Developing climate change information for the Pacific

Guidance material to raise awareness and facilitate sectoral decision-making using science-based climate change information and services

Australian Aid
CSIRO
SPREP
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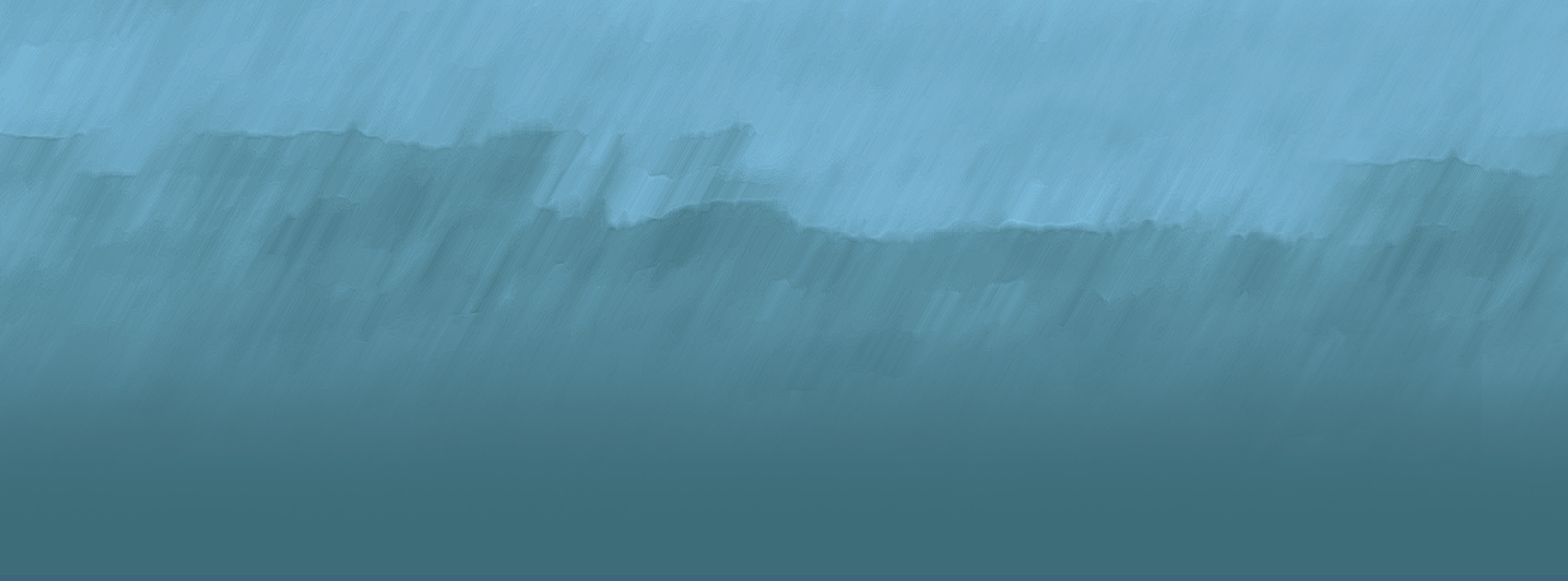

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PART 1

Introduction

Climate change in the Pacific

Small island developing states (SIDS) are among the most vulnerable to our changing climate. People living in the western tropical Pacific SIDS are already experiencing higher temperatures, shifts in rainfall patterns, rising sea levels and changes in the frequency and intensity of extreme climate events. Further changes on top of an existing, naturally variable climate are expected long into the future because of global warming.

These changes in the climate have far-reaching consequences that will affect communities and the built and natural environment. At a national level, sectors that will be impacted include health, infrastructure, water, energy, tourism, food (fisheries, agriculture), natural resources (forestry, biodiversity) and disaster risk management.

To deal with these changes, Pacific SIDS need credible, useful and accessible scientific information to inform decision-making at a sectoral level about what drives the climate in the Pacific, how it may change in the future and what the impact of these changes might be.

Climate change information for decision-making

Climate change means that the climate we have been used to in the past is not the climate that we will have in the future.

While we do not know exactly how the future will unfold in the decades out to 2100, we can draw on climate change science to tell us what the future climate might be like. In particular, we can use science-based climate change information to provide the evidence for developing 'climate smart' policies and plans for sectoral adaptation and disaster risk management. This could include:

- strategies for agricultural cropping and fisheries resource management
- building codes and engineering specifications for key infrastructure such as housing, public buildings and utilities, roads, drainage systems, bridges and ports
- planning and management of energy and water resources
- public health awareness and management campaigns.

Climate change information comes in many forms, from general, mostly qualitative overview statements through to quantitative datasets from observations and models, decision-support tools, training resources and communication or knowledge products. This information can be used for a range of purposes, from raising community awareness through to conducting detailed climate change risk assessments.

Climate change information and services

Sectoral stakeholders can only consider climate change information for risk assessments and associated decision-making if the relevant data and information are discoverable, accessible, useful and applied. The process for providing this information is referred to as climate change services.

Climate change services are relevant over multi-decadal timescales, and provide a mechanism to facilitate turning climate change data, information and knowledge into action. Climate change services:

- are based on past, present and future climate (including both mean condition and extremes), large-scale climate processes and natural variability, and related impacts on natural and human systems
- generate and provide climate projections data, information, decision-support tools and communication/awareness raising products
- inform decision-making for national governments, sectoral stakeholders and local communities in relation to climate change risk assessment and associated adaptation planning and disaster risk management.

In the Pacific, national meteorological and hydrological services (NMHSs) are one of the key providers of climate change services on behalf of local stakeholders at a national/sub-national level. Consistent with the World Meteorological Organization's Global Framework for Climate Services[1], the delivery of climate services relevant over multiple timeframes and sectoral interests including climate change is a stated priority of the Pacific Islands Meteorological Strategy 2017–2026[2].

About this publication

This publication has been prepared primarily to assist NMHSs and their sectoral stakeholders to jointly undertake national/sub-national climate change risk assessments. It broadly outlines steps for identifying, developing and applying climate change information as part of a staged risk assessment process, and provides advice and resources for undertaking each step.

These guidance materials build on existing climate change science knowledge and products developed by the Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) program and its predecessor, the Pacific Climate Change Science Program (PCCSP). The materials are, for the most part, non-technical, but some background knowledge about climate change science is assumed.

While an overview of climate variability, extremes and change is included in this publication, for more detailed information the reader is referred to the resources available at **www.pacificclimatechangescience.org**.

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[1] http://www.wmo.int/gfcs/

[2] http://sprep.org/factsheets/pacific-islands-meteorology-strategy-pims

PART 2

An introduction to risk assessment for decision-makers

Applying science-based climate change services at a sectoral level in the Pacific is typically undertaken to estimate the type and level of climate change risk that needs to be managed or otherwise mitigated. In turn, this risk is often estimated through evidence-based, sector-specific climate change hazard identification, vulnerability and impact assessment.

For such assessments, it is important for decision-makers to focus on the most important information needs and not get overwhelmed by technical detail. It is also important to systematically address the issues in order from high to low priority.

The nature of climate change risk

Risk is generally defined as a combination of the likelihood of an occurrence and the consequence (either positive or negative or both) of that occurrence. Often, the exact likelihood and consequences are not known, but risk management activities are put in place to reduce or mitigate the risk.

By way of example, studies show that young drivers have a high risk of being injured in a car crash. In practice, however, neither the likelihood nor consequences of this occurring are known with certainty – we cannot be sure which individuals will be injured, or the total number and nature of the injuries. Still, this risk is actively mitigated by safety campaigns encouraging young drivers to slow down when driving.

Similarly, there are uncertainties associated with climate change risk. Although we can be confident that the climate is changing, we do not know exactly how much greenhouse gas society will emit into the future, nor do we know the magnitude of the related changes in climate variables in some regions. The exact tipping point or threshold at which climate change could impact our area of interest is also unknown, as is how people will respond to future circumstances (measure of adaptive capacity) and what the effectiveness of these responses will be (measure of resilience).

Nonetheless, we may be able to estimate the consequences of particular events even though we are uncertain as to their likelihood, and thereby potentially mitigate impacts. For example, we know well the devastating consequences of prolonged drought on the livelihoods of farmers. Hence the consequences of an increase in drought frequency and intensity due to climate change can be estimated with confidence, even if the probability of such an event is itself very uncertain. Risk management responses can then be better tailored for specific circumstances, locations and communities of interest; thereby mitigating impacts in a more effective and efficient way to achieve preferred outcomes.

Assessing climate change risk

Approaches

There are several ways to approach climate change risk assessments:

- Impact assessment is used if the focus is on determining the effects of climate change on the subject of interest, typically at a sectoral level (e.g. impact of projected climate on land suitability for cultivating bananas)
- Vulnerability assessment is used if the analysis considers both the expected impacts and the capacity to prevent or adapt to these impacts (e.g. vulnerability of farmer community by considering impact of climate change on banana cultivation and the capacity of banana farmers to adapt)
- Risk assessment is used if the focus is on minimising the likelihood of consequences through a risk management perspective (e.g. risk of changes in area suitable for banana plantation caused by projected increase in air temperature).

These are all complementary assessments, and risk assessment is sometimes used interchangeably as a generic term for them all.

This document introduces the overall steps usually taken in climate change risk assessment and management incorporating science-based climate change information as evidence to inform decision-making. It is intended to provide an overview of the risk assessment process only, as context for developing climate change information to inform such a process, and stakeholders are advised to refer to more detailed guidance as appropriate for undertaking structured, multi-hazard, sector-based climate change risk assessments.

Factors to consider

The risks or impacts of climate change to a sector in a region do not only appear directly from changes in global, regional and local climate variables but from a chain of impacts (see Fig. 1). The changes in global climate cause changes in regional/local climate (first order impacts), which in turn may change the streamflow and groundwater of a region, depending on the characteristics of the river or aquifer and human activities such as land use (second order impacts), and so on. The higher the order of impact, the more factors (not just climate) influence the subject of interest.

Climate projections are necessary to assess first order impacts, such as changes to climate variables including temperature and rainfall. The type of climate projection information required could differ from one assessment to another. For example, the level of detail or complexity often increases with the order of assessment. As higher order impacts are assessed, non-climate factors must also be taken into account.

These resources contain examples of different climate change risk assessment approaches:

- IPCC. 2014. *Climate Change 2014: Impacts, Adaptation, and Vulnerability.* Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. VR Barros et al. (eds). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 688 pp.
- PROVIA. 2013. *PROVIA Guidance on Assessing Vulnerability, Impacts and Adaptation to Climate Change.* Consultation document, United Nations Environment Programme, Nairobi, Kenya, 198 pp.
- Carter TR and Mäkinen K. 2011. Approaches to climate change impact, adaptation and vulnerability assessment: towards a classification framework to serve decision-making. MEDIATION Technical Report No 2.1. Finnish Environment Institute (SYKE), Helsinki, Finland, 70 pp.

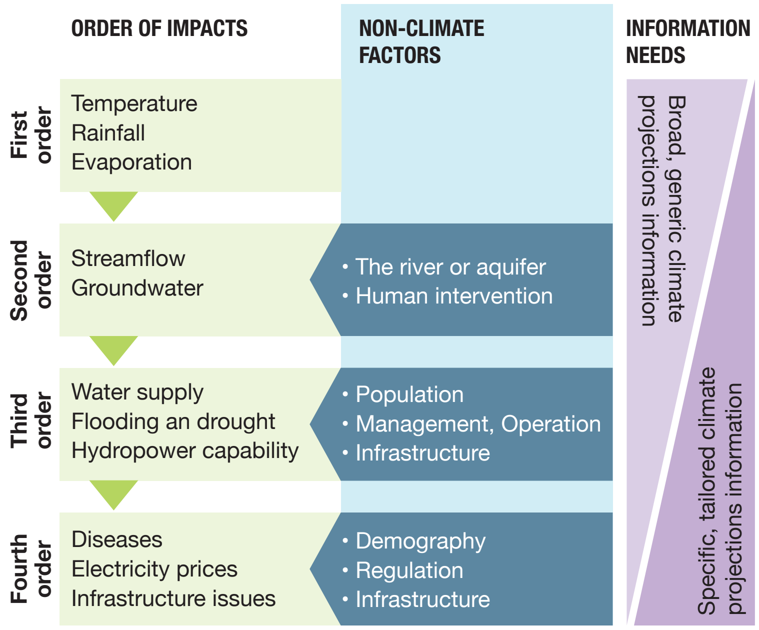


Figure 1. Climate change risk assessments must consider the chain of impacts. Higher up the chain, more non-climate factors become relevant. Climate change information needs also change.

Depth of assessment

Risk assessments can be conducted to varying depths – from preliminary rapid assessments through to detailed quantitative risk assessments, depending on the situation (Fig. 2). Not all problems need a detailed assessment to provide an answer. A rapid assessment is sometimes all that is necessary. If more information is required, the rapid assessment can be built on in stages to result in a more detailed assessment.

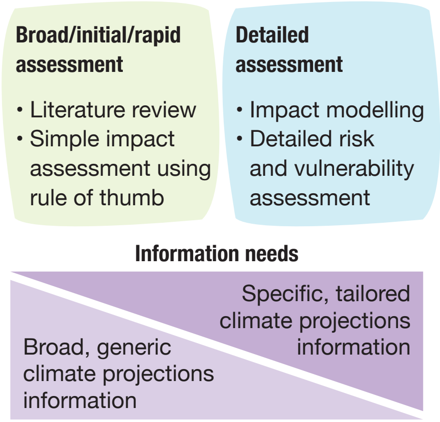


Figure 2. Risk assessments may be rapid or detailed. Information needs change depending on the assessment being conducted.

Rapid assessments

A rapid assessment, which may also be referred to as a broad, initial or preliminary assessment, is a useful way to conduct risk screening. It allows for quick identification of risks with relatively small resource and effort input. A rapid assessment is a suitable tool for decision-makers and planners to use when they are not sure how, or if, their decision or plan could be affected by climate change.

A rapid assessment uses existing climate change information, such as the information available at **www.pacificclimatechangescience.org**, to conduct an assessment that identifies and appraises key hazards, vulnerabilities and associated risks as early as possible. If necessary, the outputs of a rapid assessment can serve as the basis for a more detailed examination of risks, or to determine the most effective solutions. A desktop study, a workshop and/or focus group discussion are all ways this might be carried out.

Qualitative and generic quantitative (semi-detailed) assessments

Qualitative and generic quantitative risk assessments are useful when more detail is needed than in a rapid assessment, but a full, detailed assessment is unnecessary. They can be undertaken using a range of qualitative to simple/semi-quantitative techniques where suitable climate change data are readily available (e.g. **www.pacificclimatechangescience.org**) or easily developed (see steps 5 and 6 in Part 3 of this guideline).

For example, if the literature shows that rainfall elasticity of streamflow in a particular region is 1.5 (meaning that a 10% change in mean annual rainfall results in a 15% change in mean annual streamflow), then based on such a 'rule of thumb' and the available annual rainfall projection information for the region, the potential change in annual streamflow due to projected change in rainfall could be estimated. This semi-detailed approach was used in the sweet potato farming case study in Appendix 1.

Detailed assessments

A comprehensive, more detailed quantitative risk assessment can be complex. It usually requires more specific, tailored, climate change data (which may not be readily available), and/or additional expert technical advice to collate, prepare and interpret the data. This type of assessment may be used to address uncertainties in the likelihood of projected changes (i.e. understanding the climate change itself); further analyse the sensitivity of particular risks to changes in certain climate variables and non-climate variables; or assess various adaptation options.

