information on tropical cyclones is not only saving lives, but it is also improving smallholders' livelihoods. It is fitting that the last voice should come from the most vulnerable. "*Wala talagang alternatibo na pangkabuhayan. Maghihintay ka na lang muna na umulan. At saka itong lupang ito ay nirerentahan, diretso ang bayad kahit may El Niño*." (We do not have an alternative livelihood. One will only hope that it will rain. And this land is not ours. The rent does not stop even during the *El Niño*.) by the corn farmer in Gloria, Mindoro. This is a sobering reminder that climate information alone will not resolve all vulnerabilities. However, it would be a mistake to abandon the quest to make climate science more useful to vulnerable communities. Indeed, we owe it to these communities to not only make climate information available, relevant and clear, but also to integrate the information into broader development frameworks.

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