APEC Climate Center Research Report 2017-12

Climate Services for Agriculture in Vanuatu

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PREFACE

Informing farmers' tactical and strategic decisions with timely weather and climate forecasts as well as related climate products and services, is a fundamental means of improving agricultural productivity. In Vanuatu, where agriculture is almost 100% rain-fed and fully exposed to all natural hazards including tropical cyclones, coastal and river floods, droughts, earthquakes, tsunamis, and volcanic eruptions, access to these information products and services is instrumental in reducing the vulnerability of the Ni-Vanuatu farmers by enabling them to manage risk more effectively.

This report was undertaken as part of the "Development of Climate Information Services in the Asia-Pacific region" Project conducted by the APEC Climate Center (APCC) in 2017, which focuses on enhancing climate services for agriculture that inform decision-making for climate adaptation and disaster risk reduction planning in the agriculture sector in Vanuatu. Through the report, the authors successfully: (1) established a baseline capacity and needs on climate services for agriculture in Vanuatu to increase the awareness of present and future risks and to provide potential solutions to the identified risks in agriculture sector; (2) outlined the needs and priorities of climate products and services for agricultural stakeholders in Vanuatu and enhanced overall understanding of the key concepts; and finally (3) suggested future development strategies for climate services in agriculture to increase the climate resiliency of the agriculture sector in a sustainable manner.

As this report provides the first example of country- and sector-specific, comprehensive, climate service solutions, it should also be of benefit to other developed and developing countries in the APEC region. This is particularly the case in the National Hydro-Meteorological Services and the Ministries of Agriculture, as the primary government agencies that provide and utilize the climate-services-for-agriculture information in most countries. They will benefit the most in establishing their own national framework for climate services.

Dr. Hong-Sang Jung
Executive Director
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March 2018

EXECUTIVE SUMMARY

This study was undertaken in 2017, as part of the project "Development of Climate Information Services in the Asia-Pacific region", conducted by the APEC Climate Center (APCC). The project focuses on the promotion of climate services for agriculture that provide useful information for decision-making with regard to efforts towards adaptation to climate change and planning for the reduction of disaster risk in the agriculture sector in Vanuatu. The objectives of this study were to:

- provide background information on climate-related risks due to climate change, risks from extreme weather and climate events, and to define a baseline capacity and the needs for climate services for agriculture in Vanuatu, to increase the awareness of present and future risks, as well as to provide potential solutions to the identified risks in the agriculture sector;
- outline the needs and priorities of climate products and services for agricultural stakeholders in Vanuatu and enhance overall understanding of the key concepts; and
- suggest future development strategies for climate services for agriculture in Vanuatu to increase the climate resiliency of the agriculture sector in a sustainable manner, including a new GCF-funded project on climate information service in Vanuatu.

The general approach to the baseline assessment and identification of potential climate service solutions for the agriculture sector in Vanuatu was based on (a) a review of documents, reports, books, and surveys that described the abovementioned

information and any relevant findings, and (b) interviews with national stakeholders from both the national meteorology service and the agriculture sector to identify issues related to climate change and variability, as well as extreme weather and climate events, including lessons learned from related projects and experiences, and comments on the use of climate products and services. Consultation through emails and phone calls with experts in the Secretariat of the Pacific Community, the University of South Pacific and others, was conducted to identify appropriate climate-smart practices and technologies against extreme weather and climate events, which can be implemented together with climate services recommended for Vanuatu.

Regarding the impacts of climate change, Vanuatu is one of the most vulnerable countries in the Pacific region. These impacts are evident in the multiple climate hazards that result from climate change and variability and extreme magnitude of meteorological events. To address existing climate impacts and to prepare for predicted increases in such risks in Vanuatu, it is important to establish institutional frameworks to facilitate practical application, not only of long-term climate-smart policy development and planning, but also of short-term strategic and tactical climate-smart decisions firmly based on available climate information. These frameworks need to be constantly revamped by timely, cost-effective, and scientifically sound, evidence-based, climate products and services. Such products and services should consider multiple spatial (national to local community level) and temporal (short-term to long-term, i.e., weather to climate) scales to achieve sustainable, climate resilient adaptation and associated development outcomes for all stakeholders in Vanuatu.

Readily accessible, reliable, and scientifically based climate products and services that inform relevant aspects of policy development, planning, and associated decision-making, is a critical requirement by agricultural stakeholders in Vanuatu. The climate services for agriculture need derive from baseline climate services and they need to be based on current capacity and identified needs, resulting from comprehensive analyses by relevant organizations, including the Vanuatu Meteorology and Geo-Hazards Department (VMGD) and the Ministry of Agriculture. Baseline assessment of climate service capacity, gaps, and needs have been elucidated from the multiple ground-verified reports during previous consultation workshops and meetings with key stakeholders at the national, provincial, and local community levels, and from relevant project documents.

The recommendations to address the identified gaps and needs in climate services were developed within the boundary of the Vanuatu Framework for Climate Services (VFCS). The VFCS is mainly guided by the five pillars of the GFCS strategy, namely: user interface platform; climate services information system; observations and monitoring; research, modeling and prediction; and capacity building. The most urgent needs identified through the VFCS were the development of tailored climate products (including training on their use) and the improvement and formalization of the mechanisms for communicating and spreading climate information for sector-specific applications and related sector-specific capacity building.

Subsequently, appropriate climate information products and strategies for effective climate services for agriculture were suggested, based on current baseline climate services identified in Vanuatu, especially the operational services by the VMGD, and in consideration of the existing capacity and needs of the climate service users. In this case: public and private stakeholders in the agriculture sector in Vanuatu, such as the Ministry of Agriculture, the Department of Agriculture and Rural Development, the Vanuatu Agriculture Research and Technical Center, NGOs, farmer associations, commercial farmer groups, and subsistence farmers.

Climate information products that are relevant to the agriculture sector, with recommended directions for improving the quality of individual climate information products for better use by agricultural stakeholders include, agrometeorological observation networks; weather forecasts; seasonal climate outlooks; extreme weather and climate alerts; tailored information for users (farmers, extension workers, NGOs, etc.).

Strategies are discussed for the development and application of climate services that are critical to developing more effective and efficient counteracting measures to prevent and mitigate potential damage from extreme weather and climate events related to climate change and variability. Thus, improvement and formalization of mechanisms for communicating and disseminating climate products and services are included as a major strategy. Next, the need for clear processes and guidance for the operational application of climate services is discussed, together with the need for scientific evidence for decision-making, as well as the need for building end-user capacity to routinely apply climate services in decision making. Moreover, the need for a clear emphasis on the management and application of climate information in accordance with agro-data management to achieve long-term resiliency and sustainability is also considered.

Some of the priority strategies that need to be addressed are listed below:

- Improvement and strengthening of agrometeorological networks
- Enhancement of the availability of parallel climate and agricultural data for sound, science-supported, climate services
- Effective monitoring and early warning of extreme weather and climate events for timely informed decision-making by agricultural stakeholders
- Promotion and use of weather and climate forecasts for operational, tactical, and strategic decision-making by farmers

- Promotion of scientific research and development for reliable, science-based climate services
- Improvement of the spreading mechanisms of climate services to the next-/end-users
- Development of climate service-based adaptation strategies to climate change and variability

In order to enhance ground applicability of the identified climate services in Vanuatu, recommendations are made on appropriate local-specific climate-smart practices and realistically applicable technologies based on information from selected climate services against extreme weather and climate events, such as drought, flooding, tropical cyclones, tsunamis, and pest and disease epidemics. Effective communication of such recommendations will enhance the use of climate services by agricultural stakeholders by showing the affordable and realistic climate-smart options that can be easily taken, upon timely detection and warning (forecasts) of extreme events in Vanuatu. The underlying principle is the basic idea that information must be relayed to facilitate informed decision-making through the availability of subsequent actionable options (or plans) by the end-users of climate services.

Decision-Making Tables for six selected staple crops in Vanuatu, manioc (cassava), taro (*Colocasia* spp.), taro Fiji (*Xanthosoma* spp.), giant taro (*Alocasia* spp.), kumala (sweet potato), and yam, were developed for climate-smart practices based on the 'next 3-6 month' seasonal rainfall forecast. The aim of seasonal forecast-informed decision making through the Decision-Making Table, is to help Vanuatu farmers to make better informed decisions about what crops and varieties to grow and how to effectively manage them under the changing climatic conditions that Vanuatu is experiencing and will continue to experience.

Finally, the GCF funded Van CIS RDP project for Vanuatu is discussed as a way forward instrument for the implementation of suggested climate services in Vanuatu. The main activities and associated outputs planned for this study have been designed specifically to address the priority climate information service needs of Vanuatu and specific target sectors, including the agriculture sector. Based on the baseline information collected in the study, Climate services can be applied and mainstreamed in Vanuatu with regard to decision-making for adaptation and resiliency planning and implementation. Thus, the climate products and services proposed by the Van CIS RDP, especially the ones for agriculture, will become the most effective and efficient climate services for agriculture in Vanuatu. The project will also feature direct engagement with and among all stakeholders, from providers to users of climate services; and thereby it shall be developed and implemented to demonstrate and evaluate best practice approaches to incorporate climate services in decision-making. This is a major shift from conducting regular business to application of climate products and services to reinforce the implementation of adaptation priorities by enabling policies and appropriate institutional arrangements in each sectoral level.

CONTENTS

1. Country Background Information

Vanuatu, located in the South Pacific, is composed of 83 volcanic islands, 65 of which are inhabited. These islands are clustered along an ocean expanse approximately 1,300 km, comprising a total area of approximately 12,200 km^2 (WB, 2011). The total population of Vanuatu is over 253,000 people, evenly distributed among the six provinces: Malampa, Penama, Sanma, Shefa, Tafea, and Torba. Approximately 25% of the total population lives in the urban areas in and around Port Vila, the capital, and Luganville, the second largest city (Fig. 1).

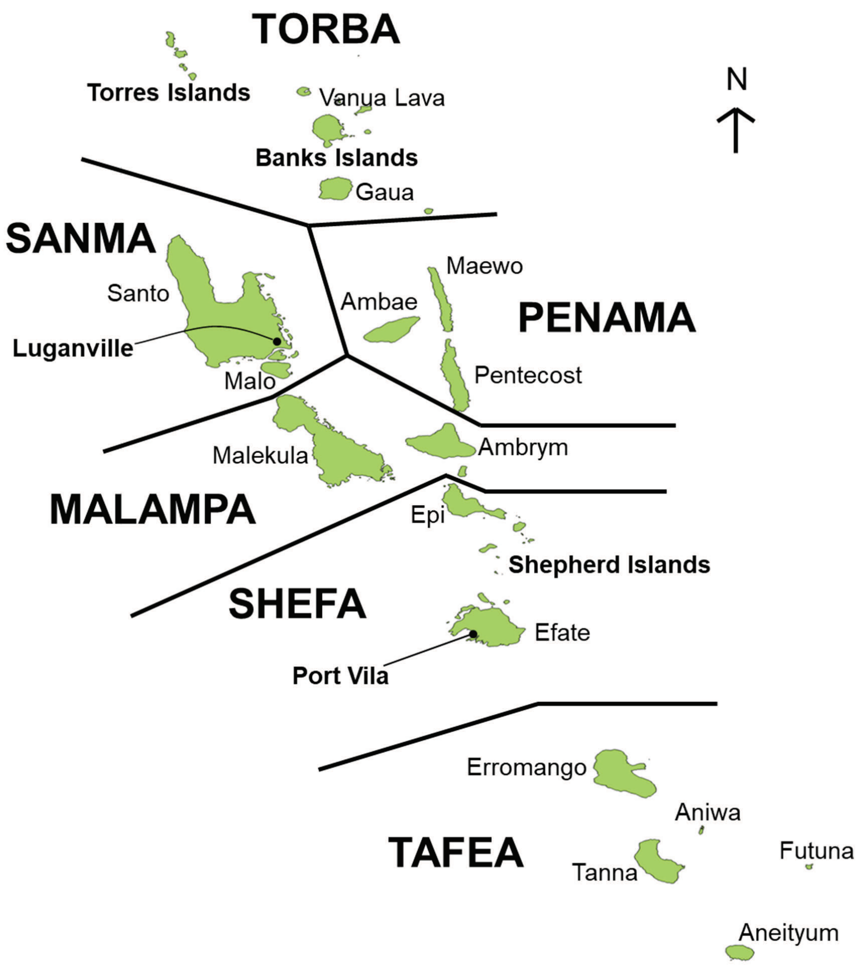

Figure 1. Map of Vanuatu showing the six provinces

Vanuatu, like other Pacific Island Countries (PIC), has a relatively small, open economy with many development and structural constraints. Although the nation possesses some important advantages, including a strong traditional culture for social stability and fertile land, as well as natural resources and a clean environment, its sustainable development is hindered by a strong dependence on relatively few primary product exports and by its vulnerability to natural disasters. In fact, Vanuatu is considered one of the poorest countries in the Pacific, and has been classified as a Least Developed Country, with a per capita GDP of US$ 1,276, in 2011 (WB, 2011).