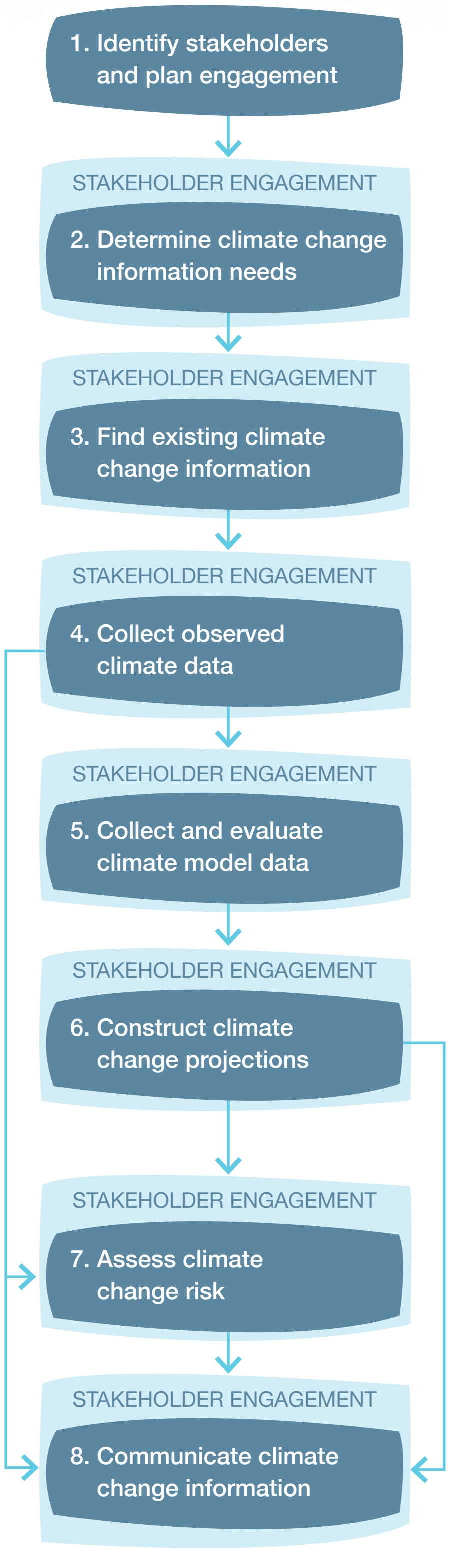
A detailed assessment can be undertaken using quantitative, multi-disciplinary science techniques (i.e. in addition to climate projections) including application of various coupled mathematical models, such as for (hydrological) water balance, crop simulation and bio-economics. In this context, climate change information usually has to be tailored for the particular impact model(s) used.

A useful way to think of a stage-based risk assessment is as a medical check-up at a doctor's surgery. A rapid assessment is like a visit to the General Practitioner (GP), while a detailed assessment is like a follow-up visit to a medical specialist if the GP has identified a potentially more serious health problem. Most times, it is only necessary to visit the GP to find the information we need to solve any health issues (and the GP is much cheaper and quicker than a specialist!).

PART 3

Step-by-step guide to developing and applying climate change information

There are eight key steps involved in the process of developing and applying climate change information for sectoral risk assessments in the Pacific. This diagram briefly describes each step and shows how they are connected. Each step is explained in detail in the following pages.



Identifying and engaging stakeholders is critical to the success of any risk assessment. The implementation of the stakeholder engagement plan is an important aspect of each of the subsequent steps in this process.

It is important to be clear about the purpose of the activity, as well as identifying important climate change systems and thresholds, variables and relevant time frames and steps.

Existing climate change knowledge is used to provide context for new analyses (go to step 4), to undertake risk assessments (go to step 7) and to form the basis of communication products (go to step 8).

Observed climate data puts climate projections (developed in step 6) into the context of what the climate has been like in the past and is like now.

Climate model outputs are used to generate climate change projections, but with many model outputs and datasets available, it is important to select the most appropriate for the assessment being undertaken.

Application-ready data from climate change projections are constructed by applying climate model projections to observed data, either as changes in average climate or as number of days over or under a threshold. Projections and associated application-ready data can be used in a risk assessment (go to step 7) or for communication purposes (go to step 8).

There are a number of approaches to undertaking a climate change risk assessment, but all involve identifying, analysing and evaluating the risk.

Effective communication of climate change information requires an understanding of the objective(s) of the risk assessment and the target audiences, so the information is conveyed in a way that is useful and relevant (and so more likely to be remembered and acted on).

1. Identify stakeholders and plan engagement

Stakeholder engagement is an essential and overarching activity for developing climate change information. Stakeholders should be engaged, consulted and participate actively in all steps of the process as appropriate. This is to ensure that the outputs are reliable and made relevant and accessible to all stakeholders.

Identify stakeholders

A stakeholder is anyone whose views need to be considered, who can contribute to the development of climate change information, and who needs to know or will use the developed information. In this context, stakeholders are also often referred to as providers, next or end-users of information.

Stakeholders can be individuals, groups or institutions. They may come from different backgrounds (e.g. science, government, communities or donor agencies), either from public or private enterprises, and typically represent a broad cross-section of interests from regional to national/sub-national and local community level.

A simple way to identify the stakeholders is to initially determine two key stakeholders, such as a representative from a NMHS (who provides the information) and a sectoral user of the information. These two key stakeholders can then facilitate broader engagement and thereby identify other stakeholders who are, in turn, asked the same question until no other individuals/institutions can be identified.

If possible, the roles and responsibilities of key stakeholders need to be defined. These roles and responsibilities may be organised according to their contribution to the proposed risk assessment (e.g. providing data for analysis, disseminating and/or applying results) or according to their influence or mandate in the relevant decision-making process (e.g. planners, policy makers, legislators, politicians).

Define why and how each stakeholder will be engaged

Defining stakeholder engagement objectives – that is, what participants hope to get out of the assessment and the relationship with other stakeholders – is important for determining the appropriate stakeholder engagement approach.

For example, the development of the information may be funded by a development partner such as an international donor who may wish to be directly involved in the assessment or otherwise requires regular progress updates. The objective is to keep such stakeholders adequately informed in a timely manner to meet their particular needs.

The primary stakeholder for sectoral risk assessments would typically be a national or provincial government sector, which has responsibility for developing strategies to enable effective and efficient adaptation to climate change or climate-related natural disasters. However, local community groups, such as farmers, fishers and church, school and women's groups, are also important stakeholders. Not only will they be affected by decisions that are made by sectoral policy-makers and planners based on the assessment, but they can also offer important local information about the risks being assessed. In this instance, there are two engagement objectives: to collect first-hand information including any traditional knowledge about the climate hazards and impacts being considered, and to share the outcomes of the assessment to raise awareness and ground-truth the results with those communities mostly directly affected by climate change.

Each of the identified stakeholders or group of stakeholders may require a specific engagement strategy and activities. These activities may include:

- newsletters
- emails
- meetings and workshops
- surveys or questionnaires
- interviews, videos, posters and reports.

For example, to keep donors informed of the progress of the work, periodic briefing emails can be sent with a short update, with a final detailed report prepared at the end of the work. In the case of local community stakeholders, regular on-site meetings (with a group or individually) may be an effective way to collect and share information.

Prepare a stakeholder engagement plan

The stakeholder engagement plan should outline engagement objectives for each key stakeholder (or group of stakeholders) and the activities and timeline for meeting each of the objectives. This plan will be a valuable tool for ensuring that all key stakeholders are appropriately engaged in most steps.

A stakeholder engagement plan does not have to be complex – a simple table that sets out the stakeholder details, engagement objective, activities, timing and person responsible is all that is needed to manage effective and efficient engagement. The example in Figure 3 is for a Pacific Islands cocoa farming sector risk assessment. Key stakeholder groups to consider for the first column include donors/funders, sectors (e.g. agriculture, water), NMHSs and community stakeholders (such as the cocoa farmers).

Implement the stakeholder engagement plan

Following this plan will ensure that the relevant stakeholders are involved in each step of developing climate change information, as appropriate. It is a good idea to print a copy of the plan and keep it in plain sight (e.g. on a pin board or wall) as a reminder of upcoming activities. The plan can also be revised along the way to accommodate new learnings through the subsequent steps.

Stakeholder	Engagement objectives	Activities	Timing	Person responsible
DONORS/FUNDERS				
[Donor 1] [Contact name] [Contact details]	To meet necessary administration requirements for funding	Telephone calls/email with donor contact person	As required	[Name]
[Donor 2] [Contact name] [Contact details]	To provide information on the progress of the project	Email project progress updates to donor contacts Provide a final report	Monthly At project conclusion	[Name]
COCOA FARMERS				
[Farmer 1] [Contact name] [Contact details] [Farmer 2] [Contact name] [Contact details]	To collect first-hand information/traditional knowledge about cocoa farming To understand which climate variables are most important/relevant to their farming and why	Farm visits to meet and talk to individual farmers	Twice during the assessment period	[Name]
	To share assessment outcome	Farm visits to meet and talk to individual farmers	At project conclusion	[Name]

Figure 3. Example of part of a stakeholder engagement plan for a cocoa farming sector risk assessment.

2. Determine climate change information needs

Determine why climate change information is needed

The type of climate change information required depends on the purpose of the activity being undertaken. The guidelines in this document focus on using climate change information to assess climate risk, but climate change information may also be needed to:

- raise awareness about climate change – in which case broad summary statements or figures about the climate and how it has already changed may be needed, along with some statements about changes that are projected for the future and the possible impacts of these changes.
- show the value of reducing emissions – where climate change projections and impact analyses under different emissions scenarios can be used to show the value of reducing global emissions as part of the ongoing international negotiations following the 2015 Paris Agreement.

When assessing climate risk to plan management or adaptation activities it is important to know key relationships and thresholds of climate variables that affect the things that stakeholders are most concerned about.

Define the subject of interest

To focus the development and application of climate change information, clearly define the subject of interest. Answering the following questions will assist in this activity.

- Who needs the information? Is it for a sector (e.g. health, agriculture, water, infrastructure, etc.) or targeted user group (e.g. national or provincial government, or local community group)?
- What boundaries must be considered? Is the information for administrative, legislative or compliance purposes (e.g. national, provincial), environmental (e.g. river basin, national park, marine protected area, etc.), or a planning system (e.g. allocations for an urban water supply system, renewable energy strategy for Nationally Determined Contributions, etc.)?
- What is the planning horizon for which the climate change information is needed? For example, to include climate risks into planning of a new road, bridge or drainage system, climate change projections and impacts on rainfall, river flow and sea level for the next 50 to 100 years may be required.

An important part of this activity is determining a climate change 'risk' question. This is equivalent to the 'hypothesis' in scientific research. A good question for this purpose is one that is specific and has a clear answer that can be backed up by scientific evidence.

Vague questions or questions without a specific answer are still useful, but only as a starting point. Examples of starting questions are:

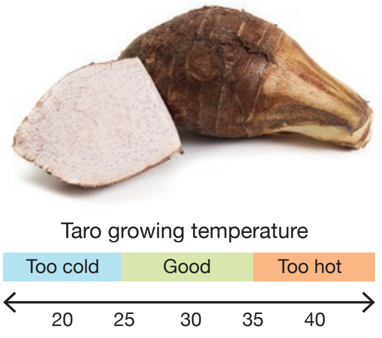
- How will climate change affect me?
- Will climate change affect my employment opportunities?
- How bad could climate change be, and could it be good?
- How can we be better prepared?

The answers to these questions are vague and subjective, and may even be more questions! Refining these questions so they are more specific leads to useful questions for a climate risk assessment that addresses climate change impacts. Examples of good questions include:

- Could my island become unsuitable for growing cocoa by 2030 or 2050 if the world follows a high ('business as usual') emissions scenario or if we don't otherwise meet the Paris Agreement targets?
- Is there a higher risk of bleaching to coral reefs from increasing sea surface temperatures and acidification under a high emissions scenario than a low one?
- Is it more likely that impacts from extreme rainfall and/or sea level on coastal communities and infrastructure will increase or decrease under different scenarios?
- How might climate change impact on large-scale natural processes such as the El Niño–Southern Oscillation and associated extreme climate events, and when will these impacts occur?

Climate threshold example

Taro growing is sensitive to air temperature.



Taro cultivation in the Pacific has a bio-physical relationship to air temperature. By better understanding this relationship, we could estimate that if the temperature is projected to become too hot (i.e. above 35 °C most of the time) for some areas, there could be a risk that taro cultivation may become uneconomic and therefore may need to relocate to areas that will become more suitable in future.

Figure 4. Temperature thresholds for growing taro

Determine how the subject of interest reacts to the climate

To identify climate change information that is needed for an assessment, it is necessary to understand the links between the climate and the subject of interest. Conduct a literature review and talk to stakeholders (including experts and traditional knowledge holders) to identify relevant climate variables and any important thresholds, triggers and/or critical ranges for these variables.

Identify the relevant climate variables

Climate variables are the particular factor in nature that we can quantify, measure or model. There are many climate variables, each with their own characteristics and uses. For looking at how the climate affects our lives, the most useful climate variables are those at the Earth's surface and in the ocean, including standard observations collected by NMHSs and international agencies in the Pacific such as:

- Air temperature (measured at a height of 1.5–2 m at weather stations) – this includes the warmer temperatures during daytime (daily maximum temperature) and the cooler temperature during the night (daily minimum temperature).
- Sea surface temperature – the temperature of the upper layer of the ocean where many plants, animals and coral reefs live.
- Precipitation – a measure of all forms of moisture falling to earth, including drizzle, rain, sleet, snow and hail. In the tropics, we often just refer to rainfall since other forms of precipitation are very rare.
- Wind speed and direction and associated frequency and intensity of tropical storms and cyclones.
- Humidity – both specific humidity (the amount of moisture in the air) and relative humidity (the amount of moisture compared to the maximum that air can hold).
- Sea level – a measure of natural tidal fluctuation.

Take care to identify all the relevant variables. For example, when looking at water balance consider run-off and evaporation where available as well as rainfall.

Identify the time frame of interest

The future time frame that is used should be relevant to an important decision that has to be made. For example, if a new bridge is intended to last to 2050, changes in the climate by 2050 will need to be considered as part of the engineering specifications. Even if most decisions are relevant over shorter time frames, a far future time frame may be relevant to a long-term strategy in the sector of interest. For example, most decisions by farmers about growing crops happen year to year, but it is useful to think about the long-term view about what agriculture may look like for the next generation, such as where and what types of crops will be grown if indeed this may be different from the present in order to respond to an expected change in key agro-met variables such as temperature and rainfall.

Understand your choices: time frame

Choice	Useful for	Watch out for
2030	Many planning decisions	Climate variability often larger than climate change signal. Emissions scenarios similar.
2050	Some strategic decisions	Scenarios separating – low emissions see less impacts than high emissions
2070	Some strategic decisions	Scenarios separated, must choose scenarios
2090	Long-term strategy or projects, such as major infrastructure or sector planning. Climate change signal can be strong compared to natural variability.	Large difference between scenarios. Make sure this timeframe is relevant or useful to your question

Make sure the time frame is relevant to your question. For example, to illustrate potential impacts to coral reefs in the next 10 years, climate change by 2090 is not appropriate. Instead, you should use projections to 2030, but also consider natural climate variability over this time period).

Do not underestimate the influence of climate variability in the near-term climate. Natural decade-to-decade variability can 'mask' the climate change 'signal' at timeframes of 10–20 years, so you should carefully examine climate change projections and climate variability when considering this time horizon.

Identify an appropriate time step

The time step is the length of time between values of the climate variable. The main time steps in climate datasets are sub-daily (such as hourly or 3-hourly), daily, monthly, seasonal and multi-decadal.

A climate change climatology is the average over a long period such as 30 years or more. Longer time steps or climatologies can be the average value, or other statistics of the climate including for extreme events – for example, for temperature the climatology may be of the average temperature, or the average of the daily maximum temperature, the average daily maximum temperature in July, or even the average of the annual maximum temperature (hottest day of the year) and frequency of drought.

The choice of time step is an important decision when looking at climate analysis. There are two aspects of this decision:

1. What time step is most appropriate for your analysis? Sub-daily or daily data are useful for looking at short-lived extremes, and are needed for some applied models. Monthly, seasonal and annual data are useful for analysis of variability and change, and are used in some applied models. High-resolution climatology data are used for looking at spatial time slices of climate conditions (e.g. agriculture zones, species distribution modelling, zoning regulations).
2. What is available and is it able to be used? Sometimes climate change information or assessment requirements have to be altered depending on what data are available and what you can use. It is necessary to read the relevant data guides and websites on what data are available, how reliable they are, and whether there are any gaps. Daily and hourly datasets can be very large and may require specialised computer skills.

Understand your choices: time steps

Choice	Useful for	Watch out for
Sub-daily or daily	Extreme events, certain models such as hydrological or agriculture simulators	Check data availability and quality, datasets can be very big
Monthly, seasonal and annual	Variability and change over decades, some applied models	
Climatology (long-term statistics)	Species distribution models, agriculture and other zones	Does not account for change in variability and extremes

⚠

Using monthly or annual data doesn't account for the effect of daily extremes, which might be important in terms of impacts.

Decide how the information will be found, developed and/or applied

Is the climate change information that is required for the assessment already available, or is a new analysis necessary? All key stakeholders should be involved in this decision.

In many cases, existing information can be used for an assessment (see step 3).

If new analysis is required, then it may be necessary to draw on available datasets to develop new climate change information to apply in the risk assessment. Always use the simplest analysis that will do what is needed, and only use complex methods that need complex datasets and analysis if required.

