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Providing future climate projections using multiple models and methods: insights from the Philippines

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Abstract To meet the growing demand for climate change information to guide national and local adaptation decision-making in the Philippines, the climate science and services community is producing an increasing volume of future climate data using a range of modelling approaches. However, there is a significant methodological challenge in how to best compare and combine information produced using different models and methods. In this paper, we present the landscape of climate model data available in the Philippines and show how multi-model, multi-method climate projections are being used and communicated to inform climate

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change policy and planning, focusing on the agriculture sector. We highlight the importance of examining and communicating methodological strengths and weaknesses as well as understanding the needs and capabilities of different user communities. We discuss the assessment of projections from different methods, including global and regional downscaled simulations, and discuss ways to summarise and communicate this information to stakeholders using co-production approaches. The paper concludes with perspectives on how to best use an "ensemble of opportunity" to construct defensible, plausible and usable climate projections.

1 Introduction

Reliable information about how regional and local climates have changed in the past, and may change in the future, is important for managing climate change risks. Whilst global climate models (GCMs) can provide large-scale future climate change projections (Stocker et al. 2013), dynamical downscaling using regional climate models (RCMs; Rummukainen 2010) and statistical downscaling methods (Hewitson et al. 2014) can provide more spatial detail to better inform local adaptation to climate change.

As one of the most exposed and vulnerable countries in the world to climatic hazards, understanding how climate change might affect the Philippines is essential to help manage climate risks in the future. Here, as in many other countries, there is an increasing volume of future climate data from GCMs and downscaling methods. The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) has recently produced a new set of national projections (PAGASA in preparation) using downscaled simulations from RCMs and statistical methods. In addition, GCM and downscaled data are available from the wider climate modelling community in the Philippines, Southeast Asia and internationally. Whilst the objectives and design of these modelling experiments vary, each new simulation adds to a growing pool of datasets. This provides an opportunity for climate scientists to explore uncertainties associated with climate projections in the Philippines. Yet, the challenge facing climate service providers is how to process and communicate data from different models and methods, produced at multiple institutions, and with different spatial and temporal scales of relevance. Using the available data, there is a need to distil coherent messages (Goodess 2014) that are scientifically defensible and relevant to users across different sectors and levels of society.

There is currently no consensus on how to combine, compare and communicate climate change information produced from different models and methods (Tebaldi and Knutti 2007; Knutti et al. 2010). However, without sufficient guidance from the climate science community, there is a risk of inappropriate use of climate model information potentially leading to maladaptation (Ekström et al. 2016). The appropriate extraction, accurate interpretation and effective use of climate model projections depend on users' underlying knowledge and capabilities as well as clear and consistent guidance by the provider community on their appropriate use. Communicating multi-method, multi-model projections to different audiences is not straightforward, and a central challenge is communicating the uncertainties in the model projections whilst simplifying and tailoring the information to meet specific user needs.

This paper provides perspectives and experiences from providers and users of climate change information in the Philippines. We focus on approaches to assess and simplify multi-model, multi-method climate projections into information for local planning and adaptation decisions, and issues in applying this information in impact assessments, such as those conducted in the agriculture sector. The situation facing the Philippines is not unique, and the experiences, approaches used and lessons learned have wider relevance to climate service providers across the world. The paper therefore also aims to inform the development of climate scenarios for use in services in other countries where the availability of multiple models and methods poses challenges for comparing, combining and communicating climate projections.

Section 2 summarises the available climate model data and methods used in the Philippines. Section 3 focuses on the challenges of comparing and assessing this information. The following two sections discuss how climate projections can be communicated to address different user needs; Section 4 outlines recent work to improve the uptake of climate information at the local scale, and Section 5 focuses on climate change information use in agricultural impact assessments. Section 6 discusses lessons learned relevant to the international climate science and services community. Final conclusions are provided in Section 7.

2 Climate projections for the Philippines: available data and methods

2.1 Overview of projections

Many studies have been conducted to better understand and prepare for climate change in the Philippines, but past studies have had limited access to detailed and comprehensive climate projections. For example, a study on the impacts of climate change on the country's water resources was based on climate projections derived from coarse-scale GCMs and crude rainfall-runoff relationships (Jose and Cruz 1999). GCMs typically simulate the climate at horizontal spatial resolutions of 100 to 300 km, which is generally too coarse to be used directly in impact models, such as crop models (e.g. Mearns et al. 1997; Hoogenboom 2000) or hydrological models (e.g. Olsson et al. 2013). The demand for high-resolution climate projections is further compounded by a need for local scale climate change information to guide adaptation decisions. Therefore, recently, both dynamical and statistical downscaling methods have been used to produce more detailed future climate information for the Philippines to inform climate change decision-making. Dynamical methods have been used to produce national projections (PAGASA 2011, in preparation), and statistical methods have been used to provide very high spatial resolution data for use in crop modelling studies (see Section 5).