The economy of the country is primarily based on smallholder subsistence agriculture, a livelihood for approximately 70% of the citizens of Vanuatu (referred to as Ni-Vanuatu). The primary sectors, including agriculture, contribute to approximately 25% of the GDP, compared to the service sector which contributes to approximately 69% (WB, 2011).

Although the secondary (construction and manufacturing) and tertiary (tourism and service) sectors offer a great contribution to the economy of Vanuatu, the primary sectors play a major role in the sustained development of tourism, manufacturing industry, and socio-economic and ecological well-being of Vanuatu.

Nevertheless, the remote location of the country, the small land areas and their separation by vast oceans from main markets and from neighboring islands, and the high costs of providing basic services, render Vanuatu extremely vulnerable to the adverse impacts of climate change and extreme weather and climate events (natural disasters).

Overall, the extreme vulnerability of Vanuatu is attributed to a complex combination of permanent exposure to the risk of natural disasters, such as tropical cyclones, earthquakes, volcanic eruptions, and flooding and drought, and the limited financial and technical capacity of the small country to prepare for and respond to the associated risks, largely imposed by its geographical constraints.

The recent devastating consequences of category 5 tropical cyclone PAM in March 2015, and the subsequent severe El Niño event, highlighted the magnitude of the threat posed by natural disasters in Vanuatu (Government of Vanuatu, 2015).

Predicted increases in extreme weather and climate events caused by climate change indicate greater impacts across all levels and sectors in the future. Vanuatu is also under the threat of volcanic eruptions, earthquakes, and tsunamis similar to other neighboring countries in the South Pacific.

Figure 2. Damage to agriculture throughout Vanuatu caused by the Tropical Cyclone Pam (photos by FAO/C. Spencer)

1.1 Climate

Vanuatu has a tropical maritime climate with relatively uniform temperatures and high humidity throughout the year. The country observes a dry season from May to October and a wet season from November to April (Fig. 3), during which the risk of tropical cyclones is greatest. Rainfall often peaks early in the calendar year because of heavy rainfall associated with cyclones or depressions during that period.

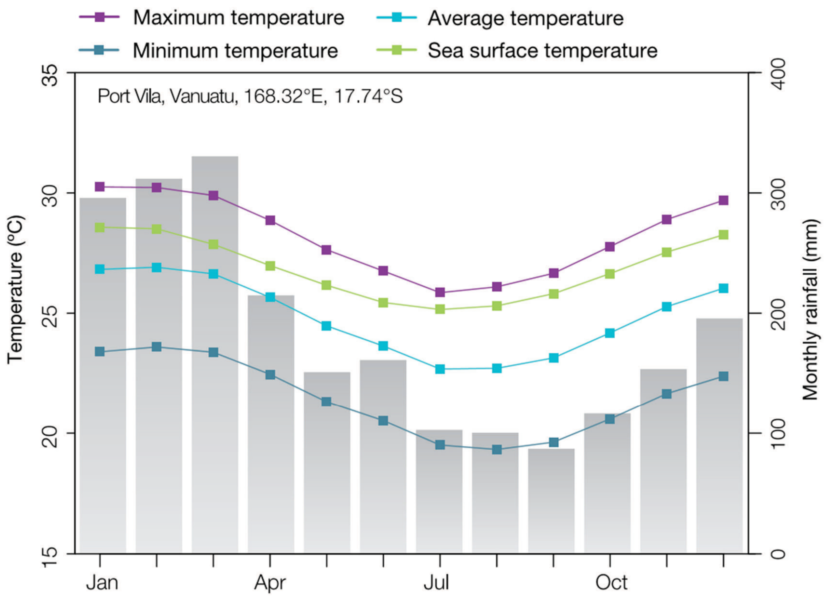

Figure 3. Monthly average rainfall and temperature at Port Vila, Vanuatu (Source: VMGD)

Vanuatu's climate varies with latitude, from wet tropical in the northern islands, which receive over 4,000 mm of annual rainfall, to drier subtropical in the southern extremes of the archipelago, where annual average rainfall amounts to 1,500 mm (Bani, 2016). Average temperature ranges between 21˚C and 27˚C. The state of the El Niño Southern Oscillation (ENSO) and the associated positioning of the South Pacific Convergence Zone (SPCZ) have considerable implications for rainfall during the wet season.

ENSO is a large scale climatic phenomenon that occurs across the tropical Pacific Ocean and affects the weather worldwide in different magnitudes. There are two extreme phases of the ENSO: El Niño and La Niña. In Port Vila and Aneityum, El Niño events lead to drier conditions as well as a late start of the wet season, resulting in lower than normal rainfall and cooler than normal dry seasons. The opposite occurs during La Niña events, resulting in higher than normal rainfall. Vanuatu is prone to a broad range of natural disasters. Cyclones often occur during the warmer months from November to April. The country is also highly vulnerable to other extreme events, including storm surges, coastal and river flooding, landslides, and hailstorms.

1.2 Agriculture

1.2.1 Agriculture Sector in Vanuatu

The economy of Vanuatu is largely comprised of a smallholder subsistence agriculture sector. This small-scale agriculture provides livelihood for approximately 70% of the Ni-Vanuatu population. The agriculture sector is dominated by land cultivation. Crop production represented 79% of the contribution by the sector to the GDP in 2013, a significantly higher proportion than that contributed by livestock (14%), forestry (4%), and fisheries (3%) (Government of Vanuatu, 2016).

Dominant food crops in Vanuatu include taro, yam, banana, plantain, peanut, corn, and leafy vegetables. Copra (dried coconut kernels), kava, and cocoa are the major export crops and important sources of cash income for many rural households.

The agriculture sector in Vanuatu is divided into three distinct sub-sectors, with the subsistence sector accounting for more than 75%, located in tiny village communities throughout the islands. The rest of the agriculture sector consists of a growing semi-commercial sector and a commercial plantation sector. The semi-commercial sector is based on a limited range of traditional cash crops and has the potential for expanding into the emerging vegetable market. It contributes to around 10% of the total production in the agriculture sector.

The subsistence sector is engaged in farming on small agricultural plots called the food garden. It is predominantly centered around root crops (taro, yam, cassava, and sweet potato) for both consumption and cultural purposes, and is characterized by total dependence on rain-fed irrigation. The small plots provide for the subsistence needs of farmers who grow these root crops and sell the produce at local markets. However, productivity of these food gardens is low; thus, the challenge for this sector is to increase productivity and minimize climate risks by introducing sustainable and affordable management practices.

Increasing the number of small plots is a strategy favored by the Ministry of Agriculture, as opposed to increasing the size of existing farmlands. This is because most smallholder farmers are isolated and separated from each other by long distances, with poorly maintained access roads, thereby transportation of products and equipment is extremely difficult and expensive.

Nevertheless, the smallholder involvement in the agricultural cash economy has increased remarkably in recent years. Output from export commodities composed of smallholder farmers exceed the output of the purely commercial plantation sector; smallholders contribute to 80% copra, 70% cocoa, 20% beef, and the entire kava production. In the 1990s, beef was mainly supplied by the smallholder farmers, although this has changed in recent years with the commercialized operations now providing the bulk of the beef consumed locally.

1.2.2 Vulnerability of the Agriculture Sector

Although natural resources, including climatic conditions, are ideally favorable to the agriculture sector of Vanuatu, extreme weather events caused by climate change and variability undermine efficient management and rational use of natural resources. Under these circumstances, while planning strategies for future management and use of the national resources, the impacts of climate change and variability on the natural environment, human health, and other development sectors, should be taken into account. The major factors that are likely to contribute to the vulnerability of the agriculture sector in Vanuatu are discussed below (Reti, 2007).

- **Increasing climate variability and extremes** – The negative effects of climate change and variability exacerbate the inability to increase and sustain agricultural production in Vanuatu. With the increase in temperature and shift in seasonal rainfall patterns, the incidence of frequent and severe extreme events is drastically hampering the already risk-prone agricultural production. The wet season is from November to April, which coincides with the cyclone season. Out of the total number of tropical cyclones affecting Vanuatu over the last 49 years, 36% carried hurricane force winds, 23% storm force wind, and 20% gale force winds (Barnett, 2001). The probability of occurrence of hurricane force winds every year is very high in Vanuatu, which results in storm damage to crops and critical agricultural infrastructure. Although agricultural climate adaptation policies and plans are now widely established, there is still a severe deficit in climate knowledge, information, and implementation of technology in vulnerable agricultural communities.

- **Increasing seasonal variability** – Prolonged wet seasons lead to favorable conditions for pests and diseases that could considerably reduce crop production. Similarly, prolonged dry seasons cause plant stress, leading to reduced production. These seasonal abnormalities are causes of concern for national food and socio-economic security.

- **Lack of access to supporting infrastructure in remote farms** – Due to the great distance, irregular air and boat transportation, and poor road conditions, it is extremely difficult to provide services to the large number of small farms scattered over the islands, especially during times of natural disasters. In addition, extreme weather and climate events have implications for the transportation of agricultural produce from rural areas to markets in the main urban areas In this regard, declining productivity of these small farms will surely affect food security of the smallholder farmers who cannot afford access to distant markets.

- **Loss of traditional farming techniques** – Since ages, wild yam, taro, and sweet potato have been stable food crops, particularly during times of natural disasters. However, yields have been declining in recent years. Besides change in climatic conditions, the loss of traditional planting techniques is believed to be largely responsible for this situation.

- **Poor understanding of the country's forest resources and lack of a sustainable forest management plan** – Knowledge of Vanuatu's forest resources is based on outdated forest inventories. Detailed, up-to-date inventories of the national forests do not exist; therefore, it will be extremely difficult to plan effective management strategies for the valuable forest resources against climate change and variability.

- **Lack of understanding of the impact of climate change on coastal ecosystems and fisheries resources** – There has been no attempt to monitor changes in the health of coastal ecosystems or to establish the association between such changes and climatic events that affected the country over the years. It is likely that coastal ecosystem trends in Vanuatu are similar to those of other PIC, necessitating serious and urgent action. If degradation continues unchecked, the productivity of these coastal ecosystems may collapse, affecting food security of the coastal population.

- **Lack of understanding of the impact of climate change on livestock** – How climate change and climate variability impact livestock remain poorly understood, compared to other sectors. Any climate-change-induced health risks in the livestock animals in the country could pose severe risk to animal production and food security in the country.

- **Limited irrigation water supply** – Prolonged dry spells and drought periods can cause exhaustion of irrigation water, particularly on the small outer islands in the northern part of the country. Many ground water sources on the outer islands of Vanuatu have been rendered useless due to salt water intrusion or simple by overuse. Water levels in the few rivers that exist on the larger islands are reported to be declining, and this trend will continue considering projected decline in rainfall. Such situations will adversely affect agricultural production and food supply in Vanuatu.