Simple analyses to generate preliminary, application-ready climate change data include applying a change factor to existing observed datasets using the range of projected change in key variables as summarised in the PACCSAP report[3] (steps 3, 4 and 5 provide additional guidance.) More complex methods often require assistance of technical experts such as climate and crop modellers, hydrological modellers or coastal hazard analysts and data which are often not readily available. (This is further discussed in step 6.)

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[3] PACCSAP. 2014. *Climate variability, extremes and change in the western tropical Pacific: new science and updated country reports*. Available at **www.pacificclimatechangescience.org**

3. Finding existing climate change information

Search for relevant studies that have already been carried out

A review and understanding of existing information is essential, even if a new analysis is being undertaken. A summary of previous climate change and other relevant studies provides context for any new work.

Accessing previous relevant studies will likely require some searching at the library or on the internet, as well as making enquiries with relevant stakeholders (including regional organisations and technical experts). There may also be relevant studies that have been carried out on the same subject but in other countries or on a slightly different but otherwise still relevant subject in the country of interest.

Revise background information about climate change

If you are not clear on any climate change concepts or processes it is important to revise background information about climate change to ensure you understand the results of the relevant studies you have identified. Relevant background includes the physical drivers of climate variability, extremes and change and the local climatology including past climate and current observations and trends. A more general understanding of global emissions scenarios, climate models and issues around confidence and uncertainty in model projections is also helpful (See Part 5 of these guidelines for explanations of important concepts and processes.)

Collect traditional knowledge on the topic

Local communities in the Pacific have considerable knowledge on weather and climate systems relevant to their immediate location based on traditional understanding of how the physical and biological environment interact. Traditional knowledge of this type is critically important to better understanding the physical scientific knowledge underpinning climate change in the Pacific. The practical integration of the two approaches as part of an integrated assessment is often the best way to raise awareness and communicate key climate change information at the local community level.

Summarise and synthesise information

Sort and categorise the information from all sources. Information that is less relevant can be identified and put aside. Focus can then be turned to the relevant information that has been found.

There are many ways to do this, depending on individual preference. One way is to prepare a simple review table (see Fig. 5). The first column lists topics of interest, and subsequent columns list information by source (see example). As information is collected from each source, notes can be recorded in the appropriate cell.

Carefully record source details. At a minimum, this should include the author’s name, title of the source, year published and URL address for written sources, and the name of the expert if it was a personal communication. Where information is collected at a meeting or workshop, it can be useful for future reference to record the date and location of the meeting.

Topic	[Source #1]	[Source #2]	[Source #X]
Temperature projection	For 2050 and beyond, projections vary within the range of 0.50-1.20C, depending on the emission scenario. The region will also see more hot days and warm nights. Has a simple map showing projected mean temperature for 2050. Projection is based on CMIP5 GCMs forced by RCP2.6 and RCP8.5	-	-
Climate change impacts	-	A warming temperature will enable crops to be cultivated in locations currently unsuitable, for example, banana cultivation in areas of higher altitude. Climate can affect crop quality. Higher temperature can reduce vitamin content in fruit and vegetable crops	The productivity of agricultural pest and diseases is influenced by temperature and rainfall. Increasing temperatures could see decline in the importance of some viruses in the tropics.

Figure 5. Example of a review table used to summarise existing climate change information.

Watch out for misleading information – use only trusted websites, books and papers. Check the validity of sources that are unfamiliar. Try to be as comprehensive as possible – use more than one or two sources.

Where possible, always use existing information rather than do new work. If new work does have to be undertaken to generate the required information, use the simplest and most robust method available, based on expert technical advice and guidance material from reputable sources.

Useful resources for finding climate change information include:

- PACCSAP publications, available at **www.pacificclimatechangescience.org**
- The Pacific Climate Change Portal at **www.pacificclimatechange.net**
- The Pacific Meteorological Desk Partnership at **www.pacificmet.net**
- SPC publications, available at **www.spc.int/resource-centre/**
- Traditional knowledge collected through the Climate and Oceans Support Program in the Pacific (COSPPac) at **http://cosppac.bom.gov.au/traditional-knowledge**

If this climate change information is being used as context for a new analysis, go to **Step 4: Collect observed climate data**

If this climate change information is being used for risk assessment, go to **Step 7: Assess climate change risk**

If this climate change information is being used for awareness raising or another purpose, go to **Step 8: Communicate climate change information**

4. Collect observed climate data

Climate projections tell us about how the climate may change under future emissions scenarios, but this needs to be put in context of what the climate is like now and in the past. For this, we need historical observed climate data. When projections are applied to observed data, 'application-ready' projections data can be generated. This is very helpful to inform sectoral climate risk assessments, climate sensitivity screening and related 'climate-smart' decisions for more effective and efficient adaptation and disaster risk management planning.

Determine what type of observed data is needed

There are three main categories of observed data:

1. Raw measurements from places such as weather stations managed by NMHSs
2. Quality-controlled (error-checked) measurements such as those available at the Pacific Climate Change Data portal (**www.bom.gov.au/climate/pccsp/**). These are generally more useful for climate studies than raw measurements.
3. Processed climate datasets which use the observations, plus other input such as satellite data or modelling to produce gridded climate datasets (also called reanalysis datasets).

These datasets can be very useful, but it is important to understand what each one offers. For example:

- Spatial coverage – some are global; some just cover the tropics or a particular region.
- Spatial resolution – some are for point locations; others are on a grid. For gridded data, ensure that you understand the size of the grid cells, and how the dataset fills the gaps between measurements to create the grid.
- Time frame – some go a long way back in time, while others only contain more recent data.
- Time step – different datasets may contain data at different time steps, such as annual, seasonal, monthly, daily or sub-daily.
- Variables – these differ between datasets.

Understand your choices: observed data

Choice	Useful for	Watch out for
Raw measurements	Looking at past weather events	Limited availability; not quality controlled; can have gaps
Error-checked measurements	Local analysis of weather and climate including extremes and trends; producing 'application-ready' datasets for a location	Can have gaps; not available for every station; Read the manual and the metadata to understand how data is generated
Processed climate datasets	Spatial analysis (e.g. looking at map plots); Local and regional analysis, if local data unavailable.	Accuracy can be low if based on limited data inputs and fill large gaps; may be coarse spatial resolution; Read the manual and the metadata to understand how data is generated, what is the assumption and caveat

Find an appropriate dataset

Raw station datasets usually can be found through the relevant NMHS, but access requires formal approval by the NMHS Director or delegate (see also **www.pacificmet.net/national-met-services** for relevant details).

For processed climate datasets, the National Centre of Atmospheric Research (NCAR) in the United States has compiled a useful guide at **https://climatedataguide.ucar.edu/climate-data**. Some of the major processed datasets include:

- The Hadley Centre Sea Ice Sea Surface Temperature dataset (HadISST)
- Various gridded air temperature datasets to look at long-term temperature change (GISTEMP, HadCRUT4, MLOST, Berkeley)
- Tropical Rainfall Measuring Mission (TRMM) of high-resolution rainfall data.

High-resolution climate surfaces of the average climate in recent years (e.g. WorldClim) are also useful for looking at questions that require highly localised climate information (such as the difference between one side of an island to the other, or temperature over mountain ranges), but it is important to understand the features and limitations of producing these fine scale surfaces using statistical techniques.

Access the dataset

Once all the available datasets have been reviewed, the features of each one have been understood and there is a clear plan, then the data can be accessed. This is not always simply a matter of downloading all the data to a desktop computer. Issues to manage include:

- Size: Datasets can be very large, so either need a lot of disk space to download, or just the part of the dataset that is needed can be accessed or downloaded (e.g. just the area, time period or time step that is needed). Datasets can be kept on large central computers rather than desktop computers.
- Updates: Datasets are often updated with new data and there are also different versions of datasets released – a plan for updating your dataset with the latest data and latest version is needed.

Some datasets are very large, so may need a lot of internet bandwidth for downloading and/or computer disk space for storage.

Process the dataset

Once access has been established, the dataset needs to be checked and set up ready to use. Checks include the area or location, coverage, time period, variables, time steps and the presence of gaps or errors.

Data come in various computer formats, each requiring certain software and skills. Time series from a particular site (e.g. from the Pacific Climate Data for the Environment/CliDE data management system operated by NMHSs) can be downloaded and plotted in software such as Excel, but others such as gridded datasets, need specialised software and skills. Specialised skills are also required to examine and analyse the data.

It is good practice to have quality control checks on the analysis at all steps, thereby ensuring that the data is suitable for what is necessary, doesn't have errors in it and is updated regularly. This may require assistance from experienced data managers. Assistance to analyse the data, and to check the analysis, may also be needed.

Some datasets are specialised, so need high-level computer skills to use them.

Determine the quality and uncertainty of the data behind the dataset

As well as quality controlling data, it is important to understand how the datasets were generated and what this means for how they are used. Considerations include:

- The inputs – what data went into it and the quality of those data (e.g. a gridded temperature surface may only use a few station records for a whole island)
- How gaps are filled – gaps in time or space can be filled using various statistical methods. These methods may involve the use of simultaneous values at nearby stations to calculate an estimated value for that missing data time. For some variables, gaps in the data might be filled based on other variables, for instance, humidity can be calculated from the minimum temperature and solar radiation can be calculated from extraterrestrial radiation which is a function of geographic location and the Julian day[4]. The users need to be aware of the pros and cons of the method being used and understand all related caveats.

Datasets with few inputs, poor quality inputs or large gaps to fill should be treated as having lower confidence, and this should be noted.

Use the simplest dataset available that covers the required range of relevant climate variables.

Useful resources for collecting observed climate data include:

- Your national met service
- CliDE: **http://www.pacificclimatechangescience.org/climate-tools/clide-climate-data-for-the-environment/**
- Pacific Climate Change Data Portal: **www.bom.gov.au/climate/pccsp/**
- The NCAR/UCAR data guide: **https://climatedataguide.ucar.edu/climate-data**
- WorldClim: **http://worldclim.org/version2**

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[4] For examples see **http://www.fao.org/docrep/X0490E/x0490e07.htm#estimating%20missing%20climatic%20data**

5. Collect and evaluate climate model data

Climate projections data are usually generated from climate model outputs. With so many climate model outputs and datasets available, it is not possible to look at all the raw model data that are available. It is essential to identify your requirements so you can collect appropriate climate projections data about the future climate.

The closer the model simulation is to the observed climate, the closer the modelled climate change response of the simulation will be to the real-world response, and the higher the confidence rating in your projections.

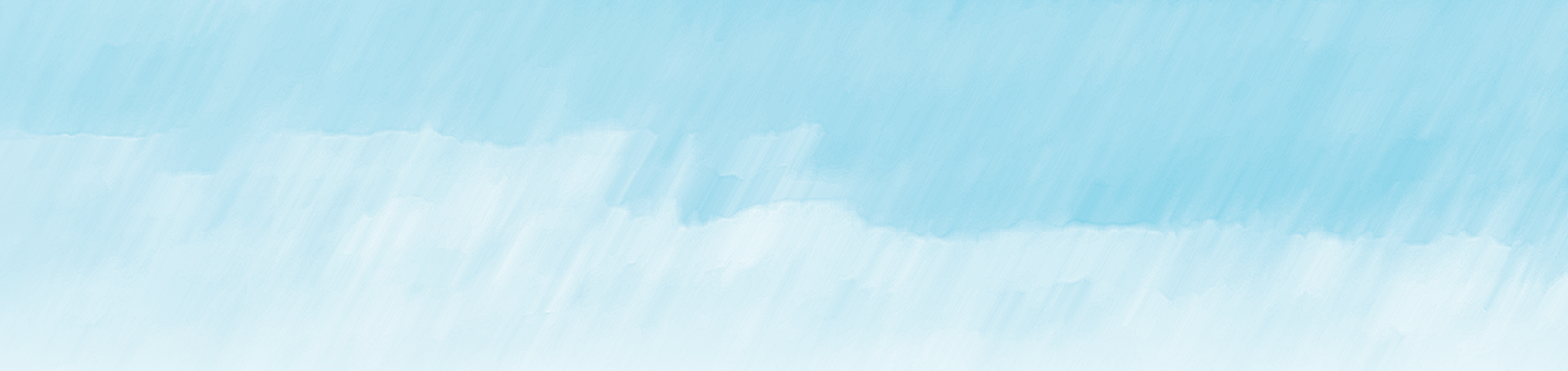
The PACCSAP management tool, Pacific Climate Futures (www.pacificclimatefutures.net), is a valuable online resource for accessing and evaluating regional climate projections for the western tropical Pacific. The activities outlined in this step are for the most part based on use (access and application) of this tool.

Pacific Climate Futures

Pacific Climate Futures is an online tool that aids the selection of climate projections for impact assessments and adaptation planning. It allows for consideration of projections for two climate variables at the same time (e.g. temperature and rainfall) and displays the results by model consensus.

The tool provides varying levels of access (basic to advanced) to projections data and enables users to develop a range of plausible 'climate futures' for a particular country, along with an ability to evaluate the individual model outputs to determine which one most appropriate for the intended application. Online training resources are also provided for basic and intermediary users, but for advanced applications users require face-to-face training. More information is available on the Pacific Climate Futures website at **www.pacificclimatefutures.net**.

		Annual Surface Temperature (ºC)			
Annual Rainfall (%)		Slightly warmer < +0.5	Warmer +0.5 to +1.5	Hotter +1.5 to +3.0	Much hotter > +3.0
	Much wetter > +15.0				
	Wetter +5.0 to +15.0		2 of 30 GCMs +	9 of 30 GCMs 1 of 6 DS +	2 of 30 GCMs +
	Little change -5.0 to +5.0			12 of 30 GCMs 4 of 6 DC +	3 of 30 GCMs
	Drier -15.0 to -5.0			2 of 30 GCMs +	
	Much drier < -15.0				



Identify the baseline period

Climate projections describe ranges of possible change into the future relative to a 'baseline' period in the past. The climate has changed in the past, so the choice of baseline is important.

Some information is given relative to the 'pre-industrial era', which means before industry ramped up in the 1800s. For example, the global average temperature is around 1 °C warmer than pre-industrial times. However, most climate projections are given relative to a recent baseline (a 20- or 30-year period in the recent past), so that we can understand the future relative to what we have recently experienced. For example, PACCSAP[5] refers to 1986–2005 as the baseline period. This baseline is also used by the Intergovernmental Panel on Climate Change (IPCC) for its assessment reports[6].

Identify the scenarios of interest

We can't predict how greenhouse gas and aerosol emissions will continue in the future, or what their atmospheric concentrations will be. However, this is important information for generating climate projections. To overcome this problem, a set of scenarios have been developed that describe conditions for a range of emissions and concentrations. These scenarios are called representative concentration pathways (RCPs). There are four RCPS: RCP2.6 (lowest), RCP4.5, RCP6 and RCP8.5 (highest). Because of natural variability in the climate, the results from the different scenarios are quite similar to 2030. However, after this time, the higher the emissions, the more climate change you see by 2100. To show the 'worst case' you might only consider the highest scenario, while a 'best case' would consider one of the lower scenarios.

⚠

Be careful with the choice of emissions scenarios (that is, not using enough or using the wrong one for the analysis). Using inputs that are too specific could mean that not all future climate possibilities are taken into consideration for planning, which could result in inappropriate or 'mal-adaptive' responses. For example, considering only a best-case (low emissions) scenario for temperature change may be overly optimistic and thereby under estimate the associated risks of increasing incidence of temperature extremes with consequent impacts on human health, water and food security. Similarly, considering only a worst-case (high emissions) scenario for rainfall may result in the commitment of valuable but otherwise limited resources to unnecessary adaptation activities, such as building reservoirs or desalination plants to accommodate a change in water supply that does not eventuate. Including the best and worst cases provides a range of possible climate futures.