Despite the demand for high spatial resolution information, when using climate projections a range of plausible futures must be considered: the range resulting from different models and emission scenarios as well as natural climate variability (Hawkins and Sutton 2009). Some of these dimensions have been explored in the Philippines through downscaling with data from multiple GCMs under different greenhouse gas (GHG) emission scenarios. In the Philippines, as elsewhere, climate models have been driven by two sets of emission scenarios: the Special Report on Emission Scenarios (SRES; IPCC 2000) used by GCMs in the third Climate Model Intercomparison Project (CMIP3; Meehl et al. 2007) for the third and fourth Intergovernmental Panel on Climate Change (IPCC) assessment reports, and Representative Concentration Pathways (RCPs; van Vuuren et al. 2011) used by GCMs in CMIP5 (Taylor et al. 2012) to inform the IPCC fifth assessment report (AR5). Due to differences in their design, such as assuming significantly different future aerosol emissions, projections from SRES and RCP scenarios are not directly comparable, though they can be approximately compared in terms of equivalent CO_2 concentrations (Stocker et al. 2013).

The following sections describe the available climate projections for the Philippines produced using the SRES scenarios and CMIP3 GCMs, and more recently the RCP scenarios and CMIP5 GCMs.

2.2 First generation of climate model projections for the Philippines

National climate projections for the Philippines produced using the SRES scenarios (PAGASA 2011) have been used to inform policy (e.g. Climate Change Commission 2010). Due to human and computing resource constraints, projections were based on dynamically downscaled simulations using a single GCM (HadCM3, McSweeney et al. 2012) and a single RCM (PRECIS, Jones et al. 2004) at 25 km horizontal resolution. Subsequently, the Southeast Asia Climate Analysis and Modeling framework (SEACAM; Rahmat et al. 2014) coordinated a set of RCM experiments to cover the whole region. SEACAM was initiated by the Centre for Climate Research Singapore in partnership with the Met Office and involved a number of countries in Southeast Asia, represented by PAGASA in the Philippines. SEACAM produced multiple SRES-based dynamically downscaled climate projections for Southeast Asia through sharing computing and analysis tasks among member countries.

2.3 New generation of climate model projections for the Philippines

To update the national projections, and better quantify climate change uncertainties, PAGASA has partnered with international climate research organisations to perform several new simulations, downscaling CMIP5 GCM projections using the RCP scenarios. Downscaled RCM simulations were produced by the UK Met Office using the HadGEM3-RA model at 12 km resolution as part of a project to study climate change impacts on tropical cyclones in the Philippines.[1] Simulations were produced for 30-year time slices from 1971 to 2000 and 2036 to 2065. At the same time, PAGASA produced RCM simulations using PRECIS and the Abdus Salam International Centre for Theoretical Physics RCM version 4 (RegCM4) (Giorgi et al. 2012) at 25 km resolution over the same domain for the period 1971 to 2099. The method for selecting GCMs used in these simulations is discussed in Daron et al. (2016).

Another set of simulations was conducted as part of the High-resolution Climate Projections for Vietnam (HCPV) developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) (Katzfey 2015). The HCPV projections used the Conformal Cubic Atmospheric Model (CCAM) to downscale six GCMs for the period 1970 to 2100. The projections sample two RCPs at 50 km resolution with bias and variance-corrected GCM sea surface temperatures (SSTs) (Hoffmann et al. 2016). These simulations were further downscaled using a stretch-grid version of CCAM to 10 km centred on Vietnam, with resolutions of about 25 km over the Philippines (Katzfey et al. 2014; Katzfey et al. 2016). An additional downscaled simulation of the stretch-grid version of CCAM (using bias- and variance-corrected SSTs from CNRM-CM5) was run and re-centred over the Philippines, referred to as CCAM (PH) in Fig. 2a.