2. Understanding Climate Change and Extreme Weather and Climate Events in Vanuatu

Strong scientific evidence links climate change with increasing extreme weather and climate events (IPCC, 2014). More intense extreme weather and climate events could lead to loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources (SPREP and GIZ, 2015).

Extreme weather and climate events are generally defined as the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) end of the range of observed values of the variable (WMO, 2016). In many cases, weather or climate events with a high impact are deemed as extreme events, such as droughts, floods, tropical cyclones, extreme sea level, storm surges, and landslides. For example, droughts and floods may be the result of an accumulation of weather or climate events that are not extreme by themselves, yet the resulting accumulation is extreme. Many weather and climate extremes reflect natural climate variability (including phenomena such as ENSO).

Climate change is likely to have substantial and widespread impacts on Pacific Island Countries (PIC), including Vanuatu. However, the greatest impact will occur on the poorest and most vulnerable segments of the region (ADB, 2013). Coastal areas will witness some of the most substantial damages resulting from sea level rise, leading to soil erosion and coastal inundation; more intense cyclones and storm surges will cause flooding and severe damage to crops and infrastructure; while, higher sea surface temperatures will lead to a decline in coral reefs and fishery production (WB, 2009).

The PICs experience the highest numbers of cyclones in a season during El Niño events. For example, during the 1992/93 El Niño, there were 16 cyclone events, and in the 1997/98 El Niño, there were 17 events. The average (mean) for the South Pacific is between 9 and 10 cyclones per season (Reti, 2007). During October 2007, rainfall was extremely high in areas under the active South Pacific Convergence Zone (SPCZ). Heavy rainfall and flooding occurred in parts of Vanuatu at the end of the month, with Aneityum registering a record monthly high of

443.8 mm. Mean air temperature in October was 1.5˚C or more above normal in parts of Tonga and the Southern areas of Cook Islands. Temperatures were also above normal in Vanuatu at that time.

Agriculture will be mostly affected through the changes in rainfall and temperature, sea level rise, and intensified climate variability. In this chapter, we discuss the impacts of climate change and extreme weather and climate events on Vanuatu in general; long-term impacts of climate change are reviewed, as well as extreme weather and climate are discussed primarily based on their short-term impacts on the agriculture sector in Vanuatu.

Historical and projected impacts of climate change on Vanuatu, and specifically on the agriculture sector, are discussed in the first section of this chapter; while, extreme weather and climate events over the historical periods and the possible impacts of the extreme events on agriculture are discussed in the last section.

2.1 Impact of Climate Change on Agriculture

2.1.1 Climate Change

The impacts of climate change are already being felt across Vanuatu, including sea level rise, increased intensity of extreme events, and changes in agricultural productivity and water availability (WB, 2011). Historical trends in Vanuatu suggest a gradual increase in temperature (1950–2010) that is more pronounced in the south (Fig. 4). Aneityum, located at the southern tip of Vanuatu, has witnessed an overall gradual decline in rainfall, although there are no clear trends in seasonal or annual rainfall over Vanuatu. There has been substantial variation in rainfall from year to year over this period. Similarly, there has been a significant increase in the frequency of tropical cyclones in the country over the recorded period (CSIRO et al., 2015); however, the introduction of the satellite tracking technology and the improvement of recording technology could influence this apparent trend.

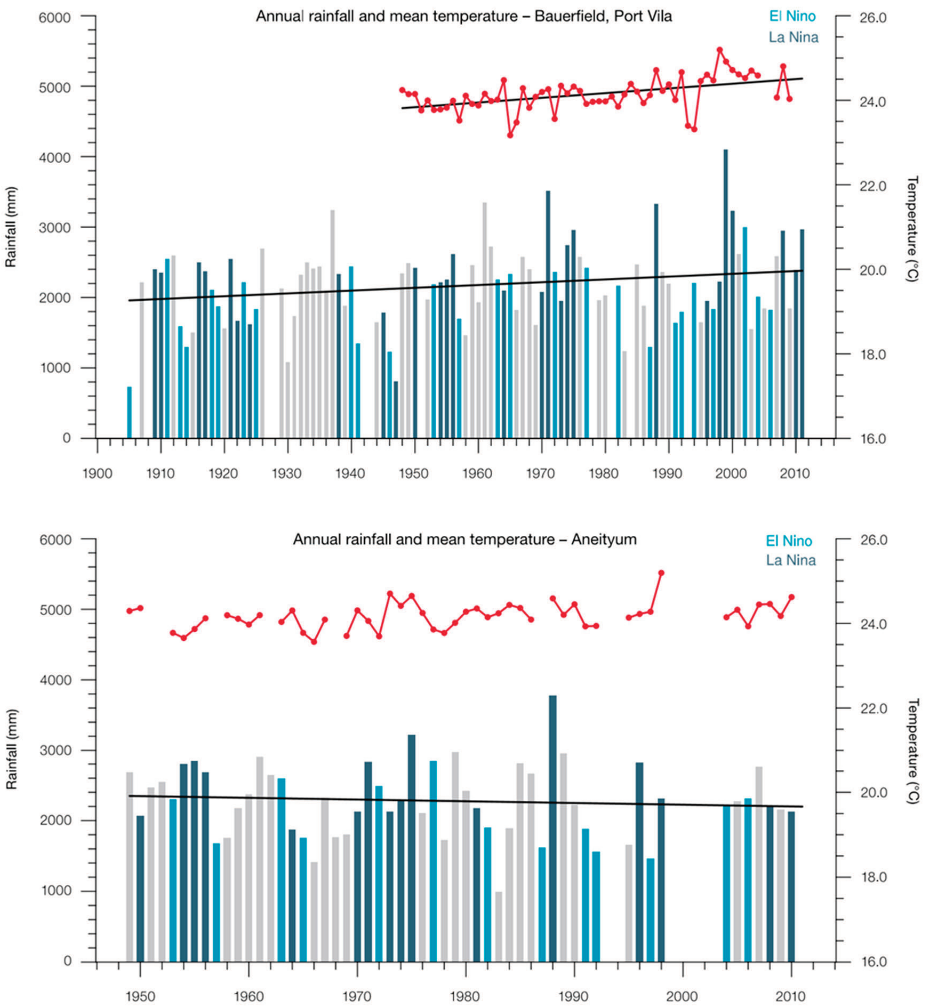

Figure 4. Annual average air temperature (red dots and line) and total rainfall (bars) at Bauerfield Airport, Port Vila (top), and Aneityum (bottom). Light blue, dark blue, and grey bars indicate El Niño, La Niña, and neutral years, respectively. No bars indicate no available data. Solid black lines show the trends (Source: CSIRO et al., 2015).

Based on climate scenarios from global climate models and historical records available, it has been predicted that climate change will lead to warmer and drier conditions in much of Vanuatu over the next century, with the magnitude of the change increasing, away from the equator (CSIRO et al., 2015). However, the possibility of increased rainfall should not be dismissed. These effects will be accentuated by more frequent and severe cyclone events. Heavy rainfall is a normal component of tropical cyclones; thus, a greater proportion of rain will be associated with the passage of cyclones. Indications are that there will be more frequent El Niño type condition s, which are usually associated with prolonged dry seasons, eventually leading to severe drought.

Some of the climate risks expected include the following (BoM and CSIRO, 2014):

- by 2040, daily temperatures will increase by 1.2°C relative to the 1995 levels;
- sea level rise will continue and accelerate; whereby, risks of coastal inundation will be high when combined with storm surges and high seas;
- ocean acidification will degrade 80% of coral reefs within 20 years;
- extreme temperatures will reach higher levels and become more frequent;
- extreme weather events, including cyclones and storms, will increase in intensity, although not necessarily in frequency;
- dry periods will last longer; and
- extreme rainfall will be more frequent and intense; thus, Vanuatu will be susceptible to erosion and flooding due to expected periods of intense rainfall.

Climate change is likely to impact all sectors that are pertinent to the sustainable development of Vanuatu (NACCC, 2007). Therefore, the Vanuatu Climate Change and Disaster Risk Reduction Policy 2016–2030 (SPC, 2015) sets the framework for mainstreaming climate change and disaster risk reduction into sustainable development processes for Vanuatu. The policy identifies key climate change impacts for Vanuatu as follows:

- reduced availability of freshwater (in quality and quantity)
- shifts in crop seasonality of planting, fruiting, and harvesting
- more pests and diseases of animals, crops, and trees
- saltwater intrusion into areas critical to sustainable food security and groundwater
- compromised food security due to less favorable growing conditions for certain important crops

- damage to coral reefs and fisheries leading to reduced fisheries productivity
- increased risk of human disease and health problems, including vector-borne diseases and heat stress
- damage to infrastructure and loss of coastal land
- reduced economic growth and revenue generation

2.1.2 Impacts of Climate Change on Agriculture

The impacts of climate change on agriculture in Vanuatu are not well understood. However, general knowledge of possible impacts suggests that changes may be detrimental to overall aspects of agriculture and, thus, to national food security. In fact, the limited historical data, necessary for the reliable assessment of the likely impacts of climate change on the agriculture sector in Vanuatu, suggest that the impacts given below are likely to be realized for the various components of the agriculture sector in Vanuatu. The following excellent review on the long-term impacts of climate change on crop production, livestock, agricultural water management, and soil and land management in Vanuatu was adopted and modified from the study by Reti (2007).

2.1.2.1 Crops

Although the impacts of climate change on plant growth, productivity, and the nutrient value of crops commonly grown in Vanuatu are not well understood, climate-related incidences are already affecting crop production. Increased temperatures, more frequent and prolonged dry conditions, increased variability of rainfall, salt-water intrusion, drought, soil erosion, and frequent cyclones have been experienced in the past decades. Some crops are showing signs of stress under current climatic conditions. Phenological changes observed show earlier flowering than usual in some plants; while, others are late fruiting than normal during the past 3-4 years. Pest activities have also increased, with yams being the most affected crop in Vanuatu. Water scarce areas and small islands that depend entirely on rainwater are also experiencing severe water shortage resulting in reduced crop production. Therefore, food supply has become limited in dry areas such as the flat-plains immediate to the Yarsu (Tanna), and Benvor and Marum (Ambrym). A similar situation exits in the atoll island of Lau in the Toress Group of islands and the northern part of Marae (Emae) (FAO, 2013). Coastal erosion and inundation are reported from coastal communities in recent years. These problems will be aggravated by any further changes in current climatic conditions (Kumar and Taylor, 2015).

Although some progress has been made in recent years to understand and appropriately address climate change issues, there is currently limited data to enable Vanuatu to plan effective responses to climate change impacts. At the projected temperature increase, heat tolerance threshold of crops is likely to be reached and this will most likely induce heat stress, wilting, and crop failure. Subsistence crop production may fall as a result and, in turn, threaten food security on the islands.

Both commercial and subsistence agriculture in Vanuatu are based on rain-fed agricultural production systems. Changes in rainfall, high intensity storm events, increased evaporation, and more pronounced dry seasons could have severe impacts on crop production. Intense rainfall during planting seasons could have severe impacts due to soil waterlogging and, thus, cause decreasing agricultural production. In contrast, increased humidity and rainfall could provide ideal conditions for the proliferation of many plant pathogens. On the other hand, more pronounced dry seasons, warmer temperatures, and greater evaporation could induce plant stress, thereby, reducing productivity and subsequently affecting food security in the country.

2.1.2.2 Livestock

It is predicted that increased carbon dioxide concentrations in the atmosphere and warmer temperatures will be conducive to rapid growth of green matter rather than crops (NACCC, 2007). However, rapid growth of pastures could decrease their nutritional value, which in turn would result in fewer animals supported per unit area of pasture land; thereby, potentially reducing beef production, both for export and for local consumption. In fact, the Ministry of Agriculture has reported an increased incidence of intestinal problems in cattle, which is likely associated with the low nutrient pasture. Similar problems (parasites and infections) have been encountered by pig farmers.