Understand your choices: emissions scenarios

Choice	Useful for	Watch out for
High scenario only	Illustrating strong climate change for taking a precautionary approach	Doesn't illustrate outcome if emissions are lower
Low scenario only	Illustrating 'best case'	Not precautionary, doesn't show strong case
Low and high scenarios	Illustrating a larger range of possibilities, and effect of reducing emissions	Can be more difficult to communicate and discuss than a single scenario

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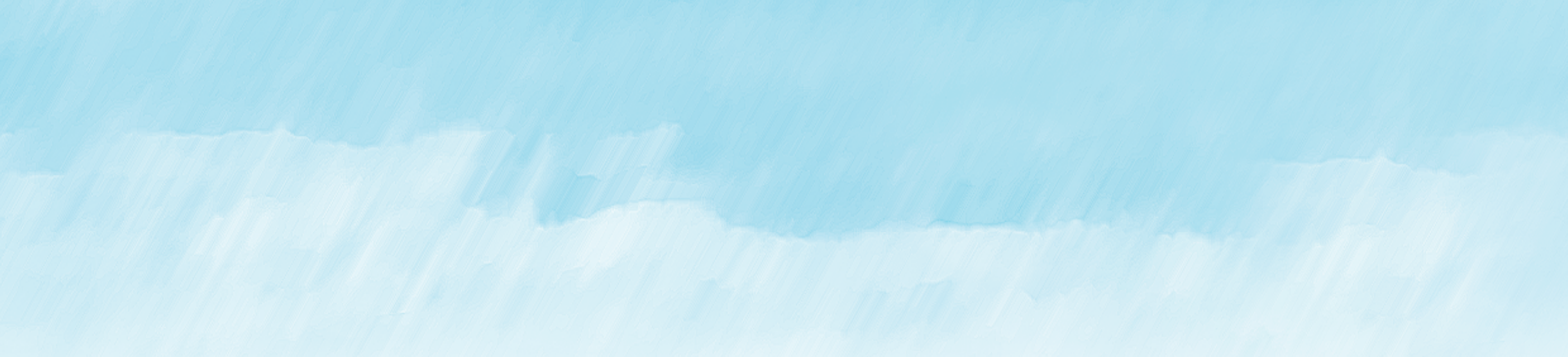
[5] PACCSAP. 2014. *Climate variability, extremes and change in the western tropical Pacific: new science and updated country reports*. Available at **www.pacificclimatechangescience.org**

[6] The IPCC assessment reports are available at **www.ipcc.ch**.



Decide which climate models to use

All climate models simulate the climate a little differently due to how they are set up and how they work. For this reason, it is important to never just look at one model. It is generally a good idea to reject models if they are completely unsuitable (perhaps due to inherent bias or other design limitations in the model), but then compare all the rest of the acceptable models to make projections (e.g. PACCSAP[7] looked at 27 CMIP5 models and rejected three as unsuitable but then used the rest). Projections from technical forms of downscaling (statistical or dynamical models) may also be available.

If a change in the average for just one variable over the nation is needed, use model ranges from reports. If using daily or monthly data and more than one variable, choose a set of representative models using the Pacific Climate Futures tool.

Create the application-ready dataset

Global climate models have coarse spatial resolution (typically 100–250 km grid box), and contain biases or offsets compared to observations, so their outputs don't look exactly like observations. Model outputs generally can't be used directly – additional steps must be taken to make a future dataset that is locally relevant and has no biases. The simplest way to do this is by scaling observations. Various technical downscaling methods exist that can also achieve these goals, as well as potentially showing more information about regional climate change (see facing page).

Scaling observations is also known as the 'delta', 'perturbation' or 'change factor' method. Scaling involves applying the projected climate change to the observations to make a hypothetical dataset of the future conditions. The observations can be scaled up or down by the projected average change, called mean scaling. Observations can be scaled using a different scaling for different values (with scaling factors calculated from model outputs), which is an example of complex scaling. Other complex scaling methods exist, including 'weather generators'.

Mean scaling is the simplest method. To do this:

1. Take a suitable observed dataset.
2. Collate a range of suitable change factors from climate projections.
3. Apply the change factor to the observed dataset to make the future dataset. The change factor is applied using an addition for variables such as temperature, or as a multiplication for variables such as rainfall.

Scaling observations using global climate model projections is the default option for producing locally-relevant, application-ready datasets. It is important to collect a representative set of scaling factors to cover the changes of interest (showing the range from sets of relevant models for each emission scenario). If complex or technical downscaling has been done for the area in question, and the downscaled outputs are available to be used, these outputs can be used instead or as well (see box).

Understand your choices: climate models

Choice	Useful for	Watch out for
Multi-model mean of global climate models (GCMs)	Showing 'best estimate' of climate change for a particular scenario	Doesn't show range of possibilities. Model mean averages out variability
One GCM	Showing variability and change	Not representative of full range
Each of a representative set of GCMs	Showing range of from all models, shows variability and change	Make sure models are representative to your analysis
One source of downscaling	Showing useful regional patterns	May not use all relevant inputs
Selection of GCMs and downscaling	Showing range of change from various sources	May not be available, or might be hard to get hold of

⚠

Do not just look at one climate model output – models give different estimates of change, and just looking at one model won't give the range indicated by the climate models. Instead, use a representative set.

CMIP

CMIP is the World Climate Research Programme's Climate Model Intercomparison Project. The project makes simulations from climate models around the world publicly available in a standardised format. These simulations are used by researchers around the world. Simulations from CMIP5, the fifth phase of this project, underpinned the Intergovernmental Panel on Climate Change's fifth assessment report.

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[7] PACCSAP. 2014. *Climate variability, extremes and change in the western tropical Pacific: new science and updated country reports*. Available at **www.pacificclimatechangescience.org**

Downscaling

Modelling the climate at a higher spatial resolution can potentially reveal new information about climate change at regional, national and in some cases sub-national level. Global climate models don't simulate the local extreme events or the effect of mountain ranges, coastlines or fine-scale weather phenomena which effect local climate, and these may affect how climate change may specifically affect sectors and local communities. Technical downscaling may offer insights about this, and can also be used to produce locally-relevant, application-ready datasets. Downscaling uses either a high-resolution climate model (in the case of dynamical downscaling) or a statistical model (in the case of statistical downscaling) to transform global climate model simulations into finer resolution climate simulations.

Downscaling potentially:

- makes the outputs look like observations – finer-scale spatial resolution in maps, more realistic detail of variability through time including extreme events
- reveals extra detail in climate change – either details in space (e.g. between one region and another) or in terms of local extreme events
- reveals a more reliable climate change projection by correcting some errors in the direct GCM input.

Downscaling requires special technical skills, but downscaling in your area done by others may be available for you to use. You can see the statistical and dynamical downscaling done for the Pacific in Volume 1, Chapter 7 of the PCCSP technical reports and also from the 2014 PACCSAP Technical Report[8].

Newer downscaling may be available soon under the CORDEX project (**http://www.cordex.org/**).

The downscaling may not use a representative set of GCMs as input, so the downscaling datasets may not provide a sample of the uncertainties provided by the GCM ensemble.

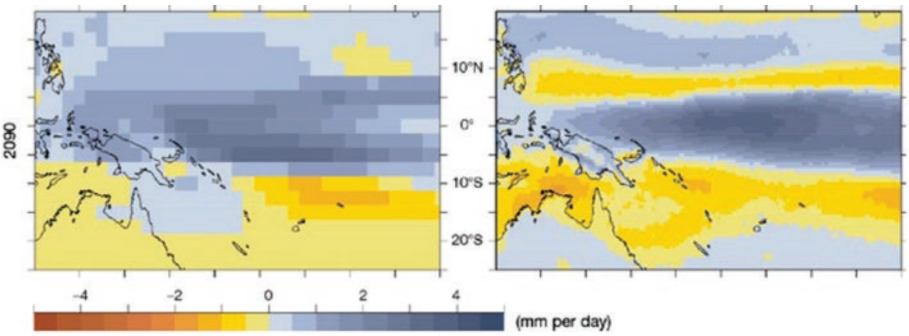
Downscaling may not produce regional detail, or the detail may not be reliable. Check if the advantage of the downscaling is explained in a report or paper.

The error corrections may not be effective and may introduce some technical complications, such as understanding the effect of the correction has on the dynamical balance of the model.

Should I use data from global climate models, regional climate models or both?

If downscaling data is available, then it can be used instead or as well as global climate model projections. If not, then scaling of observations should be the default method. The decision to use data from global climate models, regional climate models or both will depend largely on what is available and the purpose of the risk assessment. If presented with the option of using either or both, the following points should be considered:

- If there is a good case put forward in reliable scientific literature that one source of information is more reliable and the other is unreliable, it is best to use the reliable one.
- If the available downscaling dataset is not done for a representative set of GCMs, or if it has big differences to the GCMs that aren't explained, then it is not wise to use the downscaling only.
- If the downscaling is not available for the time period or the emissions scenario you want, then use the GCMs.
- If it is not clear which is more reliable, use the Climate Futures approach to choose a set of results drawing on both GCMs and downscaling.



This figure is taken from the PCCSP report. It shows projected change in November–April rainfall in the Pacific by 2090 under a high emissions scenario. The left panel shows the average of global climate models, while the right panel shows the average of six simulations using the regional dynamical downscaling climate model CCAM.

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[8] These reports are available at **www.pacificclimatechangescience.org**

Evaluate the model data

Model data evaluation may simply be a case of comparing the modelled climate against the observed climate. You might include the long-term average, standard deviation (which represents year-to-year variability) or annual or seasonal cycle of the relevant climate variables (e.g. temperature and rainfall).

When resources permit, it is also useful to assess how the model represents the observed characteristics of large-scale climate features such the El Niño–Southern Oscillation or the major rainfall bands called the Inter-Tropical Convergence Zone (ITCZ) and the South Pacific Convergence Zone (SPCZ), or how the model reproduces the observed relationship between climate variables (e.g. rainfall) and large-scale climate features (e.g. ITCZ or SPCZ).

Use the simplest dataset available that covers the required range of relevant climate variables and projections.

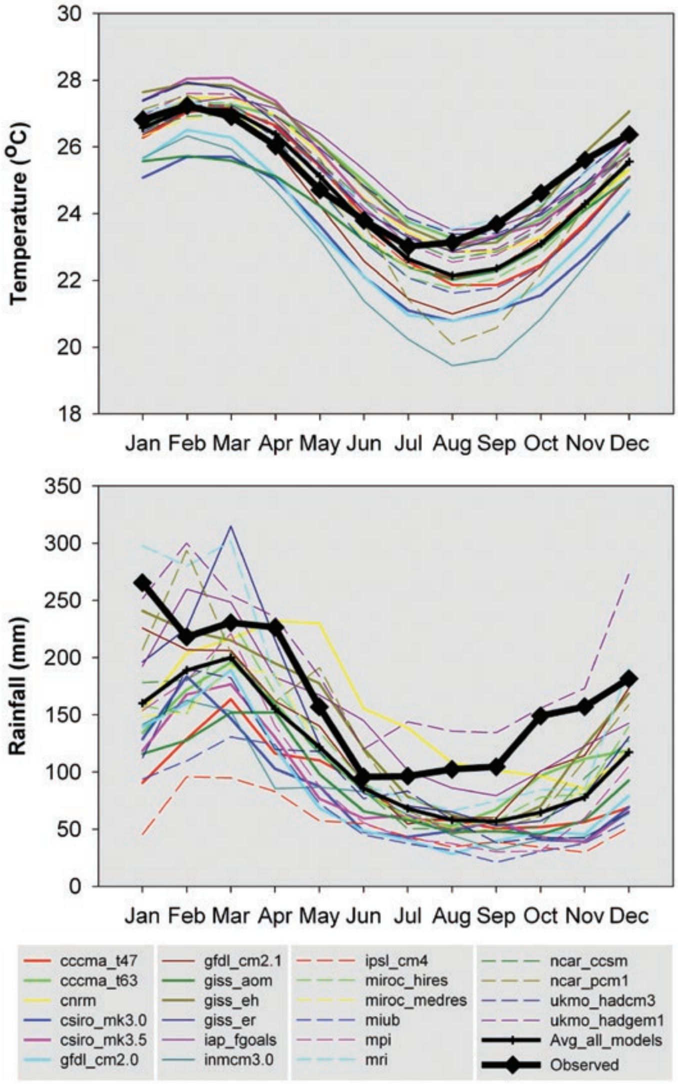

Figure 6. Comparison of observed and modelled climatologies during 1975–2004 for temperature and rainfall for Niue[9].

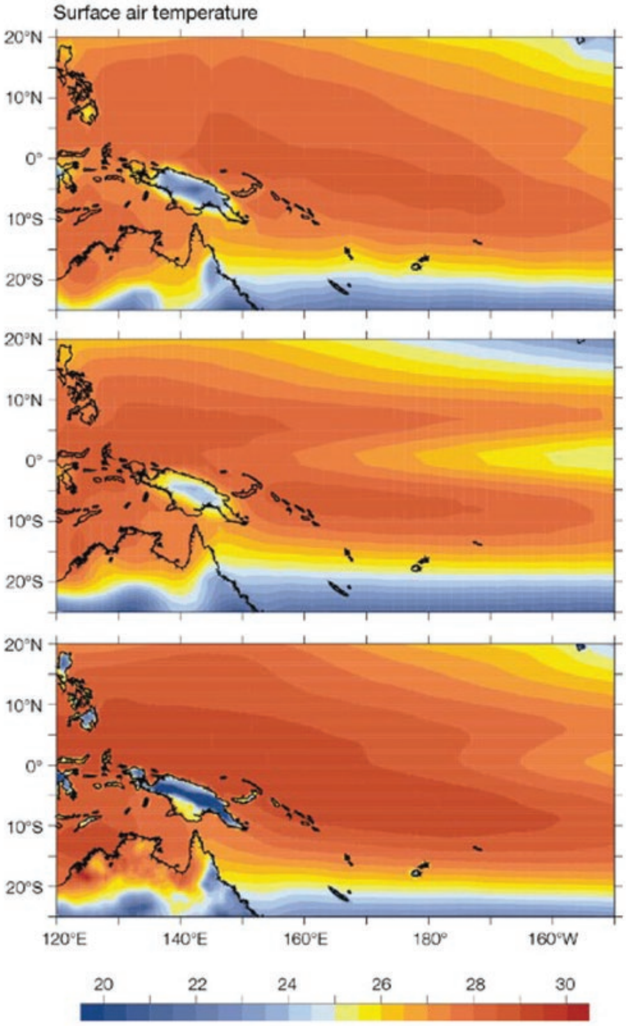

Figure 7. Comparison of annual mean air temperature for 1980–1999 observed dataset (ERA-40 reanalysis) (top), for the global climate model multi-model mean (middle) and CCAM dynamical 60 km downscaling six-model mean (bottom)[10].

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[9] Source: Kirono DGC, Jones RN and Bathols JM. 2008. Climate Change in Niue, A report prepared for the Government of Niue, CSIRO.

[10] Source: Australian Bureau of Meteorology and CSIRO, 2011. Climate change in the Pacific: Scientific assessment and new research. Volume 1: Regional Overview. Volume 2: Country Reports. Available at **www.pacificclimatechangescience.org**.

6. Construct climate change projections

Climate change projections are a useful way to present climate change information. They show how the future climate might look relative to an observed baseline historical climate depending on different greenhouse gas and aerosol emissions scenarios. (See Part 4 of this document for more background information about climate change projections.)

Projections can be constructed by combining observed data and climate model data to generate application-ready data (see also step 5). The simple scaling of observations by changes from global climate model projections is an easy way to produce a projections dataset, and downscaling may also be used if it is available (see step 5).

It is important to remember that projections are not forecasts or predictions. A forecast or prediction aims to tell you exactly what the future will bring and when, while the purpose of projections is to provide a credible range of possibilities for the future.

Figure 8 shows a hypothetical example of what projections look like, and what a prediction might look like for the same case. The projected range of change is the blue window, the range of projected change and the natural variability is dashed blue lines – the future values of the climate variable are likely to be in this window, but we don't know what they will be year-to-year. If we could make a reliable prediction of the climate years into the future, it may look something like the red line – tracking the past observations and then producing a sequence of events into the future.

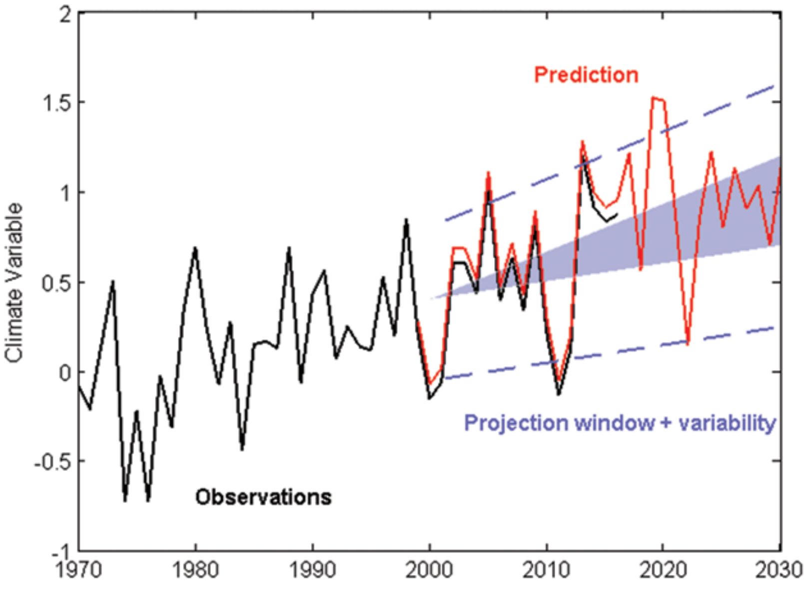

Figure 8. Hypothetical example of observations, projections and predictions for a given time period. Observed data are in black, prediction is in red, and projections are shown by the blue window. Dashed blue line shows natural variability.