A regional downscaling activity is being conducted as part of the Southeast Asia Regional Climate Downscaling/Coordinated Regional Climate Downscaling Experiment–Southeast Asia (SEACLID/CORDEX-SEA) project[2] (Juneng et al. 2016; Ngo-Duc et al. 2017; Cruz et al. 2017; Chung et al. 2018). With participating members from 20 institutions and 14 countries, including the Manila Observatory in the Philippines, the project aims to generate high-resolution climate change scenarios for the Southeast Asia region at 25 km resolution based on multiple RCP scenarios, GCMs and RCMs. The RCMs being used include RegCM4,

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[1] http://www.metoffice.gov.uk/research/applied/international-development/philippines

[2] http://www.ukm.edu.my/seaclid-cordex; http://www.apn-gcr.org/resources/items/show/1886

CCAM, the Rossby Centre regional climate model (RCA4), the Weather Research and Forecasting (WRF) model, the Non-hydrostatic RCM from the Meteorological Research Institute of Japan and PRECIS. Efforts are underway to publish the key findings of this project, whereafter the data will be hosted in an Earth System Grid Federation (ESGF) node for efficient dissemination (F. Tangang, personal comm., 7 June 2017).

Statistically downscaled CMIP3 climate projections driven by SRES scenarios are also available for the Philippines. Identification of GCM-derived predictors for rainfall in the Philippines (Manzanas et al. 2015) served as the basis for deriving statistically downscaled climate projections over selected locations in the north-western Philippines (Basconcillo et al. 2016) that were later extended to the whole country and made publicly available.[3] These simulations used the Downscaling Portal[4] of the University of Cantabria as part of the MOSAICC (MOdelling System for Agricultural Impacts of Climate Change) system,[5] developed by the Food and Agricultural Organisation of the United Nations (FAO) to provide local scale climate information for agricultural applications. Work is ongoing to produce statistically downscaled RCP-driven simulations from CMIP5 GCMs.

Table S1 (see Supplementary Material) provides details of all dynamically and statistically downscaled climate simulations available for the Philippines.

3 Using different climate model simulations to provide coherent outputs

Section 2 outlines the large volume of climate projection data now available in the Philippines, from GCMs, RCMs and statistical downscaling methods. However, there remains a significant challenge in how to use this data and communicate meaningful information to different users. Section 3.1 outlines previous approaches to combining different model simulations, and Section 3.2 then focuses on the key scientific and practical issues of dealing with and using this information.

3.1 Existing approaches to combining different climate model simulations

Various approaches have been applied to assess and synthesise multi-model, multi-method climate projections. An IPCC expert meeting discussed ways of assessing and combining multi-model climate projections (Stocker et al. 2010), resulting in guidance to IPCC authors that encourages consideration of different standardised model performance metrics. Most approaches include evaluating models' ability to represent past climate conditions (e.g. Maraun et al. 2015; Park et al. 2016) as a measure of reliability for future climate simulations. Model weighting (e.g. Murphy et al. 2004) and Bayesian statistical methods (e.g. Tebaldi et al. 2005) use assessments of model reliability to produce probabilistic projections, giving higher weight to more "realistic" models. However, Weigel et al. (2010) show that weighting does not necessarily improve predictive skill and models can perform well or poorly depending on the choice of metrics, stating that "equal weighting may be the safer and more transparent way to combine models". Yet Knutti et al. (2017) argue that equal weighting may no longer be justifiable when considering both model performance and interdependence. A different

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[3] http://www.pagasa.dost.gov.ph/index.php/climate/climate-projection

[4] https://meteo.unican.es/downscaling

[5] http://www.fao.org/in-action/mosaicc/en/

approach to weighting is documented in McSweeney et al. (2015) where particularly poor performing models are excluded and all other models considered equally plausible.

Despite efforts to evaluate climate models, there remain fundamental issues in using data from imperfect models to guide future societal decision-making (Frigg et al. 2013). Furthermore, downscaled simulations rarely sample more than a small subset of the available GCMs (McSweeney et al. 2012, 2015) and we cannot expect to fully sample the range of plausible outcomes. Acknowledging the reality of small ensembles, Ekström et al. (2016) warn of the possibility for biased climate change projection advice and the risks of subsequent maladaptation.

3.2 Comparing climate model simulations for the Philippines

Below, we summarise key strengths and weaknesses for the different modelling approaches used to generate climate projections for the Philippines; other studies provide more rigorous comparisons (e.g. Murphy 1999; Christensen et al. 2007).