The Ministry of Agriculture offers limited veterinary service to farmers on Efate and Espiritu Santo only, but is not equipped to offer proper assistance during major outbreaks of animal diseases due to climate change-related events or otherwise. Hot temperatures could result in the relocation of stocks to cooler climates as an adaptation measure, which could translate into significant costs to the farmers, especially given the poor state of most roads in Vanuatu.

Increased temperatures and drought will mostly affect small-scale livestock farmers, as they could cause soil compaction and drying of river streams on which the farmers depend for their primary source of water. Overstocking and overgrazing could result from dried conditions, which in turn would result in loss of animal weight and further degradation of pasture lands.

2.1.2.3 Water Management

Water is vital to agricultural production in Vanuatu. Population growth, particularly in urban areas, is already placing increased pressure on water resources and supply. Climate change is likely to escalate the demand for water and yet reduce the quality and quantity of water sources. This will have implications for water resource management and water use, especially for industry and agriculture, which are heavy water users.

Vanuatu has limited surface water resources; therefore, people on many rural areas and residents of both urban areas (Port Vila and Luganville) are dependent on ground water. Increased temperature is likely to increase the demand for drinking water; however, increased heat, greater run-off from high intensity rainfall events, decreased rainfall, and an associated increase in evaporation, could reduce the rate of ground water recharge and decrease surface water flows. Water shortages that already occur in dry seasons, would become more pronounced, and thus may require a more strategic water management scheme to maintain human populations and agriculture production in severely affected areas.

Any increase in sea level could cause salt water intrusion into the shallow groundwater lens in coastal areas, particularly if ground water recharge is reduced or ground water is over-extracted. Increased rainfall often associated with cyclones could also cause flash floods, soil erosion, and further pollution of freshwater and marine environments. Increasing population will place additional pressure on the already stressed water supply systems and any further pressure resulting fro--m climate change and variability would compound the issue, posing serious problems for Vanuatu.

2.1.2.4 Soil and Land Management

Increased rainfall could result in waterlogged soils, unsuitable for agriculture and other uses. It could lead to soil erosion and loss of soil nutrients that are important for plant growth. Climate change could influence the traditional methods of land management in Vanuatu. Change in rainfall could lead to the introduction of crop species and varieties with lower water demand or the introduction of new land management regimes that are better tailored to cope with the changing rainfall patterns. Monoculture plantations may no longer be suited to the changing climate in certain parts of the country, and changes in rainfall and temperature could result in the proliferation of new or dormant pests and diseases that could cause considerable damage to crops and hence, endanger food security for the people of Vanuatu.

Agriculture crops, such as wild yams, traditionally used as a soil cover to minimize run-off, are reported to be sprouting during the wet season, later than the regular sprouting time at the end of dry season. This means that this crop might have lost its soil protective function because of shifts in weather patterns. The promotion of multi-cropping systems, which are likely to increase the resilience of agricultural crops to extreme weather and climate events and to prevent the spread of pests and diseases often associated with increased temperature and rainfall, may be an appropriate approach to managing soil and land in response to future changes and shifts in weather patterns.

2.2 Impacts of Extreme Weather and Climate Events on Agriculture

Between 1950 and 2004, Vanuatu reported the highest number of natural disasters in the Pacific Islands region (Bettencourt et al., 2006), including droughts, floods, extreme temperatures, earthquakes (and tsunamis), and cyclones (WB, 2009).

Based on (a) the impact of external shocks over which an affected country has little or no control and (b) the resilience of a country to withstand and recover from such shocks, the Commonwealth Vulnerability Index ranks Vanuatu as one of the most vulnerable nations to natural disasters in the Pacific (Atkins et al., 2000).

According to Mahul (2013), the estimated financial losses inflicted by natural disasters are the highest among PICs (Fig. 5). Furthermore, the high population growth rate and the rapid urbanization in Vanuatu have compounded the magnitude of these losses. An ADB report indicated that exposure to cyclones is 40% higher for urban than for rural populations; while, the risk of floods is 17% worse in urban areas in the PICs (ADB, 2012).

A FAO report (2013) identified extreme weather and climate events commonly affecting Vanuatu and geographical distribution of the extreme events over six provincial areas in this country. Fig. 6 shows the geographical location of the six provinces of Vanuatu where impacts of extreme weather and climate events are prominent.

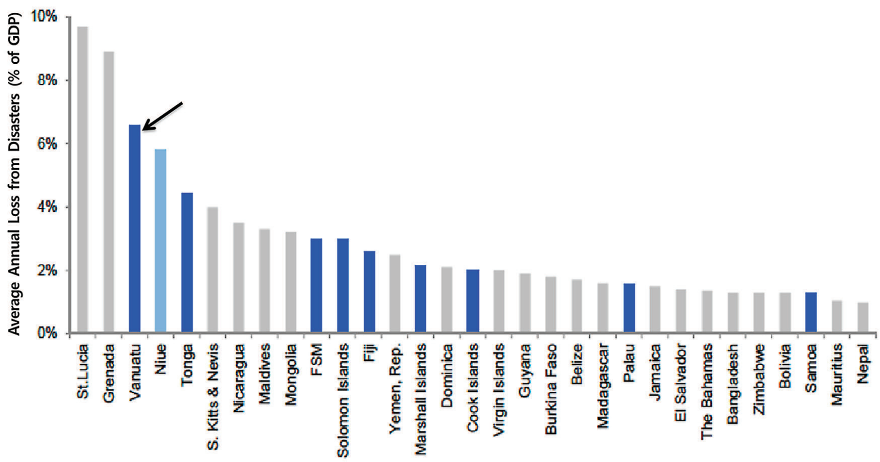

Figure 5. Estimated average annual losses from natural disasters (% of GDP) (Sources: Mahul, 2013)

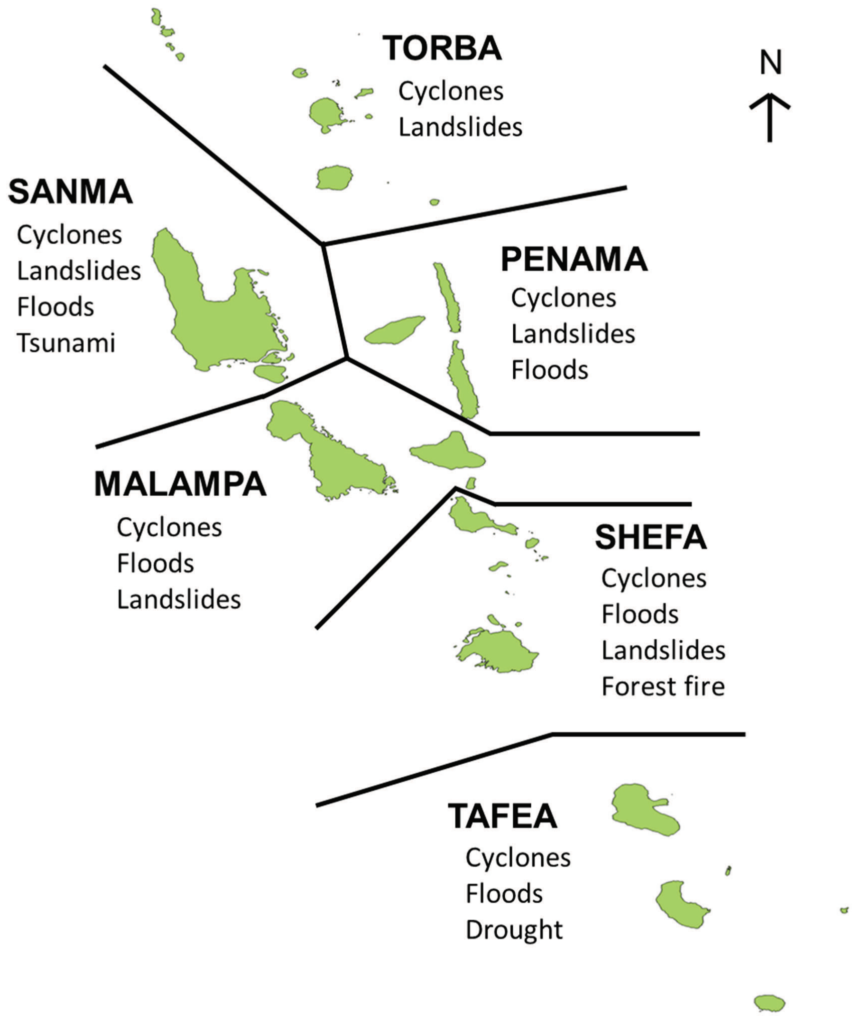

Figure 6. Distribution of extreme weather and climate events among the Provinces of Vanuatu (Adopted and modified from the source: FAO, 2013)

As a direct effect of altered rainfall and temperature patterns, climate change is projected to multiply the risks of extreme weather and climate events over the next decades (IPCC, 2013). Impacts from the extreme events will be inequitably spread throughout the islands; especially in the agriculture sector, predicted severe damage includes contamination of water resources, loss of crops or livestock, increased susceptibility to pests and diseases, and destruction of agricultural infrastructure, such as irrigation systems (Chung, 1996).

As Das et al. (2003) explained that extreme weather and climate events have direct and indirect effects on agriculture. Direct effects result from the physical damage on crops, animals, and trees caused by the extreme hydro-meteorological event. These effects range from short-term temporary damage to complete crop loss. Within hours of their occurrence, extreme events cause acute damage to agriculture in terms of total or partial destruction of farm buildings, machinery, equipment, means of transport and storage, as well as damage to crop land, irrigation works, reservoirs, and destruction of crops ready to harvest.

Loss of perennial crops, such as banana trees or forests, has long-term consequences on the ability to regenerate income. Floods make arable land unsuitable for agricultural production until water is drained, while cyclones might completely wash out arable land or permanently increase salinity through storm surges and flash floods.

Extreme weather and climate events also cause indirect damage; this refers to the loss of potential production due to disturbed flow of goods and services, lost production capacities, and increased costs of production. Indirect effects also include the evacuation of people in the event of cyclone-induced landslides, disruption of households, and stress-induced sickness (Sivakumar, 2008). Such indirect effects manifest progressively, because of lower income, decreased production, environmental degradation and other factors related to the disaster (Das et al., 2003).

Extreme weather and climate events and their impact on agriculture in Vanuatu are discussed below. Definitions of selected extreme weather and climate events are provided in Box 1.

Box 1. Definition of Selected Extreme Weather and Climate Events

Drought is the consequence of a natural reduction in the amount of precipitation over an extended period, usually a season or more in duration. Drought is not a purely physical phenomenon, but instead, it is an interplay between natural water availability and human demand for water supply. For example, agricultural drought is caused when there is insufficient soil moisture for average crop or range production. This condition can arise, even during average precipitation, due to soil conditions or inadequate agricultural management practice.

Flood is the condition that occurs when water overflows the natural or artificial confines of a stream of other body of water, or accumulates by drainage over low-lying areas. A flood is a temporary inundation of normally dry land with water, suspended matter and/or rubble caused by overflowing of rivers, precipitation, storm surge, tsunami, waves, failure of water retaining structures, groundwater seepage, and water backup in sewer systems.

Tropical cyclone is a rapidly rotating storm system in the tropics, characterized by a low-pressure center, a closed low-level atmospheric circulation, strong winds, and a spiral arrangement of thunderstorms that produce heavy rains. Depending on its location and strength, a tropical cyclone is referred to by different names, including hurricane, typhoon, tropical storm, cyclonic storm, tropical depression or simply, cyclone.

Heat wave is a prolonged period of excessively hot weather, which may be accompanied by excessive humidity. The term is relative to the usual weather in the area, so temperatures that are considered normal for people from a hotter climate can be considered a heat wave if they are outside the normal pattern for a cooler area.

2.2.1 Droughts

Droughts are common in Vanuatu and are predicted to become more extreme as the change in weather pattern intensifies (McGregor and McGregor, 1999). Rainfall in the wet season provides most of water supply to the smaller islands of Vanuatu. However, El Niño conditions in this part of the Pacific can shift rainfall patterns, causing significant decrease in rainfall and leading to drought conditions. Droughts are especially damaging in the more remote islands lacking sufficient rainwater harvesting/storage capacity to withstand dry periods, as is the case with most of the southern islands.