Without climate change projections, we would have to plan for almost every climate possibility for the future. Imagine if you had to plan for all the temperature possibilities from 10 °C cooler to 10 °C hotter than today, or where sea levels might be anywhere from 100 cm lower to 200 cm higher than today. It is very hard to make decisions that will be right for all these possibilities.

Using the latest climate science and modelling, climate projections can help us plan for a smaller range of options by narrowing down the range of possible future climates.

Two useful ways to apply climate projections using a simple scaling approach are to show changes in average climate and days under or over thresholds, such as triggers of known impacts from extreme climate events.

Presenting climate change projections in terms of average climate is very useful. For example, the average climate determines the average growing conditions for agriculture. The average air temperature and rainfall regimes determine suitability of certain farming methods and crop types, and geographic zones where pests and diseases are common, along with many other useful things for planning sustainable agricultural development.

Sometimes it is hard to relate a climate impact for any one sector to the average climate, and it is more relevant to look at climate extremes such as the number of days over or under a critical threshold. A threshold may be the number of very hot days, or the number of cool nights, which collectively or independently may affect human health or are important for some crops to grow.

Construct projections as changes in average climate

The average climate is generally measured over a 30-year period, and it changes over time. When preparing and presenting projections using this approach, it is important to be clear that we are using the 30-year average. Individual years will be higher or lower than this.

This approach is particularly useful to show changes in the average climate across an area in space. Since the spatial patterns are the focus here, and we don't need a time series dataset, we can focus on high-resolution maps of climate conditions, such as for maximum temperature, and then look in detail at the respective climate zones.

To construct projections as changes in average climate:

1. Gather the inputs: the observed dataset (collected in step 4), the relevant thresholds (identified in step 2) and the scaling factors (see step 5)
2. Apply the scaling factors to the observed data. Scaling absolute changes, such as for temperature, is done by an addition; proportional changes (%) are applied by multiplication.

Change factors are applied to the relevant geographic area. If you have a single change factor for the whole area (e.g. for a country in the PACCSAP reports), then this one value is applied everywhere. If you have a spatial map of change, then this should be applied in space.

For example, high-resolution maps of daily maximum temperature for Viti Levu island in Fiji are shown In Figure 9. The map on the left shows the mean annual Tmax (the daily maximum temperature) in 1970–2000 using the WorldClim dataset (**www.worldclim.org/version2**). Note that the temperatures are cooler in the mountains than at the coast. On the right is a map of the same area with a change factor of 1.4 °C applied (this is the median projection for 2050 under high emissions (RCP8.5); the model range is 0.6 to 2 °C)[11]. Values over 30 °C are blanked out, so if this threshold were meaningful (say, a cropping zone is marginal at 30 °C), then this new zoning would be notable.

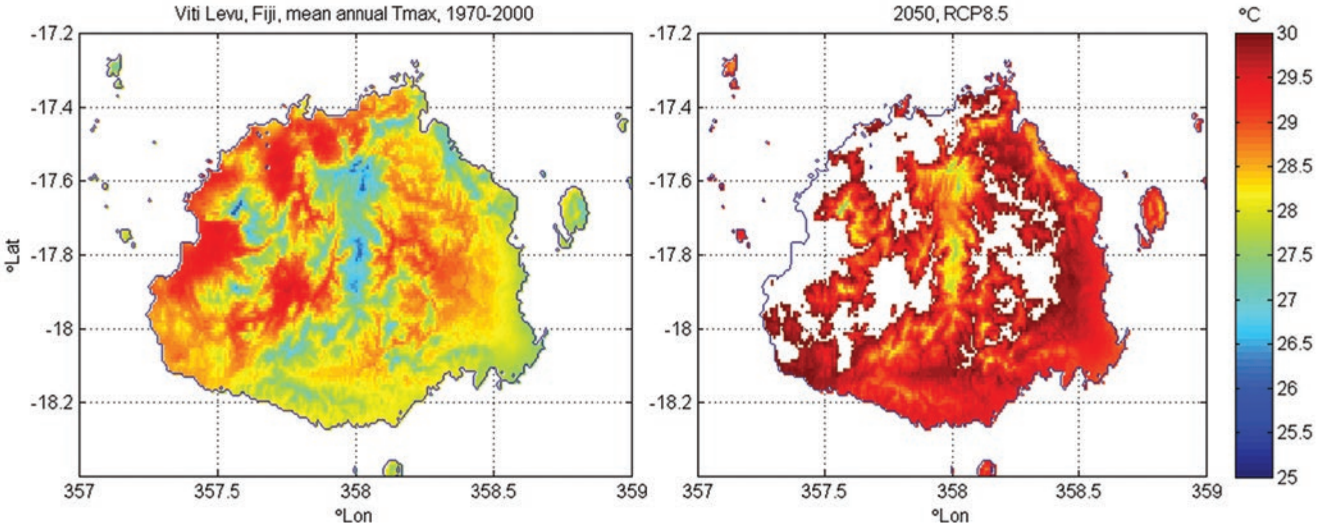

Figure 9. Daily maximum temperature for Viti Levu, Fiji for 1970–2000 (from WorldClim dataset) (left) and median projection for 2050 under RCP8.5 (right). Values over a 30 °C threshold have been blanked out to help identify zoning.

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[11] PACCSAP. 2014. *Climate variability, extremes and change in the western tropical Pacific: new science and updated country reports*. Available at **www.pacificclimatechangescience.org**

Construct projections as days over or under thresholds

Good-quality daily observation datasets are required for this analysis to understand the current climate. The same threshold can then be examined in the projected future climate.

To construct projections as days over or under thresholds:

1. Gather the inputs: the observed dataset (collected in step 4), the relevant thresholds (identified in step 2) and the scaling factors (see step 5)
2. Calculate the days under/over the threshold in the observed climate.
3. Apply the scaling factors to the observetd data. Absolute changes, such as for temperature scaling, are done by an addition; proportional changes (%) are applied by multiplication.
4. Calculate the days under/over the threshold in the future dataset.

In the example in Figure 10, the graph on the left shows that in the past there were 12 days below the 30 °C threshold of interest in this period for Darwin, Australia. Hypothetically, if the climate is scaled up by 2 °C (say due to global warming), then there are only two days below this threshold.

It is important to note that this example shows only three months, for the purposes of clearly showing the effect of scaling. To take account for natural climate variability, this analysis should be done on 30 years of data.

This gives more reliable results (9.8 days/season now, 1.6 days/season with +2 °C). Even when 30 years of data are used, results will show the effect of the change in the average, with no change to natural climate variability. In practice, changes to natural climate variability are in fact possible and should be noted when the results of such an analysis are discussed.

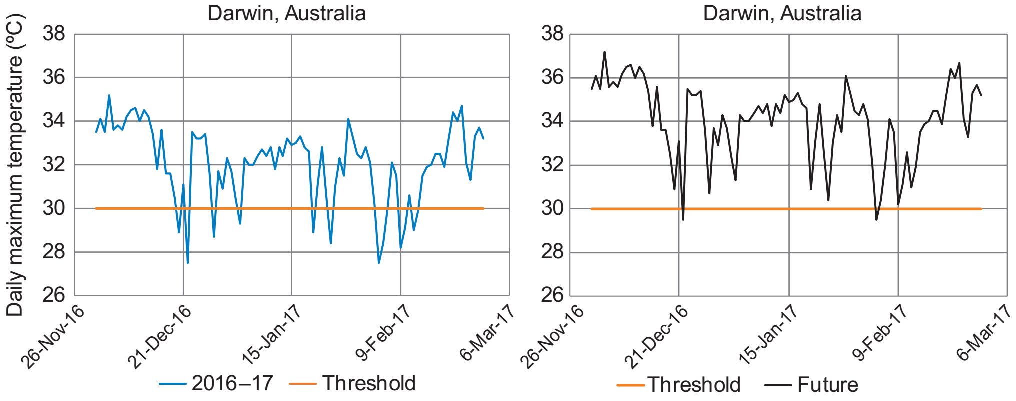

Figure 10. Days below a maximum daily temperature threshold of 30 °C using observed data (left) and if the temperature is scaled up by 2 °C (right).

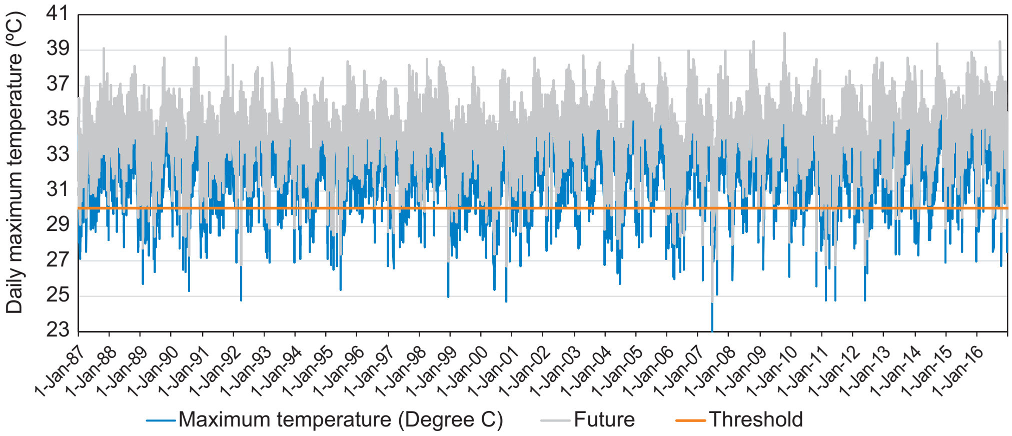

Figure 11. Thirty years of daily maximum temperature for Darwin (blue) and the same data scaled up by 2 °C (grey). The orange line shows the 30 °C threshold.

Provide information about the confidence and uncertainty in climate projections so the limitations of the data are taken into account in decision making. (See Part 4 of this document for more about confidence and uncertainty.)

If using projections for risk assessment, go to **Step 7: Assess climate change risk**

If not using projections for a risk assessment, go to **Step 8: Communicate climate change information**

7. Assess climate change risk

The approach and the associated needs of climate change information for climate change risk assessments may vary depending on the context, especially the depth of the assessment (see Part 2 of this document). Therefore, it is always essential to establish the context first when determining climate change information needs (step 2). That step defines the purpose and the scope of the assessment, the relevant climate change information to be used, how the risk assessment will be conducted and so on. Following that, and after finding climate information (step 3) or constructing climate change projections (step 6), the assessment can be undertaken in three broad activities: identifying, analysing and evaluating risk.

This step provides an overview of these three key activities. More detailed information can be found in the Australian Government's climate change impact and risk management guide for business and government[12], which is a good example of a climate change risk assessment procedure that is compatible with the international risk management standard ISO 31000:2009.

Identify the risk

Identifying climate change risk is identifying how climate changes impact on each of the elements of the sector, location, community or other matter of interest for the assessment. This can be done by simply describing and listing what may happen and how.

This activity requires some initial understanding of the links between the current climate and the matter being assessed. It also often requires knowledge of critical thresholds of which the degree of change could lead to the onset of the consequence. For example, studies show that banana, a staple food in Papua New Guinea, is sensitive to extended periods with temperature beyond the 20–30 °C range[13]. If the frequency of temperatures above 30 °C is projected to increase in Papua New Guinea due to climate change then there could be significant impacts on banana productivity in the future.

Likewise, engineering specifications for the construction (location and design) of critical coastal infrastructure such as public buildings, ports, roads, bridges and drainage systems need to factor in climate change related risk from rising sea levels and more frequent and/or intense extreme rainfall events to avoid impacts of flooding, storm damage and/or erosion over the effective life of the investment.

The links between climate change and associated risk may be direct or indirect, and may also include non-climate factors such as population growth and urbanisation of communities. The example in Figure 12 shows that the risk to a municipal water company as a provider of clean water supply in a city may not arise directly from changes to climate variables, but from a chain of consequences that affect water supply and demand. There may also be coincident risks to the energy sector through impacts on electricity consumption/demand.

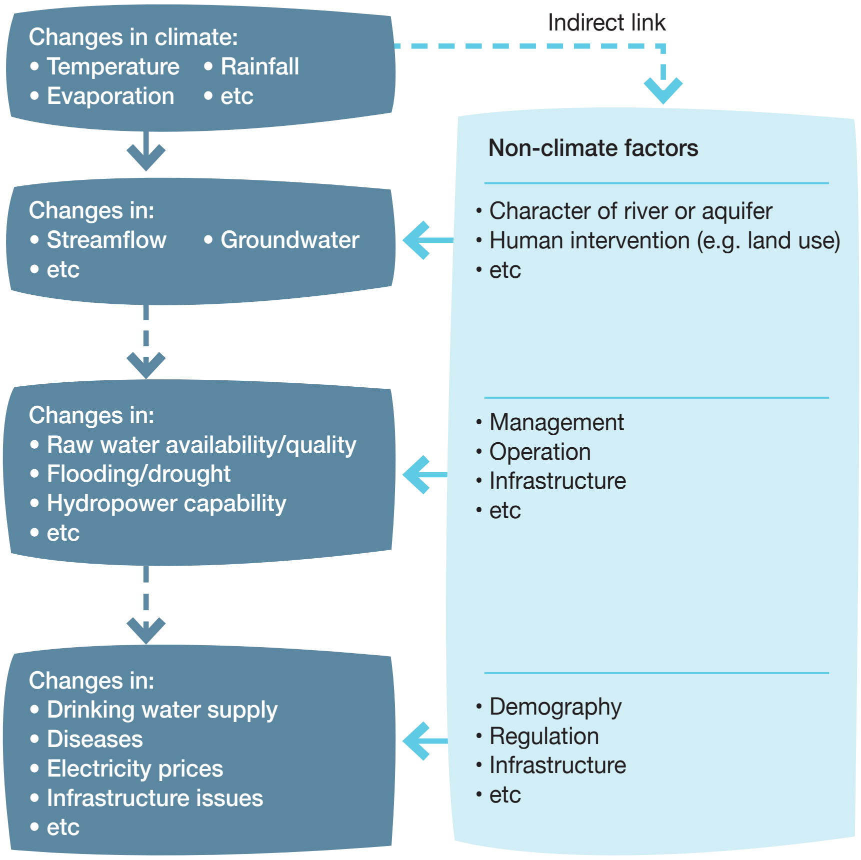

Figure 12. Illustration of links between climate and some sectors (i.e. water supply, energy and infrastructure). The links also influenced by non-climate factors – some of them which are also indirectly influenced by climate.

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[12] Australian Greenhouse Office, 2006. Climate change impacts & risk management: a guide for business and government. Department of Environment and Heritage, Canberra, 74 pp. Available at **http://www.environment.gov.au/climate-change/adaptation/publications/climate-change-impact-risk-management**

[13] McGregor A, Taylor M, Bourke RM, Lebot V. 2016. *Vulnerability of staple food crops to climate change. Vulnerability of Pacific Island agriculture and forestry to climate change*. M Taylor, A McGregor and B Dawson. Noumea Cedex, New Caledonia, Pacific Community (SPC): 161–238.

Drawing a causal diagram that shows the links between climate change and risks for key elements of the area of interest can be a useful way to identify risks. Figure 13 is an example using clean water supply as the area of interest.

Risks can also be identified by undertaking a literature review and by brainstorming in a workshop or focus group with people who already hold basic knowledge, such as agricultural extension officers or engineers. If this activity has already been conducted when determining climate change information needs (step 2), then the list of the identified risks may just need to be validated or re-affirmed with relevant stakeholders (e.g. banana growers, urban water supply manager, consulting engineers, disaster risk managers) and edited as appropriate.

Analyse the risk

The main purpose of this activity is to determine preliminary levels of each of the identified risks.

Risk can be analysed qualitatively (e.g. in a workshop) and/or through quantitative analyses, depending on context of the risk (e.g. country, sector, time period, other non-climate factors) and the scope of the assessment (i.e. initial, rapid or detailed assessment).

Assess the consequences of each identified risk to the sector of interest. Take into account any existing factors that will control the risk, such as the existing practices which people can adopt to mitigate impacts as the climate changes, and other non-climate trends that could happen at the same time and which might somehow modify the effects of the risk.

Next, form a judgment about the likelihood of each identified risk, assuming that each of the climate change scenarios being considered arises.