- *GCMs* provide global coverage with relatively coarse spatial resolutions (typical CMIP5 resolutions were about 150 km), which is problematic for nations with many islands and complex topography such as the Philippines. GCMs are typically fully coupled (atmosphere-ocean) and dynamically based—i.e. based explicitly on physical representations of climate processes—but are limited by the quality of the representation of the dynamics, physics and parameterisations included.
- *Dynamical downscaling* uses a limited area domain (RCM) or a stretched/variable resolution global domain focused on a specific region. Like GCMs, the projections are dynamically based but usually only represent the atmosphere and are subject to the quality of the representation of atmospheric dynamics and physics. Dynamical downscaling uses SSTs and lateral boundaries (for RCMs) provided by GCMs and hence retains errors propagated from the GCMs. Although the stretch-grid approach uses a global atmospheric model (i.e. no lateral boundaries), bias-corrected SSTs from GCMs can introduce errors due to assumptions in the bias correction process.
- *Statistical downscaling* methods vary in complexity (Hewitson et al. 2014) but typically use empirical-statistical relationships between large-scale predictors (i.e. GCM-derived atmospheric parameters) and local predictands (e.g. rainfall or surface air temperature) derived over a historical period. Results are typically very good over the historical period, as they are "trained" using observations, but sufficient temporal and spatial density of observations is necessary. Also, predictors should be robust across space and time and empirical relationships are assumed to hold in the future.
- *Simpler statistical methods* include interpolation and scaling applied to GCM data. These methods are inexpensive and can therefore produce detailed high-resolution information but are subject to significant caveats. For example, the WorldClim dataset provides 1 km resolution projections from high-resolution observational data combined with projected climate changes from coarse-resolution GCMs. It is thus dependent on the quality of the observations and does not account for climate change signals resulting from local or high-resolution dynamical influences.

A key contributor to the spread of future climate projections is uncertainty in future CO_2 emissions and concentrations in the atmosphere. Figure 1 shows the impacts of different emission scenarios (RCPs) on the rate and magnitude of warming over the Philippines from RCM projections (see Section 2). By the mid-twenty-first century, temperature changes over the Philippines overlap between the lower (RCP4.5, + 0.9 to + 1.9 °C) and higher (RCP8.5, + 1.2 to + 2.3 °C) scenarios, showing that the choice of emission scenario is not critical at this timescale; the range of projections results primarily from the use of different climate models. By the end of the century, the range of temperature changes does not overlap (RCP4.5 + 1.3 to + 2.5 °C and RCP8.5 + 2.5 to + 4.1 °C) showing that different emission scenarios need to be considered to characterise the range of possible futures on longer timescales.

Figure 2a shows the projected changes from RCMs, GCMs and WorldClim datasets for annual mean temperature and total annual rainfall for the future period (2036–2065) minus the historical period (1971–2000) for the RCP8.5 scenario. All projections indicate warming (+ 1.2 to + 2.6 °C) but the direction of change in annual rainfall (− 16 to + 18%) is less certain, and the range from the RCMs is different to the range from the GCMs. Further analysis, for example on why the CCAM projections show more negative rainfall changes than their driving GCMs, would provide insight into the reliability of the projected range of precipitation changes, which can be used to inform adaptation decisions. Evidence that RCM changes can differ, even in sign, from those produced by their driving GCMs further emphasises the need to consider the physical reasoning (Gao et al. 2012) (see Table S2, Supplementary Material).

Comparison of the dynamically and statistically downscaled simulations (Fig. 2b) shows that care is needed when interpreting the results of different downscaled projections. In this case, the statistical downscaling approach used specific humidity as a predictor (Manzanas et al. 2015). In the current climate, when this increases there is, on average, potential for greater rainfall as it is linked to increasing relative humidity. Yet, in a warmer climate, specific humidity increases for the same level of relative humidity (i.e. warmer air holds more water) meaning the statistical model predicts more rainfall even when the relative humidity does not change. The result is a systematic bias towards predictions of increasing rainfall in a warmer climate, showing the results are unreliable. More recent experiments using statistical downscaling with alternative predictors show results more consistent with the RCM-produced changes (J. Basconcillo, personal comm., 05–02-2018). However, the statistically downscaled results still show increases that are larger than those produced using other methods.