The latest El Niño events, which resulted in dry conditions in Vanuatu, occurred in 1982/83, 1991/92, 1994/95, and 1997/98. The worst period of drought in Vanuatu was registered in 1993, between two consecutive El Niño years, causing significant declines in agricultural productivity and exports. More frequent El Niño events could increase the intensity and occurrence of drought. The National Adaptation Program of Action, notes the special vulnerability of the western region of Tanna to drought, with significant negative impacts on both, agricultural productivity and the all-important tourism sector (NACCC, 2007).

Agricultural drought is defined as a reduction in moisture availability below the optimum level required by a crop during different stages of its growth cycle, resulting in impaired growth and reduced yield. Most parts in Vanuatu experience a normal dry season from May through October, which cropping patterns have adjusted to and depend on. In some years, the dry season can be pronounced and extended; thereby, subjecting agricultural activities to severe pressure. Occasional severe drought, as has occurred in Vanuatu a few times over the last decades (1978, 1983, 1993, 1997), can cause not only shortage of food, but also shortage of planting material for rehabilitation in the next season.

During drought, short-term impacts on agriculture include water shortage for agriculture purposes, which rapidly affects health, production, and reproductive capacity of animals; slow growth and low yields from food crops; low productivity from home gardens for subsistence farmers, leading to food insecurity; and increased risk of fires due to prolonged dryness.

2.2.2 Floods

Floods are also common in Vanuatu and are predicted to become more intense similar to droughts, under conditions of climate change and variability. Flooding in Vanuatu is highly associated with tropical cyclones and heavy rainfall over a short time period during La Niña years. Combined with poor farming practices, flooding is responsible not only for heavy and immediate crop losses, but also for soil erosion and nutrient loss from agricultural land, creating favorable conditions for the spread of pests and diseases, further threatening land stability. Additionally, flooding leads to pollution of ground water sources and coastal areas; thereby, endangering the health of rivers and marine life in or around river mouths.

2.2.3 Tropical Cyclones

Vanuatu is one of the most tropical cyclone (TC) prone areas in the Pacific. According to the Vanuatu Meteorology and Geo-Hazards Department (VMGD), geographically, wind speed in Vanuatu is at least 34 km/hr. January and February have the greatest frequency of TCs, with average 2-3 TCs per cyclone season (www.meteo.gov.vu). In total, 124 TCs have affected Vanuatu since 1939; 45 of them were categorized as having hurricane force winds (>120 km/h).

Between 1990 and 1999, Vanuatu experienced more cyclones than any other PIC, at an annual average of 2.6. Among the most devastating TCs to strike Vanuatu, Uma, in 1998, caused an estimated US$ 150 million in damage and loss of 50 lives. More recently, in March 2015, TC Pam struck Vanuatu as an extremely destructive Category 5 cyclone. As a result, an estimated 65,000 people were evacuated; approximately, 17,000 buildings were damaged or destroyed and the cyclone destroyed crops on a large scale; thereby, compromising the livelihoods of at least 80% of the rural population. Low-income victims suffered during the post-disaster period due to reduced income and food source scarcity. Among all agricultural households located in the disaster area, 50% have lost all or part of their crops.

The magnitude of the damage depends on the cyclone intensity and path. Damage to crops and vegetation tends to increase exponentially with wind speed; for example, a 4-fold difference in severity of damage is observed between 180 and 90 km/hr winds. The rapid upward spiraling air in a cyclone can cause extremely heavy rain, particularly when the system is forced to rise over mountains. Low atmospheric pressure during TC storms can raise the sea as high as 2 m, causing engulfment of low-lying areas and considerable seashore damage.

Short-term impacts of TCs on agriculture include wind damage to agricultural crops and forest trees, such as uprooting, tearing up leaves, breaking off branches and making plants unstable; decreased availability of planting material for the following season; erosion of coastal areas due to wave surges and flooding; damage to crops from salt spray and rising sea levels; intrusion of groundwater sources by salt water; destruction of farm shelters and rainwater storage facilities; loss of animals due to falling trees and buildings; damage to coral reefs; outbreaks of pests and diseases; and low fish catch.

3. Understanding Climate Services in Vanuatu

Climate services can be defined as the provision of tailored climate information products to assist user decision-making and planning in climate-sensitive environments. Climate information products (or climate products) are the result of a process whereby climate data and information are synthesized. The effective climate service is expected essentially to lead to widespread social, economic, and environmental benefits through more effective climate-risk management and increased capacities for adaptation to climate change and variability. The key definitions of some basic climate information are provided in Box 2.

A range of climate services are already provided in Vanuatu through the Vanuatu Meteorology and Geo-Hazards Department (VMGD). In this chapter, those baseline climate services that are presently generated and provided by the VMGD will be discussed first. Next, the gaps existing in the present climate services, especially those required for agricultural application, are discussed.

Box 2. Basic Definitions on Climate Information and Service

Climate Data include historic and real-time observations of climate variables, plus climate model outputs covering both, historic and future periods.

Climate Products are the result of a process of synthesis of climate data. The process includes summarizing and interpreting climate data, and generating maps, plots, pictures, tables, and summary reports from the climate data. The climate products span all time scales: past years, current conditions, weather and climate forecasts from short- to mid- and long-terms, and climate change projections for the next several decades.

Climate Services are the provision of tailored climate products to assist user decision-making and planning in climate-sensitive environments.

Weather is the state of the atmosphere as it is experienced at any given moment and location. It is usually defined in terms of temperature, humidity, precipitation, and wind.

Climate is often described as the average weather conditions over a period of a few weeks or more at a specific location. In fact, the climate is best described not only by the average, but also by other measures describing climate variability, including the extremes.

Climate Variability refers to variations in the mean state and other statistics (such as standard deviation, the occurrence of extremes, etc.), of the climate on all spatial and temporal scales beyond that of individual weather events.

Climate Change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties; this change persists for an extended period, typically decades or longer (IPCC, 2014).

3.1 Baseline Climate Services in Vanuatu

Climate services include the production, tailoring, delivery, and monitoring and evaluation of climate products to assist user decision-making and planning in climate-sensitive environments (SPREP and UNDP, 2014). As such, to improve climate services offered to users, an inventory of the current users and providers of climate information must be made, including all available information on climate service capacity, resources and information availability, coordination, and infrastructure (Kadi et al., 2011). This inventory will establish the baseline conditions for the climate services being provided and used in Vanuatu. Questionnaires and visits to assess current level of climate services and to identify needs can be conducted among different groups of providers and users. The objective of the questionnaires is to identify what information they produce, how it is used, and what are the limitations and opportunities for improvement. Following, are the example questionnaires for inventorying the baseline climate services from a user perspective.

Inventory question 1. What kind of climate products and services do you receive and how important do you consider they are for your activity or decision-making?

- Common examples of climate products and services to inventory include, daily weather forecasts; weekly weather forecasts; agro-met forecasts; dekadal climate outlook; monthly climate outlook; seasonal climate forecast; climate change projections; climate change vulnerability assessment maps; extreme weather and climate alerts; early warnings (e.g. outbreaks of pests and diseases); advisories; frost occurrence forecast; rainfall onset and cessation dates; climate atlases.

Inventory question 2. What are the operational modes of dissemination of your climate products and services to the next-/end-users?

- Climate services also include the dissemination of climate products and services to the public or specific user groups. Common interfaces and networks for dissemination include internet; telephone; portal mail; fax; television; radio; workshops; field days/open days; traditional methods; personal contact/communication.

Inventory question 3. How are products tailored to meet your needs? Can you suggest how they could be tailored to meet your needs? If there are any tailored products and services, briefly describe how you apply the information on your operational activities or planning.

Inventory question 4. How easy do you feel it is for users to access and understand climate information in the formats that are currently provided?

Inventory question 5. Are you aware of any framework of cooperation/collaboration with providers of climate products and services?

3.1.1 Climate Products and Services Provided by the VMGD

The VMGD currently provides a range of weather and climate related services to the communities in Vanuatu. VMGD is within the Ministry of Climate Change Adaptation, Meteorology, Geo-Hazards, Energy, Environment and Disaster Management, and consists of seven Divisions, which are Administration; Weather Forecasting and Services; Climate; Climate Change/Project Management Unit; Geo-Hazards; Observations; and ICT/Engineering. These divisions work together to ensure the core functions of the VMGD as the only provider of climate products and services in Vanuatu.

Historical Meteorological and Climatological Data is recorded and collected by the VMGD through seven synoptic weather stations and the Vanuatu Rainfall Network. All the data collected through weather stations and rainfall networks are quality checked and stored in a VMGD database. These weather stations are distributed throughout the country, strategically located in each province (Fig. 7).

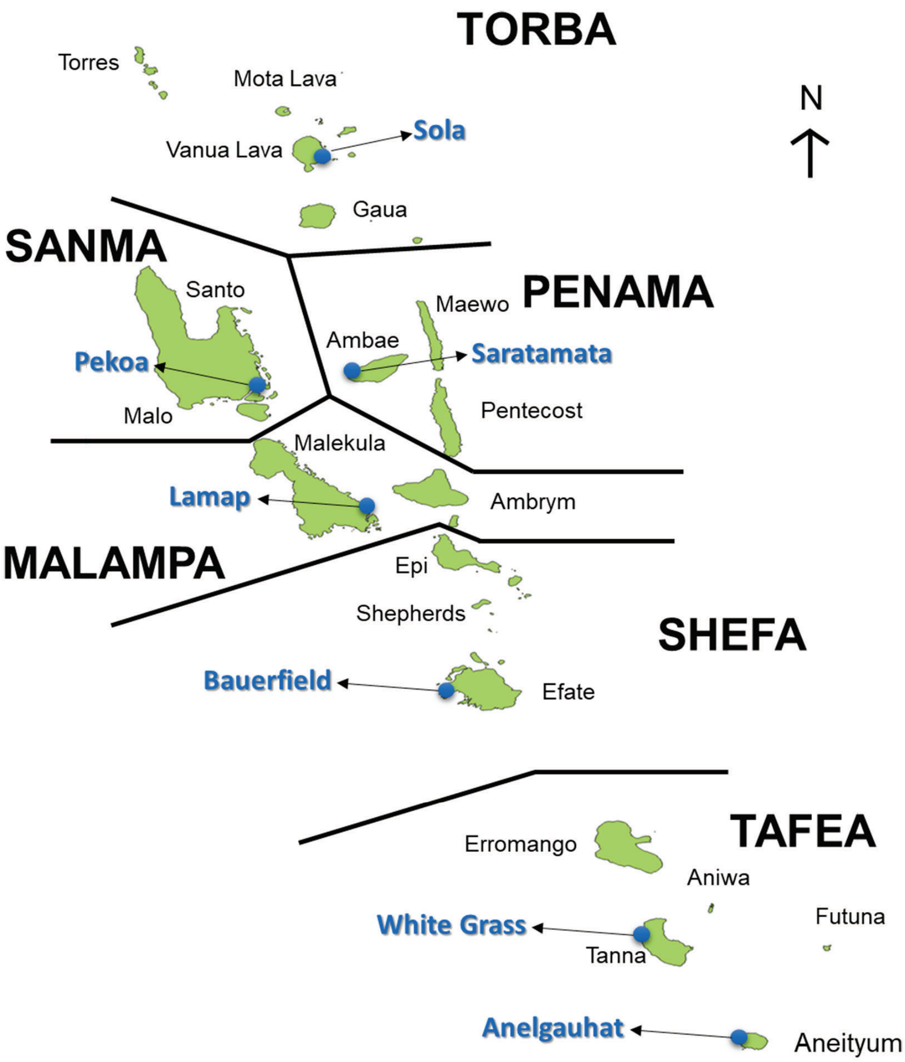

Figure 7. Map of the seven synoptic weather stations operated by the VMGD in Vanuatu

Among the seven synoptic weather stations, Sola station is in Torba Province, Saratamata in Penama Province, Lamap in Malampa Province, Pekoa in Sanma Province, and Bauerfield in Shefa Province. Tafea Province has two observation stations, one on the island of Tanna and the other on Aneityum. These synoptic sites observe and record a range of variables, including temperature, rainfall, visibility and information on cloud type and cloud cover. However, none of these were designed for agrometeorological purposes.