Combine the consequences and the likelihood to determine the level of risk (or risk rating). For example, if extreme high rainfall has a low probability of occurrence in the region but it has high potential consequences (e.g. urban flooding, landslide, disruption to water supply production due to flood and heavy soil suspension in raw water caused by the landslide, powerline disruption), the risk of water supply failure associated with projected increase in extreme high rainfall could be rated as moderate to high.

(See box over page for an application of this approach.)

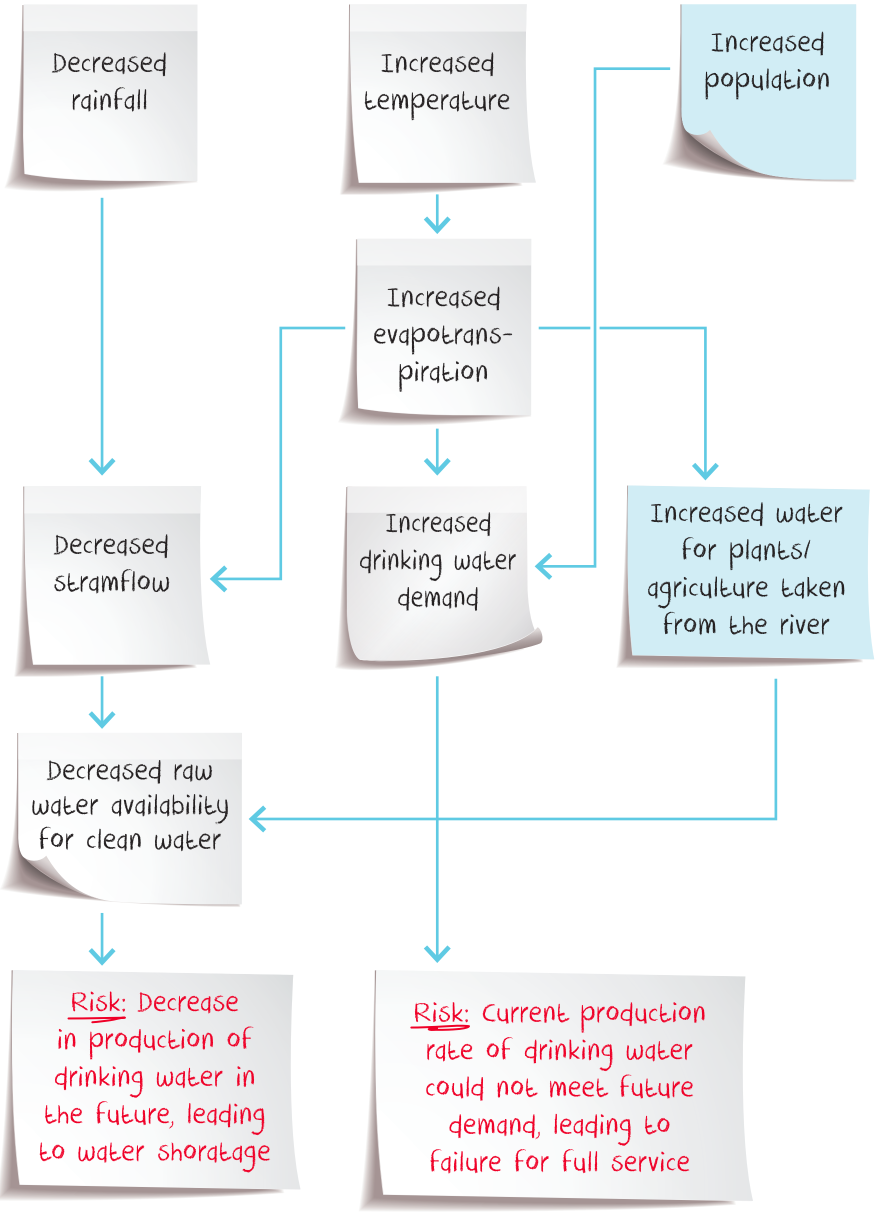


Figure 13. Causal diagram showing the links between climate change and risks to key water supply.

Qualitative risk assessment example

This hypothetical example illustrates a simple way, based on standardised methods, to undertake a qualitative analysis for identified climate risks for the water sector out to 2050.

A working group analysed the risk of climate change to providing access to clean water for 100% of the population. The working group, consisting of many experts including water sector practitioners, national and local government, engineers, hydrologists and climate science experts, met to discuss the risks.

After identifying the risk, the group defined the 'consequence' as 'How bad is it likely to be' for the said objective (also sometimes referred to as success criteria). They categorised the consequences into three levels:

Minor	Moderate	Major
A level that would need no additional attention or resources	A significant issue which may be addressed with efforts and resources	A level that would constitute a major problem close to complete failure

Based on expert views, the group also developed a way to estimate possibility of the occurrence (likelihood) of the projected change:

Very likely	Likely	Unlikely
>80% chance of occurring	20–80% chance of occurring	<20% chance of occurring

The group determined the level of risk by combining the likelihood and consequence:

Consequence / Likelihood	Minor	Moderate	Moderate
Very likely	Medium	High	High
Likely	Low	Medium	High
Unlikely	Low	Low	Medium

Using this rating system, the group applied a risk rating to a series of risks, which they recorded in a simple table:

Risk	Climate variable (cause)	Climate change impacts	Risk rating
Decrease in production of drinking water in the future, leading to shortage in domestic water storage in urban and/or rural areas	Decrease in rainfall (potentially leading to reduced run-off for storage)	Projected change of 0 to -4% in rainfall (this change could reduce streamflow, the raw water resource, up to 5%)	Low Likelihood: likely Consequence: minor
Decrease in quality/ safety of domestic water storage in urban and/or rural areas	Increased in extreme high rainfall (potentially causing flooding impacting integrity of water storages)	The frequency of extreme high rainfall is projected to increase 1-3%	Medium Likelihood: likely Consequence: moderate
Current capacity of domestic water storage could not meet future demand, leading to failure for full service	Increased temperature and increased evaporation (potentially increase plant stress, leading to high water demand for agriculture, thereby competing for raw water resources with domestic users)	Projected 0.5-0.7 °C increase in temperature, and up to 5% increase in evaporation	High Likelihood: very likely Consequence: moderate

Evaluate the risk

If more than one risk has been identified and analysed, rank the risks in terms of their severity. The ranking should consider and reflect confidence in the climate change projections used, for example, if there is confidence that some scenarios are less likely to occur than others.

Screen out minor risks that do not require further attention and identify those risks for which more detailed analysis and/or immediate adaptation is recommended. This should be carried out together with the relevant stakeholders.

Once ranked, the judgments and estimates of the risk should be re-affirmed. This can be achieved by discussing results with relevant sectoral stakeholders (e.g. farmers, fishers, extension officers, climate change advisors/coordinators, water supply managers, engineers, NGOs).

8. Communicate climate change information

Communicating climate change science is less about the science and more about the people you are communicating with.

While understanding the underlying science is important for the preparation of climate change information and risk assessment, such information is not always going to be relevant and useful to the people the results of the assessment are communicated to. If information is not relevant and useful to the target audience, it is likely that key messages will not get through.

Identify the target audiences

The most important aspect of any communication activity is identifying the audiences to be reached and understanding their needs and capabilities. Note the use of the plural 'audiences' – effective communication is not a 'one size fits all' activity. For example, the information that policy makers need from a climate risk assessment is very different from the information that is useful to farmers, as is the way information is conveyed to these two groups. it is very rare for one communication activity to be appropriate for communicating to a range of people.

To determine the target audiences, consider questions such as:

- Where do they live?
- What are their sectoral interests?
- What is their first language?
- What is their level of education?
- What do they do for a living?
- What level of responsibility and authority do they have?
- What is their level of understanding of climate change and its impacts?
- What is most important to them in terms of information needs?
- Where do they get information from?
- What do they do with the information they get?
- Do they have access to/ understanding of information technology?

The answers to these and other relevant questions help tailor and target communication messages, content and delivery methods to ensure that the communication is relevant and meaningful to the people it is aimed at.

Determine the communication objectives

For each audience group, identify the reason for the communication. Is it simply for information or awareness raising? Or is there a desired action that the communication is encouraging? Determining the objective not only helps develop the key message but also provides a means for evaluating the success of the communication activity.

Determine the key messages

When talking or writing about climate change and its impacts, there is much information to consider. Sometimes, in an effort to present all of this information, there is a risk of overwhelming the audience with detail, and they may miss the most important message.

In many cases, the science information itself is not the key message. This information simply provides the evidence for explaining or otherwise validating a particular point. Instead, the impact on the area or sector of interest and the subsequent adaptation action(s) may be the most important messages to convey. For example, a taro farmer does not need to understand the physical processes behind changing circulation patterns that will affect rainfall and temperature in 30 years; the important information is whether his land will still be suitable for growing taro, or if he should consider a different crop or acquiring land in a region that will be suitable for taro.

To identify the key message, it is useful to ask, 'If there is only one thing I want them to remember, what is it?'.

Determine how to convey the information

Ensuring that the right message and level of information is made available to the audience without causing confusion (or boredom!) can make determining how best to convey information challenging. To successfully convey information, both the content and delivery method must be considered.

Language is an important content consideration. Is it too technical for the target audience? Does it use jargon or terminology that is not widely understood? Is English appropriate or will a local language be more effective?

Information can be delivered in many ways. It could be as simple as a phone call or meeting, or require the development of climate knowledge products or advisory materials. Climate knowledge products deliver information about projected change in climate variables such as rainfall in the format of graphs, maps, or infographics, among others. Science-based advice can be found in reports (e.g. summary report for policy makers) or journal papers. They usually provide recommendations about plausible climate impacts on a given matter based on the results of a scientific study.

If the information is to be conveyed via intermediaries, additional products and activities may be required. For example – training materials for intermediaries and posters or presentations that they use when talking to their audiences. (See box for more about using intermediaries.)

To determine the best way to deliver your information, you need to consider the answers to the questions used to understand the audience. For example, a website full of information is not useful if the people the information is for do not have internet access, or computers or smart devices to access it. However, if the target audience have ready access to and use social media (e.g. Facebook) then this may be a very effective delivery method.

Prepare a communication plan

Much like a stakeholder engagement plan (step 1), a communication plan is a valuable tool for ensuring the intended key messages are communicated to identified audiences at an appropriate time using appropriate methods. A simple table that sets out the audience, communication objective, key message, method, timing and person responsible is all that is needed to manage effective and efficient communication (Fig. 14 is an example).

Implement, monitor and evaluate communication activities

Following this plan will ensure that communication activities are completed in a timely manner. It is a good idea to print a copy of the plan and keep it in plain sight (e.g. on a pin board or wall) as a reminder of upcoming activities.

Monitoring and evaluation is important for determining the success of your current plan and for informing future communication activities. To do this, identify ways to measure how well your communication objectives have been met. This could be as simple as the number of likes on Facebook, visitors on a website, or copies of a publication requested, or more involved, such as determining changes in behaviour or activities over time.

Audience	Communication objectives	Key message/ purpose	Activities	Timing	Person responsible
Ministry of Water	To discuss key results and recommendation from the rapid risk assessment on the national water sector To determine follow up action as needed	There is a high risk that the current capacity of domestic water storage could not meet 2050's demand, leading to failure for full service Need to decide appropriate action – e.g. whether to conduct further detailed risk assessment or to plan for adaptation	One-hour briefing at the Ministry's office (five-minute presentation, 55-minute discussion)	After the focus group discussion	Project leader

Figure 14. Example of part of a communication plan for a water sector risk assessment.

Advice for effective communication

Be useful and relevant

Information must be useful – if the audience cannot use, what is the point of communicating it? – and relevant. Relevance makes the information more easily understood and remembered.

For example, a government health official has been given funding by a donor to build a new hospital. However, the donor organisation needs to know that sea-level rise has been taken into account in the planning, so the hospital will be appropriately located to avoid coastal inundation hazards and will therefore still be around in 50 years, or at least until the useful ife span of the building expires. Useful information for the government official to communicate to the donor could include maps showing projected sea-level rise for the area near the building site, and a non-technical analysis that explains the best positioning of the hospital in light of the projections.

Tell a story

An effective way to convey information is to tell a story – focus less on the numbers and more on what they mean in terms of impacts. What will a changed climate look like in the area? How will this impact on the lives and work of the people that live there? Talking about crops no longer being viable in a particular area, or pointing which land will be under water or roads will be cut is much more meaningful to people than talking about a 1.5°C temperature rise, or 25 cm sea-level rise.

Prepare layers of information

Telling a story does not mean that the science should be ignored or avoided altogether; after all, the strength of the message is that it is based on scientific evidence. Instead, provide many layers of information. For example, a presentation may simply tell the story focusing on what life will look like under a changed climate. For people who are interested in more detail, there may be a fact sheet that provides some of the summary technical facts and figures. For technical experts who need very detailed information, there may be a technical report.

Use graphics and images

It is often said that 'a picture tells a thousand words', so using graphics and images can be a useful way of getting messages across. This may simply be relevant photos or simple infographics, or a short video.

Scientific information typically contains many graphs and complex figures that are often beyond the easy understanding of non-experts. If graphs are used to illustrate a point, ensure they are clear, simple and easily understood. Labels are very important.

Formal presentations are often accompanied by PowerPoint slides or other audio-visual aids. It is important to remember that these slides are simply signposts. Do not clutter them with text and numbers. Ideally, each slide will contain only one main message.

Use and support intermediaries

Collaborating with intermediaries to communicate information has a number of advantages. It can effectively extend the reach of communication activities beyond what project resources allow. If the intermediary is a trusted by an audience (e.g. a church or community leader, a teacher) the message may be more readily accepted and acted on. Intermediaries may also have access to existing local communication networks across different socio-economic groups in the community (e.g. NGOs, church groups, women's groups, schools) that would be otherwise difficult to access.

When using intermediaries there are two audiences to consider – the intermediaries themselves and the audiences they will be communicating with. It is important to ensure that the intermediaries are supported in their understanding of your messages (e.g. with training materials and other resources) and in the information that they pass on (e.g. with handouts, presentations, speaking points, posters).

Be practical

If the target audience access the internet via a mobile phone, and the mobile network is expensive or not reliable, posting a large, technical report online for downloading is not practical.

PART 4

Understanding climate change science

Climate variability and change

Each region of the world has its own unique climate, which is the typical weather the region experiences. However, the weather varies from month to month, season to season and year to year due to natural cycles and the influence of large-scale climate features like the El Niño–Southern Oscillation (ENSO).

ENSO is the major cause of year-to-year climate variability in the Pacific. The extent and timing of its influence vary between countries. Throughout the region, ENSO affects the year-to-year risk of droughts, floods, tropical cyclones, extreme sea levels and coral bleaching.

Climate change occurs over much longer timescales than climate variability—decades, centuries or longer. It is the result of both natural processes and human activities. It can mean long-term changes in the average climate conditions (such as average rainfall and temperature) or in the occurrence of extreme events such as tropical cyclones and droughts.

Human activities change the climate by increasing greenhouse gas levels in the Earth's atmosphere. Greenhouse gases occur naturally in the atmosphere and trap heat. However, human activities like burning fossil fuels (such as coal, oil and natural gas) are rapidly increasing the concentration of these gases in the atmosphere. This is causing the climate to become increasingly warmer and weather patterns in some places to change.

Climate extremes

Climate extremes are short-term weather or longer-term climatic events that are rare or uncommon in occurrence, and often excessively severe in impact. Extreme events resulting from natural variability in large-scale climate processes, from season to season and year to year, can cause massive loss and damage to infrastructure, industry and environmental assets, and can impact on the health, safety and overall wellbeing of local communities. These large-scale processes include ENSO, the South Pacific Convergence Zone, the West Pacific Monsoon and the Intertropical Convergence Zone. Longer-term variability and climate change compound these impacts, particularly in terms of increased vulnerability to natural, climate-related disasters.

The impacts of climate change will be felt through extreme events (changes in frequency and intensity) rather than changes in mean conditions. Consequently, climate risk assessments will, for the most part, focus on changes in extreme events.

Climate models

Global climate models

Global climate models are mathematical representations of the Earth's climate system. They are run on powerful computers to simulate the processes affecting weather and climate. There are many global climate models being used, and there is no single 'best' model. The group of current, good-quality model simulations are brought together and compared in the Coupled Model Intercomparison Project (CMIP), and the latest version in CMIP5.

Model biases

The performance of the model in the past and present climate is a general guide as to how confident we are in the projections. The difference between a model and observations is called bias. If models have low biases in the important aspects of performance, then confidence is higher. If models have high biases, then confidence is lower. Models with high biases in important features may be rejected. For example, in the PACCSAP program, three of the 27 CMIP5 models that were assessed were deemed as unsuitable for making projections in the western Pacific and so were rejected.