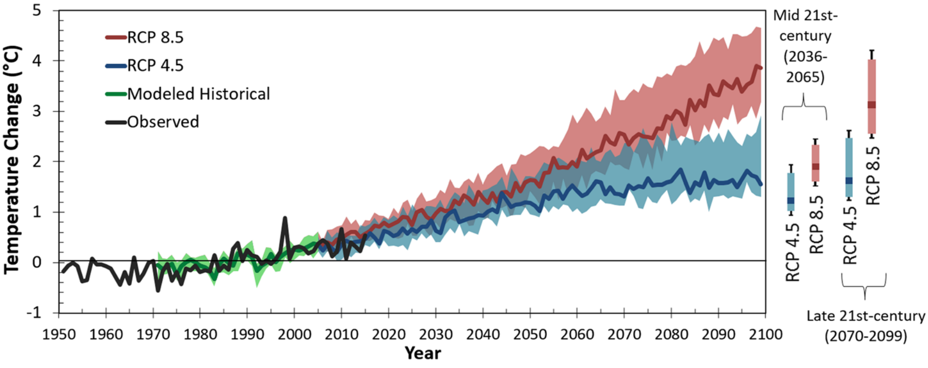

Fig. 1 Annual mean temperature change over the Philippines using a 1971–2000 baseline. The black (green) line shows observed (RCM) temperatures for the past, using observed GHG concentrations. The red (blue) line shows RCM projected changes in annual temperature for 2005–2100 for the RCP8.5 (RCP4.5) scenario. Solid lines show the multi-model ensemble mean and shading denotes the 10th to 90th percentiles. Vertical bars on the right show the median and spread of projections at the mid and end of century

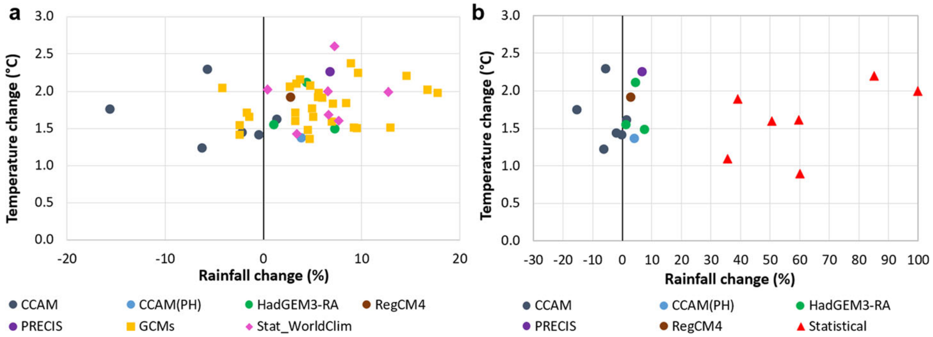

Fig. 2 Projected changes in total annual rainfall (horizontal axis) and annual mean temperature (vertical axis) in the Philippines by mid-century (2036–2065) relative to 1971–2000 for the RCP8.5 scenario using. **a** Dynamical (GCMs and RCMs) and statistically interpolated (WorldClim) simulations and **b** dynamical (RCMs) and statistically downscaled (MOSAICC) simulations. Values are given in Table S2, Supplementary Material

Comparing projections from different methods is essential as this information is being considered in adaptation planning in the Philippines (e.g. Climate Change Commission 2010; Local Government Academy 2014) and elsewhere (e.g. UN-Habitat 2014). Furthermore, several recent studies (Daron et al. 2015; Dowdy et al. 2015; Ekström et al. 2015) note that all available projections should be considered where possible but interpreted carefully to ensure there is a physical understanding of why projections concur or differ.

4 Communicating climate change information from multiple projections: an example for agriculture

There are many ways to summarise and select information from an ensemble of climate projections and this will depend on the aim of the study or decision context in which the results are being applied. An example of a decision-focused approach was developed in an Asian Development Bank project involving a regional climate consortium including PAGASA in the Philippines and partners in Thailand and Indonesia.[6] The project produced guidelines for users, emphasising the need to consider the full range of available climate projections and highlighting additional issues including understanding baseline climates of models, avoiding the combination of variables from different projections, and considering how simulations provide information for appropriate spatial resolutions and time periods. Yet whilst such guidance can help users choose suitable output for their needs, in practice (e.g. in the agricultural sector) the communication, uptake and use of climate projections are complicated by many additional context-dependent factors.

As part of a Met Office project with PAGASA, a pilot study was undertaken to assess and enhance the communication and uptake of climate information in local government and business continuity planning in two regions of the Philippines, Manila and Salcedo (Scannell et al. in review). Decision-makers from specific sectors, including agriculture, were given summary information from available downscaled projections (see Section 2) for temperature and rainfall projections over their regions for the SRES A1B, RCP 4.5 and RCP 8.5

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[6] https://research.csiro.au/climate/wp-content/uploads/sites/54/2015/11/RCCDFflyer_WEB.pdf

scenarios. It was found that the information was not being used in decision-making with participants expressing difficulty in understanding and interpreting the projections. Common issues included a lack of understanding about what the different scenarios meant, why different models were used and why results differed, as well as a lack of capacity to use multiple projections.