The network of rain gauge stations comprises of 84 locations. Rainfall data from these 84 stations are obtained daily to be used for weather forecasting purposes. These stations are maintained in collaboration with government and non-government institutions and voluntary observers. The voluntary rainfall observers record data in monthly log books, which are then sent to, and manually uploaded into the climate database at the VMGD.

In addition to the meteorological and climatological observation networks, the VMGD operates a Himawari Cast satellite imagery receiving system, two tide gauges, seven seismic stations, and 19 warning siren systems. This infrastructure currently supports the department in collecting data for issuing meteorological and geological forecasts and associated hazard warnings to the people of Vanuatu across the archipelago consisting of 83 islands. However, this infrastructure is not considered adequate to provide national coverage of real-time, high resolution data necessary to inform an early warning system tailored for sectors during severe weather events, such as a tropical cyclone and associated extreme sea level events (storm surge and coastal inundation).

Daily Weather Forecast for rainfall, temperature and thunderstorms, which may be accompanied by strong winds and heavy rainfall with the potential to affect crops, are given via qualified meteorologists and through the deployment of the appropriate, state-of-the-art weather forecasting systems. This information is used by farmers for daily on-farm operation planning.

The 4-day and 7-day Forecasts contain information on how the weather performed during the last 4 and 7 days, and how it is expected to be in the next 4 and 7 days, respectively. The 4-day and 7-day forecasts can be used for short-term agricultural planning, such as planting, drying grain, applying fertilizers and pesticides. It is issued for the five climatologically divided regions of the country based on areal extent.

Vanuatu Climate Update (VCU) is an outlook produced monthly of expected climate for the upcoming three months and includes information on seasonal rainfall, tropical cyclone outlooks, and sea surface temperature forecasts. An English and a Bislama version of the VCU are distributed monthly via the VMGD website and by email. In addition to the VCU, at the VMGD experts are testing a Vanuatu Monthly Climate Summary (VMCS), because there is considerable potential for development of this product, especially in interacting with sectoral stakeholders on a regular basis.

Monthly Climate Briefings are held by the VMGD, in which climate summary and outlook information is presented. This is one of several initiatives for the effective dissemination of climate services to multiple stakeholders. Attendees are generally from government departments and some NGOs. When required, special alert bulletins such as an ENSO update are issued.

Media Releases by the VMGD take place through a radio talk show once a month to discuss climate, weather and tropical cyclones. Media releases and television segments are also produced as required, usually prior to significant climate events.

Tropical Cyclone Seminars are held when required; these enable direct communication with end-users.

Geological Hazards Monitoring is conducted to mitigate potential impacts of geological hazards (earthquakes, tsunamis and volcanic eruptions) by preventing disastrous consequences on the people, environment and economy of Vanuatu.

One-off products have been produced, which contain information on ENSO and climate change projections. In collaboration with Red Cross, a Climate Information Toolkit was developed that provides Red Cross Field Officers with an FAQ sheet about typical climate-related questions asked in the communities. Additionally, the Pacific-Australia Climate Change Science Adaptation Planning (PACCSAP) program produced information on climate change projection for Vanuatu.

3.1.2 Baseline of Current Climate Service Capacity and Needs

The VMGD is playing an important role in the sustainable development of Vanuatu. Recently updated National Meteorological and Geo-Hazards Strategic Plan 2014-2023 (VMGD, 2014) indicates some selected goals of the VMGD in terms of climate products and services as follows.

- Improved weather services aviation, marine, and public weather services
- Improved climate services seasonal forecasting, ENSO advisory services, and public climate outreach services
- Improved climate change services the development of national policies and a framework for national coordination and their implementation
- Enhanced capacity of the VMGD to undertake research and development, extend outreach and communications, and deliver sustainable technological developments.

Climate services in Vanuatu have recently been enhanced by the increasing demand from end-users of climate information. The scope for more climate services continues to grow as the information of the needs of end-users grows and the new methodologies and tools are introduced. Although historically the Vanuatu government has rightly emphasized on climate change adaptation, it will also need to focus specific attention on climate products and services to better inform about weather and climate-related risk reduction and management.

Understanding and addressing the full scope and scale of climate service gaps and needs of end-users will provide the baseline for further development. From the baseline, the impacts from enhanced climate services can be measured.

Based on the VMGD Strategic Plan 2014–2023 and the Vanuatu Framework for Climate Services (SPREP, 2016), there seems to be no clear processes or guidance in place for the operational application of climate services as fundamental components of decision-making in relevant sectors. In addition, there are no clear capacity building targets for the collection, management, and application of weather and climate risk information in sectoral development and action strategies.

Although there is a general understanding that decision-making for climate-resilient consequences should be informed by the best available information and capacity, targeted application of climate products and services to decision-making processes, is still fairly "new" for sectors and communities due to a lack of such capacity and clear strategies for the best use of the knowledge and information from the VMGD by sectors and communities in Vanuatu.

There may also be a tendency to rely on existing local or traditional knowledge about risk and risk management. However, the applicability of this information may be decreasing as the local context changes through socio-economic pressures, such as population growth and demands, as well as the changing and increasing intensity and frequency of extreme events. As such, the existing local knowledge may no longer be sufficient to ensure resilient development.

Other identified baselines include:

- Linkage between the VMGD and sectors can be a challenge exacerbated by limited staffs at the VMGD
- Lack of feedback received by the VMGD from end-users (no feedback mechanism)
- Lack of sectoral computer simulation modeling using meteorological data as input variable to help establish the linkage between the meteorological service and end-users
- Lack of opportunities for strengthening and expanding the communication capacity of the VMGD to ensure that qualified climatologists engage with various stakeholders.
- Few alternative mechanisms identified to reach communities when resources are limited and extension services do not have sufficient reach
- Lack of formal MoUs and agreements with sectors required to overcome some of the “protocol” issues
- Non-realistic expectations placed on the VMGD, which has different levels of capacity for the climate services for different sectors

Another significant barrier is the lack of sectoral capacity to mainstream informed decision-making to support sector-specific adaptation strategies and climate-resilience improvement in the short, mid, and long term. In addition, challenges are evident due to constraints on existing capacity and resources at the national level, combined with the lack of sector specific assessments of climate service gaps and needs (or indeed, the records of any such assessments could not be found).

On the basis of these baselines, this report will address the agriculture-specific assessment of climate service gaps and needs in the following section.

3.2 Gaps in Climate Services for Agriculture

As mentioned in previous chapters, climate change poses critical challenges, particularly through the present and forthcoming impacts on agriculture. Thus, there is an increasing need to work in collaboration to ensure that national meteorological services provide climate services that can be implemented by the agriculture sector. Regarding the climate service development through strategic partnerships between meteorological service and the agriculture sector, the Regional Expert Roundtable on Climate Services for Agriculture and Food and Nutrition Security held in Samoa in 2015 (SPREP et al., 2015) identified climate information gaps and needs from the agricultural user perspective.

Some identified climate information gaps include:

- Timely access to data
- Farm-level understanding of the combination of risk, hazard and vulnerability
- Effective assessment of the needs at community level in terms of climate information to ensure that information provided is relevant
- Need for assessment of the capacity of extension staffs who provide information
- Development of effective "language" that links scientific climate services and climate change information into messages that facilitate actual changes in farming practices on the ground
- Introduction of risk indices in forecasting, to create an early warning system for the agricultural stakeholders

Based on these identified information gaps, agricultural users expressed their climate service needs:

- Climate aspects that will affect plant nutrients
- Drought risk-available water capacity for plants and prediction of water stress
- Agriculturally relevant weather variables and climate products, including forecasts
- Community-level messages must reach the farmers in a way that are actionable for them (including practical recommendations)
- An effective two-way communication mechanism must be established so that meteorological services can understand end user requirements
- For pest management, reliable forecasts are required for both macro climate (national outbreak) and micro climate (pockets of outbreak) to prepare for both scenarios
- Limited agricultural data to link to the meteorological data; these are required for historical analysis or projections

The impact of climate change and variability on agriculture and food security is not significantly different among countries in the Pacific region, indicating that identified gaps and needs in the Pacific regional meeting held in Samoa can be referenced for the Vanuatu baseline assessment of climate services for agriculture. In fact, the Vanuatu stakeholder consultation carried out as part of the GCF Readiness Project in Vanuatu revealed similar gaps and needs for the climate services for agriculture (VMGD et al., 2016).

Some of climate service gaps and needs identified through multiple interviews with agricultural stakeholders in Vanuatu are as follows:

- There is little information exchange between the VMGD and sectoral partners such as the Department of Agriculture and Rural Development (DARD) and the Vanuatu Agriculture Research and Technical Centre (VARTC), and there is a need to further enhance this collaboration.

- An automatic weather station was installed by the VMGD onsite for more than 2 years; however, the VARTC cannot access the data for research. Thus, a collaboration is required.

- Droughts due to 2015/16 El Niño affected more than 49% of the farmers. However, no alerting system for drought was available that could help farmers to access critical climate information on various climate parameters and to support decision-making and planning for their farms at different time-scales.

- Capacity building and limited human resources restrict appropriate use of the climate products and services in agricultural decision-making, because the climate information is too technical and difficult to understand.

- Some climate services have been recently made available to farmers, to determine the type of preparedness activities to be carried out if less or more rain is expected, such as through the Agro-Met Bulletin, the Vanuatu Climate Outlook Bulletin, and Climate Summary. However, there is a need to further improve the quality and quantity of climate services.

- Despite the baseline identified for current climate service capacity, climate products and services require a great deal of upgradation to improve performance at all levels. The consultation raised the need for the agricultural sector and the VMGD to collaborate and function together as this sector is the backbone of Vanuatu's economy. This is key to resilient development.

- Due to limited weather station coverage, the information collected does not reliably cover the whole of Vanuatu or, at least where agricultural activities of most farmers occur; thus, the Outlook for agriculture planning has limitations.

- The Outlook does not providing specific advice for key commercially viable crops or animal husbandry.

- There are few available agricultural data (e.g., crop yield, trials, and surveys) collected and archived to support agrometeorological service development.

- More agrometeorological observation stations are needed in the provinces and in highly risk-prone areas, where key farmers are located.
- There are challenges regarding timely dissemination of climate services to end-users and from the VMGD to Provincial Governments. The right timing of the release of climate information is highly important for timely decision-making; otherwise, late delivery may cause significant loss in farming activities.
- Local communities rely on radios for receiving climate information, but not all provinces in Vanuatu have radio coverage. The limited means of communication to users in the outer islands and more remote areas (provinces) that lack internet access and have poor radio reception should be addressed.
- The limited communications capacity of the VMGD staffs to tailor weather and climate information for farmers needs to be considered. During the consultation, farmers expressed value in having a face to face communication with the VMDG; however, due to capacity constraints it is not possible.
- Traditional knowledge is used almost ubiquitously by coastal communities in Vanuatu to prepare for extreme events and by farmers in deciding which crops to plant. Given the difficulties to access climate products and services from both, national and provincial levels, this is of course natural. The integration of this important traditional knowledge with climate products and services is a challenge for both, farmers and providers of information. Successful integration would assist in managing yield expectations of farmers.

Consistent with the priority areas for climate services for agriculture outlined in the Vanuatu Framework for Climate Services (VFCS) during the Vanuatu stakeholder consultation, some of the priorities were highlighted. Some identified recommendations for priority climate service tools and systems included, 1) establishment of new agrometeorological stations at major crop production areas/islands to be able to provide climate information for sectors in those areas; 2) development of packaged information products (such as animation, posters, etc.), specific to agriculture, that can be easily accessible to the extension officers; these products can be used to assist farmers and rural communities during field days for farmers climate-field schools and at selected climate service demonstration farms; 3) development of a mobile application for agro-climate information products for enhanced information dissemination, and 4) crop modeling for the main cash crops and root crops that are often susceptible to extreme events.