We now have a good understanding of many aspects of the climate system but our understanding and ability to model the current climate is not perfect. Also,

our understanding and modelling of how the earth responds to an enhanced greenhouse effect are not perfect.

Unfortunately, some of the biggest biases in climate models are in the western Pacific! This means that confidence in some projections is reduced compared to other regions. Particular biases include:

- The West Pacific Warm Pool and equatorial 'cold tongue' can be the wrong shape – the cold tongue is too strong in models
- The rainfall zones South Pacific Convergence Zone and Inter-Tropical Convergence zone can be too strong and lined up the wrong way

Some aspects of climate change are not currently clear, or we are not confident about, including:

- Patterns of rainfall are different with a warmer climate, but depend on many different processes, so the exact pattern of regional rainfall change is not clear
- Change in the variability and intensity of the El Niño–Southern Oscillation is not completely clear

Climate change projections

Uncertainty

We do not know how climate change will affect natural climate variability and extremes, or how greenhouse gas and aerosol emissions will change in the future, or how the climate will respond to changing emissions. For this reason, there will always be a range of uncertainty in climate projections. (It is worth noting that while non-scientists use 'uncertainty' to describe things that are unknown, climate scientists use the term to describe what they do know – so uncertainty in climate projections is not a 'bad' thing, it just tells us the limitations of the information we have.)

Variability

Natural ups and downs in the climate will always continue. There will also be unpredictable things that affect our climate, such as large volcanic eruptions. Human effects may be small or large compared to the natural changes:

- Natural effects are more important the more local and the shorter time frame you look at – such as what will be the temperature of my island one year to the next.
- Human effects become more noticeable the wider the area and longer the time frame you look at – such as the temperature trend in my country in the next 50 years.

Emissions

We don't know for sure how much carbon dioxide and other gases people will emit into the air – it depends on how society and technology develop, and whether international agreements are successful. We must make projections for various scenarios of emissions, from low to high, and we must use projections knowing that they are not an exact prediction of what will definitely happen. You may wish to show the effect of a high scenario as a worst case, or show a high and a low scenario to show the effect of controlling emissions.

Climate response

We know that increases in greenhouse gases like carbon dioxide make the world warmer, but the Earth's climate is very complex and there are a lot of things we don't have a clear idea of yet. A range of model results gives us an estimate of the range of possible change, but on top of this it is important to understand the confidence in projections, from low to very high.

Confidence ratings

Projections are given a confidence rating, generally from low where model biases are significant and the processes involved are less certain, through to very high confidence, where we have confidence in the models and understand the processes well.

There is presently greater confidence in projections of some variables (e.g. temperature) than others (e.g. rainfall), and greater confidence in projections over large spatial scales and long time periods (e.g. global climate change over multiple decades) than for smaller spatial scales (e.g. regional and national projections) and short time periods (e.g. over periods of less than 10 years).

Projections of average temperature are more confidence than rainfall.

The confidence rating should be used to inform how the projections are used – if confidence is high, then the ranges of model results can be used as a good guide to potential climate change, if confidence is low then the results are plausible but other possibilities should also be considered possible.

Do not use results with too much or too little confidence – climate projections are guides to what the future may look like under future scenarios, they shouldn't be used as precise numbers, but neither should a projection be treated as not useful.

PART 5

Tools and resources for planning ahead

Climate science tools and portals

Pacific Climate Futures

Pacific Climate Futures is a web-tool developed in collaboration with Pacific Island countries that provides free and easy access to climate projections data. These data can be used for risk assessment and adaptation planning.

The tool groups projections from individual models into a small set of internally consistent climate futures, such as ’warmer and wetter‘ or ’hotter and drier’. Each climate future is given a likelihood so the user can readily identify the most likely future, as well as less likely futures that might represent a ‘best case’ or ‘worst case’. Users can select a small set of climate models that represent key climate futures, then download data from these models into an Excel spreadsheet. Observed climate data can be imported into the spreadsheet and combined with model data to create synthetic future in climate data for use climate impact assessments.

Access to the basic and intermediate levels of this tool is available to the public, while advanced level access is subject to training and accreditation. The tool can be found at **www.pacificclimatefutures.net**.

The Pacific Climate Change Data Portal

The Pacific Climate Change Data Portal allows users to visualise historical monthly temperature and rainfall data and to explore trends from more than 100 individual observation sites across the Pacific Islands and Timor-Leste. As the largest web-based data source for the Pacific region, this tool allows users to plot time-series graphs, linear trends, multi-year running averages and long-term averages. It includes trends in daily rainfall and temperature extremes.

This tool is available to users approved by relevant national governments and can be found at **www.bom.gov.au/climate/pccsp/**.

CliDE: Climate Data for the Environment

CliDE is a PC-based, desktop climate database management system installed in National Meteorological Services in 15 countries to support day-to-day operations, including the archiving and basic analysis of historical and recent meteorological data. CliDE provides a reliable and functional platform for countries to rescue and secure hard copy and electronic data, the former of which in some countries date back more than 100 years. Accurate climate records are critical for building an understanding of how the climate is changing and for verifying climate projections, monitoring and comparing droughts and other extreme events.

CLiDE is used by the National Meteorological Services of each of the PACCSAP Program’s partner countries. More information can be found at **www.bom.gov.au/climate/pacific/about-clide.shtml**.

The Southern Hemisphere Tropical Cyclone Data Portal

The Southern Hemisphere Tropical Cyclone Data Portal improves knowledge of past tropical cyclone activity in the Pacific Islands and Timor-Leste by plotting tracks of cyclones in the South Pacific from the 1969/70 season through to the 2009/10 season, allowing users to see the characteristics and paths of past tropical cyclone events.

Meteorologists and stakeholders can use this tool to analyse the tracks of historical tropical cyclones and relate them to the impacts on lives and infrastructure recorded on the ground.

This tool is available to the public and can be found at **www.bom.gov.au/cyclone/history/tracks/**.

Seasonal Prediction of Sea Level Anomalies in the Western Pacific

The Seasonal Prediction of Sea Level Anomalies in the Western Pacific tool is focused on the development and verification of seasonal forecasts for sea level for Pacific partner countries. These forecasts are generated using the POAMA dynamical model and are aimed at developing a better understanding of seasonal sea level prediction, and prototype forecast products for the Western Pacific.

This tool is accessible to interested users who apply to the Australian Bureau of Meteorology to use the tool. Meteorological agencies from PACCSAP partner countries in the Pacific are the primary users of this tool. It is available at **www.bom.gov.au/climate/pacific/aboutsea-level-outlooks.shtml**.

Seasonal Prediction of Extreme Ocean Temperatures and Coral Bleaching

The Seasonal Prediction of Extreme Ocean Temperature and Coral Bleaching tool provides POAMA-based dynamical seasonal forecasts of ocean temperature and coral bleaching risk. This information is critical to partner countries in planning coastal development and safeguarding agricultural, marine and water resources.

This tool is accessible to interested users who apply to the Australian Bureau of Meteorology to use the tool. Meteorological agencies from PACCSAP partner countries in the Pacific are the primary users of this tool. It is available at **www.bom.gov.au/climate/pacific/aboutseasonal-extremes.shtml**.

Pacific Climate Change Portal

The Pacific Climate Change Portal (PCCP) has been developed by the Secretariat of the Pacific Regional Environment Programme (SPREP) in collaboration with its partners. The portal aims to ensure that climate change-related information and tools developed by regional and national institutions in the Pacific Island region are readily accessible to stakeholders in a coordinated and user-friendly manner. The major target groups for the portal are national stakeholders within Pacific Island countries and territories, regional stakeholders including Council of Regional Organisations in the Pacific (CROP) agencies, and development partners. The PCCP will also provide a metadata catalogue and associated access guidelines for all project-based climate science data collections generated by PCCSP and PACCSAP through the Australian Government-funded Pacific iClim project, which is being delivered jointly by Griffith University and SPREP.

The PCCP is available at **www.pacificclimatechange.net**.

Additional resources for understanding climate variability and change in the Pacific

The Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) program developed a range of resources to help Pacific island nations understand climate variability and change in the region, and use science-based information to build resilience. They include:

- *Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports*, a comprehensive technical report documenting the latest scientific understanding of large-scale climate processes, observations, extremes and projections in the western tropical Pacific.
- Country brochures, providing a summary of information from the technical report for 14 Pacific island countries and Timor-Leste.
- *Climate in the Pacific: A regional summary of new science and management tools*, a non-technical report for policy developers, planners and associated decision-makers.
- Fact sheets on climate variability, climate extremes, large-scale climate features, ocean acidification and sea-level rise.
- *The Pacific Adventures of the Climate Crab*, an animation that aims to increase awareness of the science and impacts of climate variability in the Pacific.

These and other resources are available from the Pacific Climate Change Science website at **www.pacificclimatechangescience.org**.

In addition, a range of resources – including climate change science training materials – are available through local NMHSs.

APPENDIX 1

Case study: Analysing the impact of climate change on sweet potato crops in Papua New Guinea

This case study provides a demonstration of a risk assessment following the material in this guidance document.

Background and context

Root vegetables such as sweet potato, cassava, yams and taro are important crops for local consumption in Papua New Guinea (PNG). Climate change may bring threats and opportunities to the industry. There are several research questions about climate change impact and the future of sweet potato growing we can explore to inform decisions, including:

- What is the impact of projected changes to climate envelope for growing sweet potato (e.g. temperature, rainfall)?
- Will there be a change to pests such as the taro beetle (Papua beetle) or the rhinoceros beetle?
- Will there be changes to fungi and diseases such as taro leaf blight?
- What is the potential impact from extreme events such as tropical cyclones?

In this case study, we look at the temperature growing envelope. Our research question is: Could the growing conditions in PNG reach any important thresholds this century, and could parts of PNG become too warm for growing some crops, or could other areas where sweet potato is not grown become climatically suitable?

1. Identify stakeholders and plan engagement

A full analysis of the impacts on growing root vegetables in PNG would begin with stakeholder engagement as outlined in the guidance document. However, as this case study has been developed for the sole purpose of demonstration, this has not been included here.

2. Determine climate change information needs

We would like to show the spatial extent of the temperature 'envelope' for growing root vegetables – the area within the upper and lower temperature thresholds of the crop. We will then show this envelope for different time periods and emissions scenarios in the future and see how it changes. The results can be used to fulfil three goals:

1. Raise awareness –start discussions and raise the potential issues for stakeholders involved
2. Identify climate change impacts – show the potential impact of temperature change to the growing conditions to then inform analysis of adaptation actions and pathways.
3. Motivate mitigation – illustrate the effect of a low scenario compare to a high scenario, to demonstrate the benefit of emissions reductions at negotiations.

3. Find existing climate change information

A literature and internet search reveals that there is some useful general information about growing root vegetables in PNG, including the Pacific Community (SPC) book chapter by McGregor et al. (2016). A detailed analysis of the climate envelope for growing root vegetables in PNG that includes maps has not been produced before, so there is some room for new analysis. The temperature and rainfall thresholds of the climate envelope for root vegetable growing are fairly well known. We are interested in looking at thresholds, and the upper threshold for taro, yams and cassava are fairly high and unlikely to be reached in coming decades (McGregor et al. 2016). The correlation between the spread of taro leaf blight with increasing minimum night time temperature is well studied (Bourke 2013), and would be a worthwhile case study. Here we choose to look at two important and well-studied thresholds for sweet potato:

- Tuber formation is impaired when air temperature exceeds 34 °C (Bourke 2013)
- Minimum growing temperature is 10 °C.

4. Collect observed climate data

Growing conditions are highly localised, so we need high-resolution climate surfaces of the average climate that account for factors such as elevation (higher ground is cooler than sea level). We just need the recent average conditions, we don't need time series or information about extreme events. We can get high-resolution climate surfaces for each month at **www.worldclim.org**.

Understanding the dataset: WorldClim version 2 gives climate averages for the 1970–2000 period, the high-resolution version has ~1 km^2 resolution. The dataset uses weather station data and satellite data as input, and fills the gaps between data points by using statistical techniques (thin-plate splines and covariates using elevation). All temperature datasets rely heavily on high-quality weather stations with good coverage. Parts of PNG are not well covered by stations, so the accuracy of the temperature data will not be as high as in some other places. See Fick and Hijmans (2017) for more information.

5. Collect and evaluate appropriate model data

We need change factors between a baseline period and future periods for the variables of mean annual daily maximum temperature and daily minimum temperature. We need results for all the emissions scenarios (here we look at the representative concentration pathways or RCPs) to illustrate the risk under each one and to show the benefit of mitigation. Temperature change is fairly uniform in space, so we can use a single change value for all of PNG (spatial datasets including high-resolution downscaling could be investigated as a follow-up study).

The ranges of change from the PNG chapter in the PACCSAP report (Australian Bureau of Meteorology and CSIRO, 2014) meet all these requirements. The PACCSAP results use a group of CMIP5 global climate models that have been evaluated and three unsuitable models were rejected (Grose et al. 2014). They cover a range of projected change that are plausible, and values are available for all the RCPs for various time periods.

Photo: iStock.com/Byelikova Oksana

6. Construct climate change projections

For daily maximum temperature, we look at the warmest month in the growing season. For daily minimum temperature, we look at the coolest month in the same season. The climate surfaces of these variables in the present climate are shown in Figures A1 and A2. We assume that if the average temperature for a month in the growing season is above or below a threshold, then this will limit the growth of the crop in a typical year (an examination of daily data could be done as a follow-up study).

We can apply the projected change to the observed dataset using a simple scaling approach – adjusting the observed climate surface up or down using the change factor from projections. The absolute change in temperatures (°C) is applied using an addition. Two change factors are applied for each time period and each RCP: the lower end of the model range and the upper end. For example, if the mean daily maximum temperature in a cell is 31.5 °C the range of projected change is 1.5 to 2.8 °C, then the future value of that cell is 33 to 34.3 °C. Following this, the values that are over the threshold are found, in this case 34 °C for daily maximum temperature. The cell is categorised as:

1. The range of future temperature is below the threshold
2. The range of future temperature crosses the threshold (high value is over, low is under)
3. The range of future temperature is all above the threshold

For our example above, the cell would be in category 2 (the low end of the range, 33 °C, is below the threshold of 34 °C, and the high end, 34.3 °C is above it).

Note: The baselines are slightly different: 1970–2000 for WorldClim, 1986–2005 for the projections. We can't adjust the observed data or the projections, so we will just need to use these results as they are and communicate this point in the results.