Based on the insights gained, the study then engaged pilot study participants to develop more effective methods of communicating the range of projections. A Climate Information Risk Analysis Matrix (CLIRAM) was co-produced using an iterative process between the participants and the project team. The resulting matrix relates future plausible climate scenarios to potential local impacts and solutions, aiming to aid users unfamiliar with the complexities of climate projections and help them better understand the information. Table 1 shows the CLIRAM developed with people from the agricultural sector in Salcedo.

The CLIRAM presents the range of climate projections as lower, median and upper bounds, taken from the ensemble of simulations for the RCP4.5 and RCP8.5 scenarios. Users can then identify possible impacts for each outcome and propose potential adaptation solutions. SRES-driven simulations were included in the first iteration but later removed. Given time constraints and the limited climate knowledge of some participants, communicating projections from only one set of scenarios was found to be more readily understood; participants struggled to understand why SRES scenarios were replaced by RCP scenarios and how both sets of information remain relevant. They also expressed concern regarding the reliability of the different information and how they should combine data from different emission scenarios.

In Salcedo, participants were more concerned with the risks of increased rather than decreased rainfall, concluding that a 10% reduction of winter rainfall would have little impact whilst a 10% increase could potentially reduce harvests for important crops. Participants thought that further information was needed to inform adaptation choices, and that a detailed impact assessment (e.g. using crop models) would help to distinguish the impact of a 34 and 71% increase in rainfall on crop production (upper bounds of RCP4.5 and 8.5 respectively). Climate projections alone therefore offer insufficient information to fully understand the potential impacts of climate change and inform adaptation choices, and detailed impact assessments are sometimes also required.

5 Using climate projections in agricultural impact assessments

More detailed quantitative information related to agricultural productivity under possible future climate conditions can be generated by agricultural impact assessments that apply impact models to climate information. In order to explore the range of plausible changes in productivity, it is desirable to consider many future climate scenarios. However, the structure and data requirements of some impact models make this particularly challenging.

Specific challenges can be elucidated by considering the example of process-based crop models. These simulate the growth of crops across scales ranging from individual fields (points), sub-national districts (administrative units), sometimes even to countries and the entire globe (on grids). They take climate data as input and produce output variables more relevant to agricultural productivity, such as crop yield. Crop models vary in complexity but running simulations of even the simplest process-based crop models for multiple climate datasets can be costly. A further challenge is that they typically have more stringent climate data requirements than is needed for more general communication and climate change risk

Table 1 CLIRAM example from the pilot held in Salcedo, Eastern Samar, focused on agriculture for the December to February season

Projected change in seasonal rainfall in the mid-twenty-first century (2036–2065) for Eastern Samar relative to 1971–2000: observed baseline (1971–2000)

December–January–February (baseline = 987 mm)

Scenario	Range	Projected change		Projected seasonal rainfall amount (mm)	Potential impacts	Adaptation options
		Percent (%)	Amount (mm)			
Low emission (RCP4.5)	Lower bound	− 3.1	− 30.4	956.6	Potential for smaller harvest • Crops ruined (e.g. wash out of planted cassava 6–8 months growing period) • Pest and disease infestation • Increased cost of lodging animals and crops	Extend cover/greenhouse style of planted crops Plant water resistant varieties, raise beds, transfer planting sites Provide good farm drainage
	Median bound	10.6	104.2	1091.2		
	Upper bound	34.7	342.4	1329.4		
High emission (RCP8.5)	Lower bound	− 10.4	− 102.6	884.4	Potential for smaller harvest • Crops ruined • Pest and disease infestation • Increased cost of lodging animals and crops	
	Median bound	7.7	76.4	1063.4		
	Upper bound	71.4	704.7	1691.7		

screening tools (e.g. CLIRAM and those discussed in Olhoff and Schaer 2010). They generally need realistic internally consistent datasets of multiple climate variables, typically temperature and precipitation but sometimes also solar radiation and evaporation. Daily data at a spatial resolution much finer than that of a GCM grid (sometimes down to the farm scale) is usually required.

Downscaling methods can help meet these demands but often at considerable cost. Running RCM simulations requires significant human and computational resources, limiting the number of future climate scenarios that can be downscaled. RCM outputs must often be combined with observations in some way to treat model biases and obtain realistic absolute values of relevant climate variables. This can be done by perturbing observations with simulated climate changes or through bias correction of RCM output using observations. Issues in bias correction are implicitly addressed through statistical downscaling methods as these are trained using observed data. However, in addition to the disadvantages noted in Section 3.2, statistical methods can only be used for variables and locations where climate observations are available and they may generate datasets that are internally inconsistent between variables.