Considering the baseline gaps and priority climate services identified, recommendations for climate services for agriculture in Vanuatu are discussed in the next chapter.

4. Recommendations to Address Gaps in Climate Services

Ready access to credible, science-based climate services together with the requisite capacity and infrastructure to inform all aspects of policy development, planning and associated decision-making is a critical requirement of stakeholders in vulnerable countries. As mentioned above, Vanuatu is one of the most vulnerable countries in the world to climate change and variability and in a shorter-term to extreme weather and climate events. Various temporal scale impacts of climate change and extreme weather and climate events on agriculture in Vanuatu appear inevitable due to the many fundamental vulnerabilities of the country. It was also shown that Vanuatu has the potential capacity to adapt to the climate risks by proactively applying and mainstreaming climate services in decision-making for resilient planning and implementation. In essence, this indicates that there is hope.

However, our diagnosis indicates that the baseline conditions relating to access to and use of existing climate services provided by the VMGD need comprehensive improvement in terms of quality and quantity. Furthermore, with the limited existence of tailored climate products and services, and the absence of clear processes or guidance for the operational application of those climate services, decision-making in relevant sectors lack fundamental components. Such use of climate services also needs to be mainstreamed into institutional arrangements within different levels of government, to strengthen long-term sustainability.

Based on these gaps and the prioritized climate service elements, recommendations for climate services for agriculture in Vanuatu are discussed in this chapter.

First, we focus on the Vanuatu Framework for Climate Services (VFCS), to understand the concept of national framework for climate services, in which, the priorities of the VMGD for better and more climate products and services and the mechanisms and requirements for improving the communication, dissemination and use of climate information, are identified. Finally, the roadmap for strengthening climate services in Vanuatu is outlined. Within the boundary of the VFCS, recommendations to address the identified gaps and needs in climate services for agriculture are developed.

Second, recommendations on climate services for agriculture are discussed, focusing on the improvement of the quality of climate products and services, as well as new strategies for effective climate services for agriculture.

Third, appropriate climate-smart practices and technologies for extreme weather and climate events are suggested, which are realistically applicable, based on the information from selected climate services. This is to provide available climate-smart practices as potential but realistic adaptation actions against individual extreme events.

Finally, the Decision-Making Tables based on seasonal climate forecasts for six selected staple crops in Vanuatu are suggested. These tables entail recommended climate-smart practices, based on next 3–6-month seasonal rainfall forecasts. This can help Vanuatu farmers to make better-informed decisions about the crops and varieties that can be grown, and implement strategies to effectively manage cultivation against different rainfall conditions during cropping seasons.

4.1 The Vanuatu Framework for Climate Services

The GFCS is a global partnership of governments and non-governmental organizations that produce and use climate information and services (http://www.wmo.int/gfcs/). It seeks to enable researchers, producers, and users of climate information to join forces to improve the quality and quantity of climate services worldwide, particularly in developing countries. The aim of the GFCS is to foster better management of the risks faced by the society due to climate change, as well as to seize opportunities to adapt and thrive.

The GFCS implementation plan has a structure that comprises five elements (Fig. 8):

- User Interface Platform — provide ways for climate service users and providers to interact and improve the effectiveness of the Framework and its climate services
- Climate Services Information System — produce and distribute climate data and information according to the needs of users and to agreed standards
- Observations and Monitoring – develop standards for generating necessary climate data.

- Research, Modeling and Prediction — harness science capabilities and results to meet the needs of climate services
- Capacity Building — support the systematic development of institutions, infrastructure, and human resources needed for effective climate services

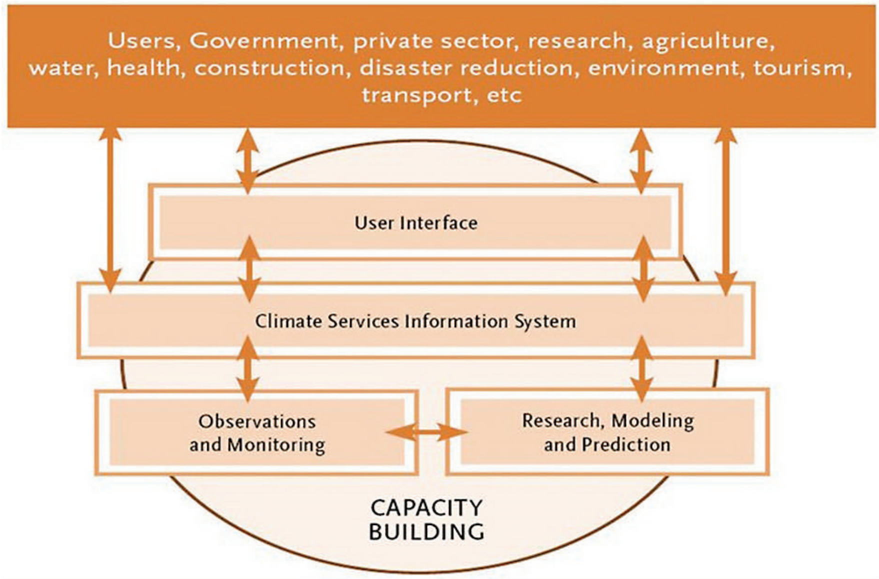

Figure 8. The five pillars of the GFCS and their links to various user communities (Adopted from WMO, 2014)

Climate information providers are generally governmental organizations established at the national level for performing meteorological and related functions. The VMGD, as the main government organization of the national meteorological services in Vanuatu, is the climate products and services provider.

The users of climate information can be divided into two categories. The first category includes those users that process climate information into possible impacts and propose mitigation options and advice (e.g. boundary organizations) to the second category, decision-/policy-makers or end-users (e.g. farmers, managers, political leaders). Boundary organization is an institution or entity that works with users in each sector or sectors at various levels and that has, at the same time, certain in-house expertise in understanding and interpreting climate information products, such as the Ministry of Agriculture, DARD, VARTC, and NGOs in Vanuatu.

Although the VMGD has been providing a range of excellent weather and climate-related services to the communities in Vanuatu, further improvements are required to strengthen these climate services, especially for relevant sectors in Vanuatu, and make them sustainable in using the services. The Vanuatu Framework for Climate Services (VFCS), which has significantly benefitted from various consultations, discussions, surveys, and other feedbacks, highlights many possible ways to achieve the goals (SPREP, 2016).

The VFCS is principally guided by the five pillars of the GFCS; it presents details of all current products and services offered by the VMGD and highlights the institutional, human, technical capacities and issues and priorities to be addressed in the future by the VMGD. The stated goal of the VFCS is to ensure that climate services for Vanuatu are sustainable, of world-class standard, are reaching all end-users, and are effectively helping people manage and adapt to climate variability and change in Vanuatu (SPREP, 2016).

The most urgent needs identified through the VFCS were the development of tailored climate products (including training on their use) through key stakeholder consultation and improvements and formalization of mechanisms for communicating and disseminating climate information. The common requirement from other sectors was appropriate information regarding current and forecasted climate, and the risk of adverse impacts pertinent to their sector and areas of responsibility. For example, the Ministry of Agriculture needs to include information on the amount of rainfall during the current wet season, whether any variation from normal rainfall, the provinces experiencing lowest/highest rainfall, and the climate outlook for the upcoming months. The Ministry then has a responsibility to act on this information to mitigate agricultural production and food security issues.

The VFCS indicates the fundamental structure for the provision of effective climate services in Vanuatu involves the core components: observations; modeling; climate services information system; user interface platforms; and capacity development.

Fig. 9 outlines several key requirements for strengthening and maintaining climate services in Vanuatu. The diagram demonstrates the flow of information from observations and research through product development, to user communities in the form of data services and product services. At each node, modes of operation, international linkages, and training needs are highlighted as ways of enhancing the capacity of both, providers and receivers of climate services.

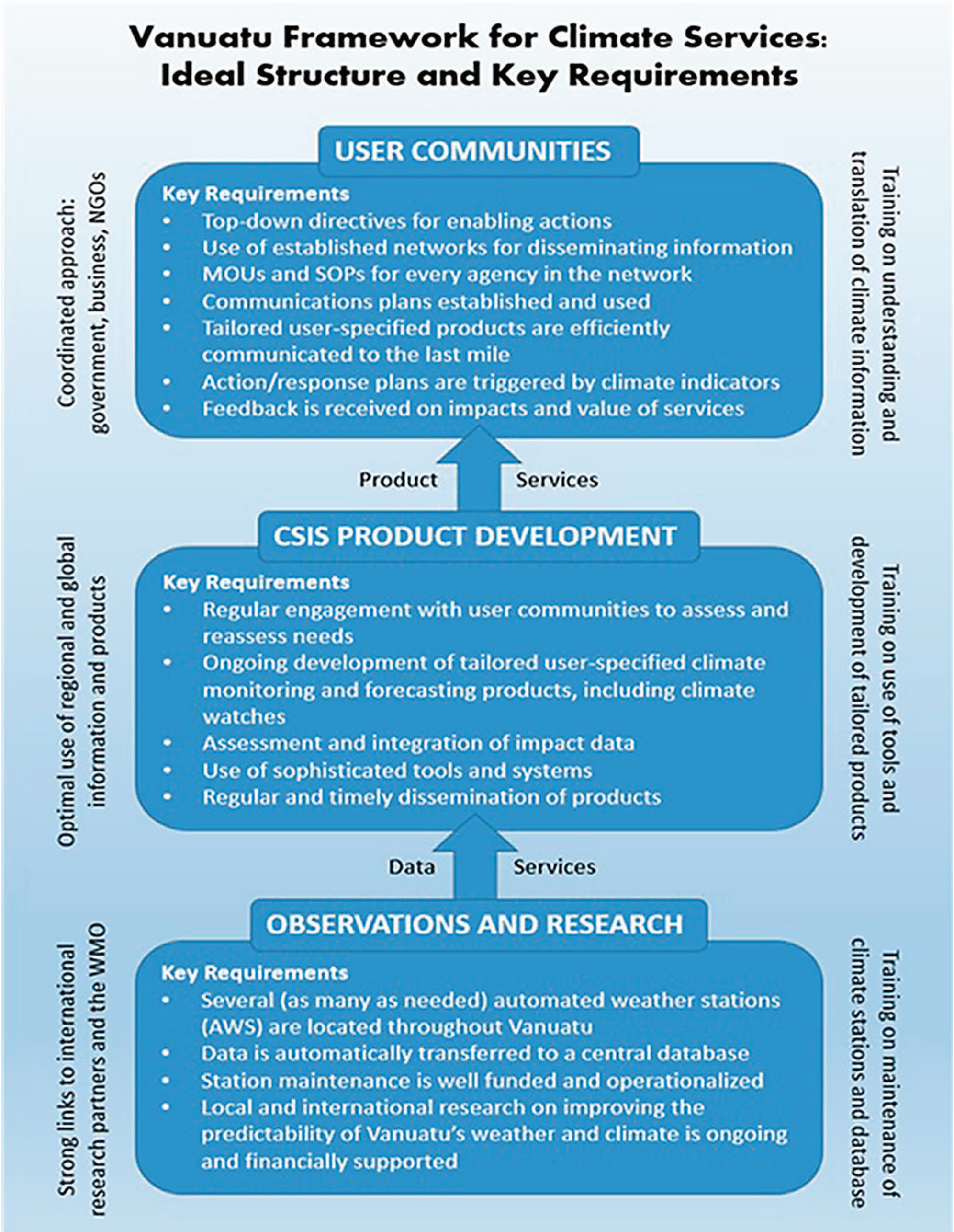

Figure 9. Structure and requirements for the VFCS (SPREP, 2016)

4.2 Recommendations on Climate Services for Agriculture

4.2.1 Improving the Quality of Climate Information Products

The National Meteorological Services (NMS), part of the Vanuatu Meteorology and Geo-Hazards Department (VMGD), generally provides climate information products. Most climate information products are useful for agriculture. However, to lead to informed decision-making in the agriculture sector, these products need to be tailored and translated into agriculturally relevant information, and would require strategic partnerships between the climate information providers and users, necessitating close communication between the two entities.