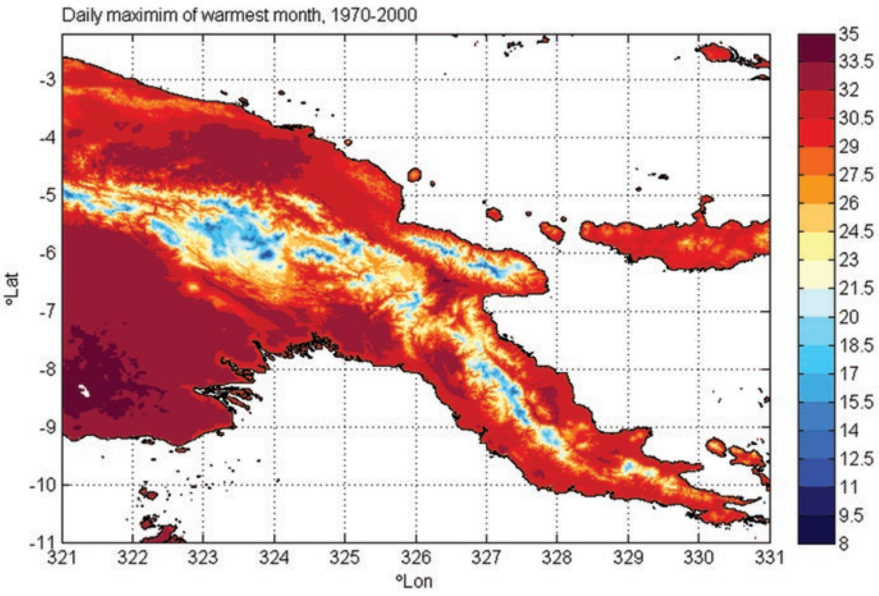


Figure A1. The mean daily maximum temperature of the warmest month in the sweet potato growing season in PNG (in the WorldClim dataset)

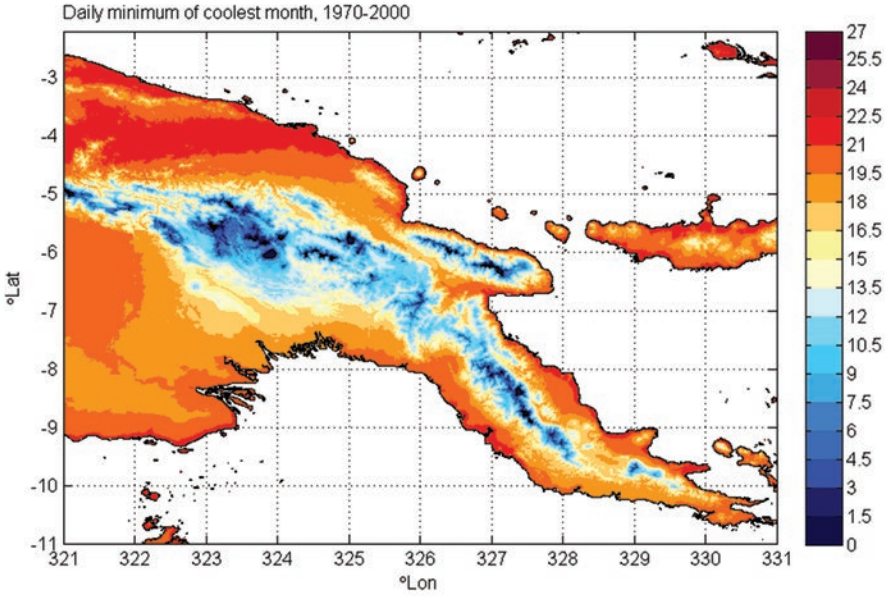


Figure A2. The mean daily minimum temperature of the coolest month in the sweet potato growing season in PNG (in the WorldClim dataset)

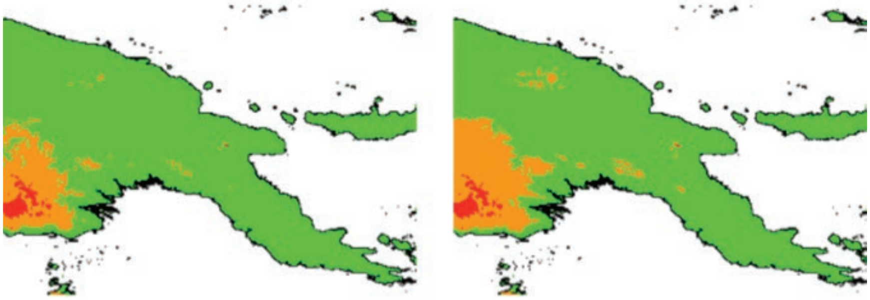
7. Assess climate change risk

The areas where the projected daily maximum temperature range sits in relation to the 34 °C threshold for three RCPs and two time periods are shown in Figure A3.

Looking at this plot in terms of vulnerability and risk, we can interpret the areas in green (temperature range below the threshold) as being fairly low risk of being limited by temperature, areas in orange as potentially at risk, and red areas as being very high risk of being unsuitable. The warmest month in the region of the southern lowlands is already close to 34 °C, so is projected to have increased risk of temperature impacts under all scenarios and time periods. Other than that region, the results suggest the effect of the emissions scenario is very important – under a very low scenario (RCP2.6), the increase in risk is seen southern lowlands, but is minimal even by 2090 over most of PNG. Under RCP4.5 some regions of the northern lowlands could be affected. Under RCP8.5, the temperature of the warmest month could be an important limiting factor to sweet potato growing in most of the lowlands by 2090.

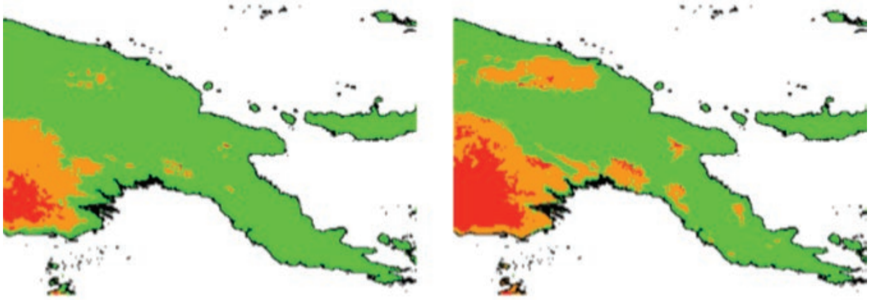
Current suitability

Figure A3. Mean daily maximum temperature in the warmest month of the sweet potato growing season of PNG today (top) compared with categorisation of regions in relation to the 34 °C threshold for growing sweet potato in 2050 (left column) and 2090 (right column) under different RCPs. Projected ranges of changes in temperature noted in brackets; green shows the range is below the threshold, orange shows range crosses threshold and red shows where the range is above the threshold.



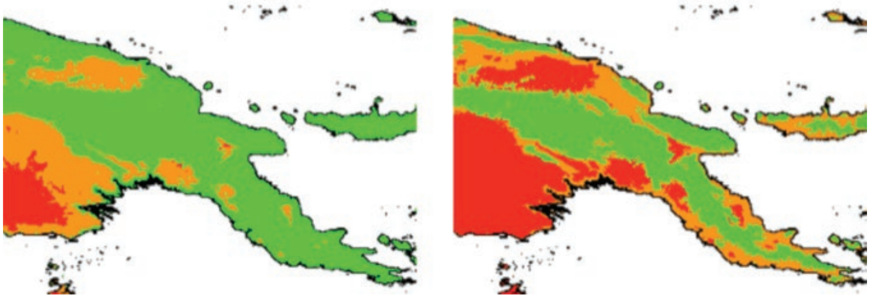
RCP2.6, 2050 (+0.4 to 1.1 °C)

RCP2.6, 2090 (+0.4 to 1.0 °C)



RCP4.5, 2050 (+0.5 to 1.3 °C)

RCP4.5, 2090 (+0.9 to 2.0 °C)



RCP8.5, 2050 (+0.9 to 2.0 °C)

RCP8.5, 2090 (+2.0 to 4.3 °C)

Looking at daily minimum temperature of the coolest month of the growing season, we see that even under RCP8.5 by 2090 (Fig. A4), relatively small new areas are projected to become less limited by cool nights <10 °C. This is expected due to the steep climatic gradients on the slopes of the highlands.

In a full risk assessment, this temperature analysis would then need to be combined with other analyses (e.g. rainfall, droughts, pests, disease, extreme events) to assess the overall risks and vulnerability of the industry.

8. Communicate climate change information

These results would be combined with other analyses (e.g. rainfall, drought, pests, disease, extreme events) and presented in the appropriate form to the appropriate audience. Forms of communication may include:

- Briefings to decision-makers
- Presentations at meetings and conferences
- Summary reports or brochures
- Media releases
- Scientific paper outlining the results (to add scientific credibility to the findings).

This communication would address the three goals set out in step 2:

1. Raising awareness– alerting stakeholders to the potential issues
2. Analysing impact and informing potential adaptation pathways
3. Motivating mitigation – there is a large benefit in staying on RCP2.6 or RCP4.5 compared to RCP8.5

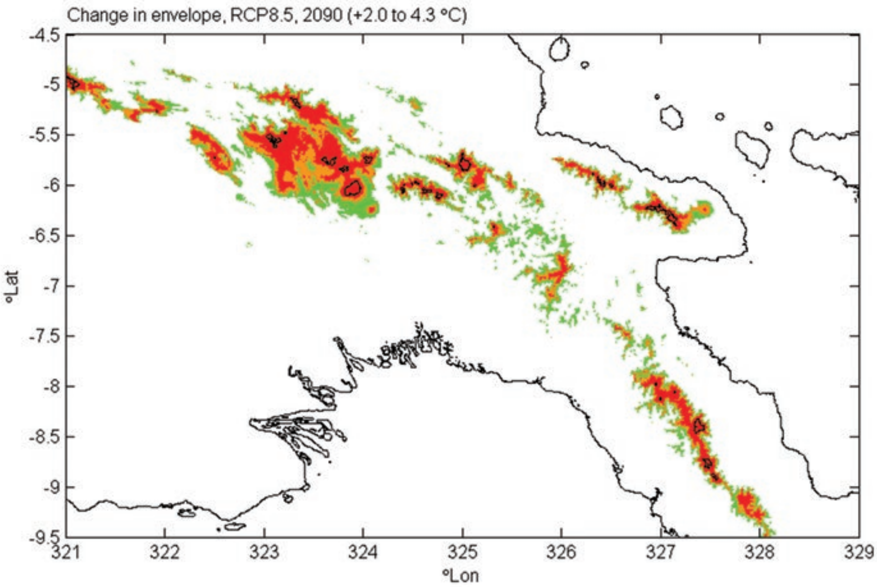


Figure A4. Mean daily minimum temperature in the coolest month of the sweet potato growing season of PNG: categorisation of regions in relation to the 10 °C minimum threshold for growing sweet potato in 2090 under RCP8.5, green shows areas where the projected range is above the threshold (areas that are likely to become more suitable for sweet potato growing), orange shows where the range crosses the threshold (areas that may become more suitable for growing sweet potato), and red areas are where the temperature remains too cool.

The framework to understand the range of results should be explained, including the emissions scenarios, time periods, range of results. Confidence in the results should be explained and given as a rating – temperature projections are generally high confidence. Important aspects or caveats of the results should be given – in this case, the observed climate surface is less accurate than in places with more weather stations, and the baseline period in observations is slightly different than in projections.

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Australian Bureau of Meteorology and CSIRO. 2014. Climate variability, extremes and change in the western tropical Pacific: New science and updated country reports. Pacific-Australia Climate Change Science and Adaptation Planning Program technical report, Melbourne, Australia. Available at **www.pacificclimatechangescience.org**

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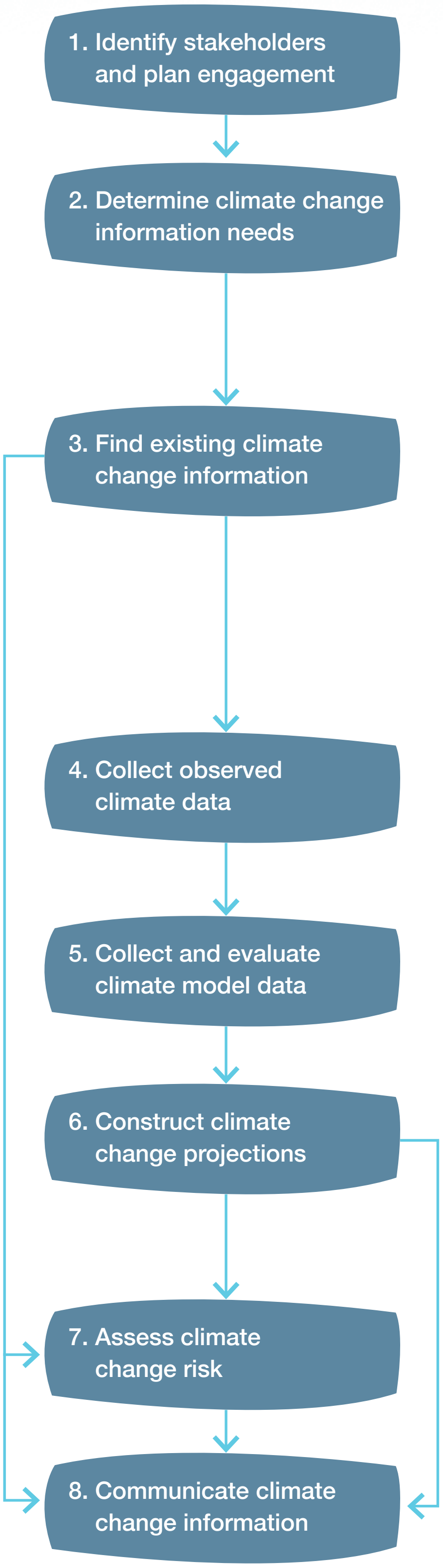
Grose MR and co-authors (2014). Assessment of the CMIP5 global climate model simulations of the western tropical Pacific climate system and comparison to CMIP3. *International Journal of Climatology*, 34: 3382–3399.

McGregor A, Taylor M, Bourke RM, Lebot V. 2016. Vulnerability of staple food crops to climate change. *Vulnerability of Pacific Island agriculture and forestry to climate change*. M Taylor, A McGregor and B Dawson. Noumea Cedex, New Caledonia, Pacific Community (SPC): 161–238.

APPENDIX 2

Checklist: Developing climate change information



☐ Identify stakeholders.
☐ Define why and how each stakeholder will be engaged.
☐ Prepare a stakeholder engagement plan.
☐ Implement the stakeholder engagement plan.

☐ Determine why climate change information is needed.
☐ Define the subject of interest.
☐ Determine how the subject of interest reacts to the climate.
☐ Identify the relevant climate variables.
☐ Identify the time frame of interest.
☐ Identify an appropriate time step.
☐ Decide how the information will be found, developed and/or applied.

☐ Search for relevant studies that have already been carried out.
☐ Revise background information about climate change.
☐ Collect traditional knowledge on the topic.
☐ Summarise and synthesise information.

> If this climate change information is being used as context for a new analysis, go to **Step 4: Collect observed climate data**; if it is being used for risk assessment, go to **Step 7: Assess climate change risk**; or if it is being used for awareness raising or another purpose, go to **Step 8: Communicate climate change information**

☐ Determine what type of observed data is needed.
☐ Find an appropriate dataset.
☐ Access the dataset.
☐ Process the dataset.
☐ Determine the quality and uncertainty of the data behind the dataset.

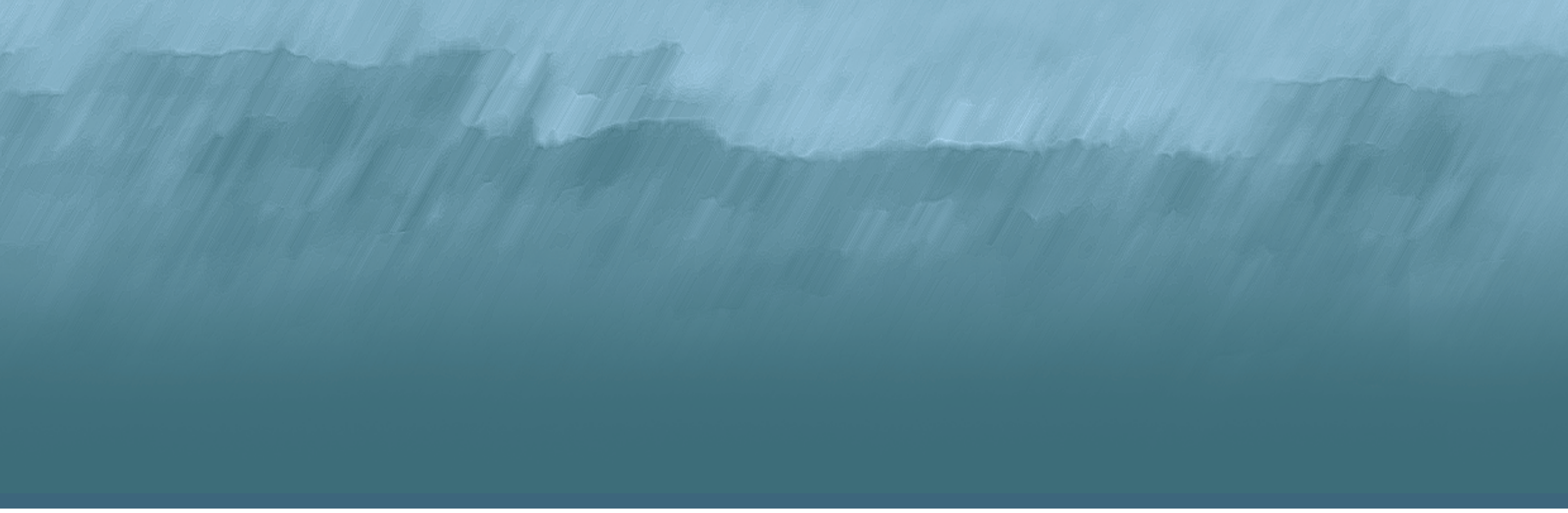
☐ Identify the baseline period.
☐ Identify the scenarios of interest.
☐ Decide which climate models to use.
☐ Create the application-ready dataset.
☐ Evaluate the model data.

☐ Construct projections as changes in average climate OR
☐ Construct projections as days over or under thresholds.

> If using projections for risk assessment, go to **Step 7: Assess climate change risk**, otherwise go to **Step 8: Communicate climate change information**

☐ Identify the risk.
☐ Analyse the risk.
☐ Evaluate the risk.

☐ Identify the target audiences.
☐ Determine the communication objectives.
☐ Determine the key messages.
☐ Determine how to convey the information.
☐ Prepare a communication plan.
☐ Implement, monitor and evaluate communication activities.



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