These challenges mean that the agricultural sector is not yet accustomed to using multiple climate scenarios and often climate change impact assessments for agriculture use a single “best” scenario from easily accessible (i.e. downloadable) data. As a consequence, adaptation recommendations will not be robust in the likely event that the future climate deviates from this scenario. A compromise is to run crop models for a small number of future climate scenarios (e.g. median, best case, worst case), carefully selected to obtain the range of relevant crop model outputs that might have been achieved using the full set of future climate scenarios. For example, the Agricultural Model Intercomparison and Improvement Project (AgMIP) has used several climate scenarios with crop, livestock and agricultural economic models, and has explored impacts on rice production in the Philippines. Although information about the range of projected climate changes (e.g. Figs. 1 and 2) can be helpful, there can be nonlinear complex responses of crops to simultaneous changes in multiple climate variables. Furthermore, the most relevant climate variables are not usually simple aggregate statistics (e.g. seasonal means) but relate to crop-specific seasons and climate extremes (e.g. heat extremes during flowering). Consequently, it is not easy for climate information providers to select representative climate model simulations for use in crop modelling.

The influence of climate on crop yields addresses only one aspect of agriculture and food security issues (Wheeler and von Braun 2013); others include non-climatic biophysical variables, availability of irrigation, risk of pests and diseases, livestock productivity and socio-economic factors such as labour and markets. These issues have been recognised in the Philippines where the Analysis and Mapping of Impacts under Climate Change for Adaptation and Food Security (AMICAF) project, coordinated by FAO and the Department of Agriculture, applied a crop model, a river runoff model, an agriculture market model and a food security vulnerability analysis using scenarios from three GCMs and two emission scenarios. Also, the International Food Policy Research Institute (IFPRI) used the DSSAT (Decision Support System for Agrotechnology Transfer) crop model to analyse crop productivity, and assessed agriculture economy impacts in the Philippines using a dynamic computable general equilibrium model (Phil-DGCE) with data from four GCMs under RCP8.5 from the WorldClim dataset (note the issues in this dataset discussed in Section 3.2 and Section 6). However, there have currently been no attempts to use both dynamical and statistical downscaling in agricultural impact modelling in the Philippines.

So there is some understanding of the importance of using multiple projections by the agriculture community in the Philippines, although accessibility to properly validated downscaled climate data is a major limiting factor. Providing a summary of all available downscaled data in the country will be useful, with information on methodologies, assumptions, uncertainties and the quality of different data products. However, existing downscaled data may not meet the needs of new research and policy. Both climate information providers and agriculture researchers need to work together to overcome this challenge. Climate information providers must consider the needs of agriculture researchers, and, since crop models were not intended for use in climate change studies, agriculture researchers need to think of innovative ways to analyse climate impacts and vulnerability.

6 Discussion

The climate model simulations outlined in Section 2 provide a rich set of data from which to derive climate change information to guide adaptation decisions in the Philippines. However, the simulations conducted to date represent an "ensemble of opportunity" (Allen and Stainforth 2002)—i.e. they represent available information and have not been designed to systematically or optimally sample uncertainties; this is also the case for new SEACLID/CORDEX-SEA projections (F. Tangang, personal comm., 07-06-2017). In addition, the dynamical and statistical downscaling methods used, each with specific strengths and weaknesses (see Section 3.2), can result in different climate change information, such as systematic differences in projected annual rainfall change (e.g. Fig. 2b). It is therefore necessary to critically evaluate data from different models and methods and communicate information about data reliability; climate change projections must incorporate interpretation of the data that includes assessments of confidence in key results. Furthermore, as stated by Ekström et al. (2016) and discussed in Section 3, downscaled climate change information should be provided in the context of GCM-simulated changes and mechanisms responsible for differences in results must be understood.

Scientific and technical issues present only part of the challenge. Providing and communicating climate change information to different audiences, in diverse decision-making contexts, adds additional complexity. Users require different levels of detail, from generic and simple-to-use information for considering broad impacts, to high spatial and temporal resolution data for use in impact models. The CLIRAM approach was developed and trialled in two regions of the Philippines to support users interested in broad impacts (see Section 4). Used as a "tool for thinking", CLIRAM can simplify ensemble-based climate projections to help users consider a range of future scenarios and their implications. However, the pilot study exposed questions around the robustness of information used, and before being more widely applied in the Philippines or elsewhere, further refinements and improvements are required.

The situation is not unique to the Philippines and numerous tools have been developed by different institutions to help improve the communication, understanding and use of multiple climate projections. For example, the Climate Futures Tool (Whetton et al. 2012) has been applied in Australia, the Pacific Islands and Vietnam, as a decision-support tool to aid the use of regional climate projections for impact assessment and adaptation planning. The tool helps users navigate a wide range of information to better inform their impact and adaptation decisions.

Climate information providers, such as PAGASA, need to be able to communicate projections in different ways to different users and in doing so ensure that the underlying messages are consistent and robust. CLIRAM and Climate Futures represent two ways to address the challenge of communicating and using complicated and uncertain climate projections for different users, though rigorous testing of their use and application in different contexts is required. How to best address the needs of users who require more detailed information, such as crop modellers (see Section 5), remains a significant challenge.

Since users have different levels of scientific literacy and understanding of climate prediction, a particularly difficult obstacle to overcome is balancing scientific credibility with ease of use. This is demonstrated in the widespread uptake of the WorldClim dataset (Thomas et al. 2016; PhilGIS 2017; Salvacion 2017), which enables users to extract high spatial resolution data (up to 1 km) to explore local scale climate change. However, the "simple and quick" method[7] means data is not spatially coherent and lacks physical plausibility compared to data from dynamical methods.

A further complication arises from different generations of model information (e.g. CMIP3 compared to CMIP5). Newer does not imply better and there is an onus on information providers to defend choices made in including or excluding different generations of climate projections, particularly if this changes the range of uncertainty. Also, as discussed in Section 4, users may find the availability of different generations of model information confusing, especially where information is contradictory.

Finally, the IPCC assessment reports provide highly authoritative summary information on climate change. This includes analysis and presentation of ranges of climate outcomes which, given their reputation, are a natural starting point for deriving and communicating climate information at national, provincial and community levels. However, a global assessment cannot reflect the complexity of all situations in which climate information is required. Thus, techniques for summarising and communicating information, such as percentile information to communicate multi-model ranges, may not be relevant in these more demanding circumstances.

The climate modelling community is increasingly adopting coordinated approaches to the generation of climate model data, for example through the CMIP and CORDEX initiatives. At the global scale, the IPCC provides coordination for the synthesis and provision of climate change information, but given the challenges identified and discussed here, there would be value in developing such coordinated approaches within the climate services community at regional and national scales. These efforts should include comparison of different approaches to information synthesis and communication, the development of best practice methods and guidelines for practitioners, and training to support different users of climate change information.

7 Conclusions

The Philippines is benefitting from a growing number of domestic projects and international collaborations producing climate projections. Whilst these data provide an opportunity to better understand climate change in the Philippines, the simulations do not fully explore the range of plausible future climates and represent an ensemble of opportunity. The challenge for climate information providers is to communicate ensemble-based climate projections in a way that faithfully represents the strengths, limitations and uncertainties inherent in the models and

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[7] http://www.worldclim.org/downscaling

methods used to produce the information, whilst enabling decision-makers to understand and appropriately use the projections in real-world decisions. And this must be done in the context of constrained resources and no established best practices for synthesising such information. This situation is common to other countries with similar levels of resourcing for climate projections, and many of the issues discussed here will be applicable.

In addition to the issues raised in this paper, a number of related challenges need to be addressed in producing and communicating climate projections from different methods and models. These include the assessment and communication of natural climate variability in the context of projected changes, scientific challenges in weighting and/or selection of models at the experimental design stage, resource limitations for downstream impact assessments, improving communication platforms used to disseminate climate projections (see Hewitson et al. 2017), and deepening understanding of the limitations of some users for assessing multiple future scenarios. We encourage others to further address these issues and share their experiences.

The challenges presented cannot be met by providers and users of climate projections acting separately but require sustained engagement and exchanges of knowledge. There is a clear role for intermediaries (e.g. humanitarian agencies, faith-based organisations, local government environment officials, public extension services, science journalists) and the burgeoning climate services community in the Philippines, supported by the wider regional and international community (e.g. the Global Framework for Climate Services, Hewitt et al. 2012), to promote collaboration and develop methods of best practice. It is equally important that this community is well embedded within networks linking researchers, modellers, practitioners, policymakers and, ultimately, those affected by adaptation decisions. Clearly, there are gaps in these networks but evidence from the Philippines shows that through collaboration between researchers, information providers and intermediaries, as well as sustained engagement with different user groups, the challenges of assessing climate impacts, communicating coherent climate projections and using climate change information in decision-making can be met.

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