This section explores a selection of appropriate, primary climate-information products that are relevant to the agriculture sector, with recommended directions for improving the quality of individual climate products for improved use by agricultural stakeholders. The agriculture sector can take advantage of several categories and types of climate products, including, agrometeorological observation networks; weather forecasts; monthly and seasonal climate outlooks (forecasts); extreme weather and climate alerts; observed climate impacts; and tailored information for agricultural users (farmers, extension workers, and NGOs), as briefly described below:

4.2.1.1 Agrometeorological Observation Networks

Application of meteorological information to enhance agricultural productivity entails helping farmers to exploit the opportunities presented by favorable weather and climatic conditions, while working with them to mitigate the expected impacts of adverse conditions. In this regard, observation of both physical and biological variables in the environment is essential in the development of climate services for agriculture. As the growth of plants and animals results from the combined effect of genetic characteristics and their response to the environment, meteorological information is necessary for assessing their performance. Detailed information on the agrometeorological observation networks is provided below, by referencing the WMO Guide to Agricultural Meteorological Practices (WMO, 2010).

Agrometeorological Station: An agrometeorological station provides meteorological data for agricultural purposes. The observations depend on the purpose for which they will be used. A principal agricultural meteorological station that is needed for basic agrometeorological services provides detailed simultaneous meteorological and biological information.

Observation Variables: The most common meteorological variables measured by agrometeorological stations include air temperature (°C), maximum, minimum, and dew point; soil temperature and moisture at different depths into the soil profile; relative humidity (%), rainfall (mm); sunshine duration (h), solar radiation (MJ m^{-2}), and wind speed (km h^{-1}) and direction. Parallel agricultural data, such as crop variety grown, development stage attained by the crop, general assessment of crop performance, damage by pests, diseases and adverse weather conditions, state of weeding in the nearby farms, plant density, and final crop yield, are also needed to assess the impacts of agricultural activities and processes on the environment.

Sensor Specification: Specifications of an automated weather station for agrometeorological purposes are attached in Appendix 1.

Site Selection: When selecting a site for an agrometeorological station, the purpose of its observations must first be decided. If it is intended to be regionally representative, then even a woody region or an open location is sufficient. If the purpose of the agrometeorological station is to assist in the operational support of a local agricultural situation, then it can be considered representative if its location is typical for that application. In addition, the site of an agrometeorological station should be on a level ground, and should never comprise concrete, asphalt, or crushed rock ground. Obstructions such as trees, shrubs, and buildings should not be too close to the stations. Accessibility to the station and the possibility of recruiting good observers locally should also be used as the criteria for site selection.

Maintenance: An important step in the observation and measurement process is quality assurance/control (QA/QC) of the data (WB, 2015). The QA/QC should be a rigorous process to ensure rapid identification of failing sensors and drifts in calibration and maintenance of accuracy and precision of measurements within the desired range. Even with simple measurements, such as temperature, the QA/QC process must be efficient to ensure that all reported values, particularly those of extremes, reflect the real situation. The QA/QC process is particularly important for detecting trends that are small in magnitude from a limited number of data.

Agrometeorological Services: The data measured or collected by the agrometeorological stations provide the background for the short-term decision-making involved in activities, such as response farming, monitoring of and preparedness and early warning for natural disasters, along with forecasts for pests and diseases. It can also be used for the preparation of agro-advisories and climate services on farming activities, including irrigation and tactical farm management and manipulation. Ample data on national coverage over several years can also be used for climate monitoring and prediction.

4.2.1.2 Weather Forecasts

Weather forecasts for the next 24–48 h, seven, or ten days are issued daily to the agricultural communities and to the public. They normally comprise detailed likelihood of forecasts (possibility of rainfall and temperature) for the following day for selected locations in Vanuatu. According to the WMO Guide to Agricultural Meteorological Practices (2010), general parameters for agricultural weather forecast include, amount and type of cloud cover; rainfall; maximum, minimum and dew point temperatures; relative humidity; wind speed and direction; extreme events, such as heat waves and cold waves, fog, hail, thunderstorms, wind squalls and gales, and cyclones.

Weather forecasts influence decision-making processes for everyday agricultural practices. For example, if the weather forecast indicates that the rainy season will begin around harvest time, farmers will need to get prepared to complete harvesting before the rain. In addition, forecasts can help farmers to manage pest and diseases, as well as irrigation and fertilizer use, for best results. If the forecast indicates longer dry seasons following short rainy seasons, farmers can take timely measures to arrange for water harvesting or other water supplementary source to ensure supplementary irrigation. Finally, the weather forecast enables farmers to manage the whole value chains (land preparation, planting, management of crops, harvesting, etc.), under appropriate and optimum conditions for increasing crop productivity. All these factors improve agricultural productivity and eventually, long-term farmer sustainability under the increasing pressure from climate change and variability.

However, using weather forecasts in agricultural decision-making, elicits legitimate concerns of credibility among users: to believe or not to believe. The credibility of the forecast is partly determined by past forecast success in predicting weather and climate conditions accurately and timely, and partly by the reputation of information providers. Based on past forecast failure, decision makers may perceive that making decisions based on forecast is risky. However, sometimes these issues can arise because the probabilistic nature of weather forecast is not effectively communicated, and users expect a deterministic forecast. Improved credibility may therefore depend not only on improved forecasts, but also on a better understanding of the varying probability of accuracy. Thus, credibility may depend on a better communication and a more careful translation from original climate information products, into agriculturally relevant information.

4.2.1.3 Seasonal Climate Outlooks

Seasonal Climate Outlooks are developed and disseminated monthly to farmers and to the public. A probabilistic outlook of temperature and rainfall for the next season (3-6 months) is issued in a tercile format (Above normal; Normal and Below normal). Currently, the VMGD provides three-month-averaged tercile probabilistic forecasts only for rainfall. Temporal and spatial resolutions of the forecasts need to be improved and temperature forecast should be added for various agricultural uses. In addition, current seasonal forecasts are quite broad and only differentiate "north" and "south" Vanuatu. However, it would be desirable to provide province-specific and even island-specific forecasts.

Other information in the seasonal climate outlook includes performance of the previous season in terms of rainfall and temperature (statistics on the observed weather variables against long-term mean), and performance of crops and observed impacts (based on regular communications or reports from designated agricultural officers). This information can also be presented in a dekadal (approximately 10 days) or monthly scale. Based on the demand from agricultural stakeholders, the seasonal outlook may include the onset and cessation dates, as well as the distribution pattern of seasonal rains, based on the selected analog years.

The National Climate Outlook Forum (NCOF) provides a suitable platform for interaction between providers and users of seasonal climate forecasts downscaled at national level for decision-making in the agriculture sector, and in other interested sectors. The Vanuatu Monthly Climate Summary (VMCS) published by the VMGD is one of the efforts to respond to the NCOF interactions. The VMCS reports on the data of previous months, large-scale phenomena influencing the observed climate, shift from the normal climate (if any) at a particular time of the year, and the impact of any specific events that occurred.

Similar to the weather forecast, credibility of seasonal forecasts is crucial. Since the forecasts are derived from statistical and/or dynamical models, there is always a degree of uncertainty in the climate products from the models. High skill seasonal climate forecasts can help not only to reduce climatic uncertainty, but also to reduce livelihood risk to farmers; however, the uncertainty associated with the forecast should be accurately communicated, understood, and integrated into the decision process.

4.2.1.4 Extreme Weather and Climate Alerts

These alerts are normally communicated when there is demand from users. Extreme weather and climate alerts provide extreme weather and climate updates, as well as timely information on major regional climate stress and impacts associated with extreme weather and climate events, such as heat waves, strong winds, drought, and floods. These weather and climate extremes are associated with either very short-term atmospheric state or long-term atmospheric phenomena such as El Niño/La Niña events. It also specifies cumulative associated impacts of previous extreme climate events.

Maps are an excellent medium for reflecting spatial variations in climatic conditions in a country. Baseline climate maps need to be produced that present the average wet season and dry season rainfall, average temperature, drought and flood risk "hot-spots", TC high wind hazard/risk maps, and climate change rainfall and temperature projections. Maps showing current weather or climatic conditions are also extremely useful. It is important to underline that, such maps can be combined with the baseline maps to indicate the differences between current and normal weather or climatic conditions.

4.2.1.5 Tailored Information for Users (farmers, extension workers, NGOs, etc.).

"Tailored information" is comprised of user-tailored climate products and services for the agriculture sector. This includes crop-specific water stress and drought monitoring or forecast, as well as agrometeorological indices and crop phenology and yield prediction, tailored for specific crops and locations. Some information requires statistical or dynamical modeling and a series of step-wise analyses to generate important information that is relevant to agricultural decision-making. Other tailored information includes onsets and cessation dates for locations, distribution of rain, including amount and time, observed climate change indices for specific locations, and advice on types of crops to be grown in each specific region. Some examples of this tailored information are provided in the next section, in one of the strategy recommendations for effective climate services for agriculture.

4.2.2 Strategies for Effective Climate Services for Agriculture

Climate services need to be developed to gain a better understanding of the climate variability and climate change, and to sustain the impacts of extreme weather and climate events. Firm strategies for the development and application of climate services are critical for developing effective and efficient counteracting measures to prevent and mitigate the potential damages from extreme weather and climate events related to climate change and variability.

Sivakumar (2015) suggested some agrometeorological strategies for reducing the impacts of natural disasters, such as improved use of climate and weather information and forecasts, early warning systems, reorienting and recasting meteorological information, fine-tuning of climatic analysis and presentation, in forms suitable for agricultural decision-making and helping marginal farmers cope with the adverse impact of natural disasters. With reference to the strategies suggested by Sivakumar (2015), some of the priority strategies that need to be addressed in the context of Vanuatu are outlined below.

4.2.2.1 Improvement and Strengthening of Agrometeorological Networks

There is an urgent need to strengthen the agrometeorological networks to support systematic data collection and analysis for the assessment of climate risks and their impacts on the agriculture sector. In many instances, the installation of weather stations does not consider the quality of the data generated, especially data for agrometeorological use. Therefore, any new agrometeorological station should be specified and installed, based on the purpose of the observations and the intended agrometeorological services to be provided.

To provide real-time climate services for agriculture, it is important to integrate the deployment of modern technologies, such as automated weather stations (AWS), for data collection and transmission. In Vanuatu, the VMGD operates seven synoptic weather stations, one for each province, where only two stations are automated weather stations. The use of AWS is becoming increasingly widespread, as they provide real-time meteorological data from various locations in agricultural areas. The AWS data have become essential in providing information for the assessment of risk management and for decision making.

In many developing countries, existing agrometeorological networks are dwindling in a relatively short time due to lack of sustained funding. As increased attention is focused on vulnerable rural areas, including those in remote areas, sustaining existing networks requires adequate response to the needs of the priority areas and to develop location-specific climate services for decision makers and the farming communities at risk. To overcome this obstacle, the NMS must seek long-term partnership within the government, and from international aid organizations, and the private sector to increase the sustainability of the agrometeorological stations. Business cases specific to each partner can be developed based on the value of real-time data and the tailored products and services relevant to such data to accomplish the mission of each, specific partner agency.

4.2.2.2 Enhancing the Availability of Parallel Climate and Agricultural Data for Sound, Science-supported, Climate Services

A basic requirement for the development of climate services for agriculture is an adequate agrometeorological database. Long-term, good quality, and parallel climate and agricultural data are necessary as basic inputs for agrometeorological research and services. Therefore, data collection and management should continuously be the focus for improving and maintaining good climate services for agriculture. The data required include meteorological data, agricultural data (phenological, crop management, pest and disease cycle, hydrological, land use, soil types), economic data, and other relevant information. Processing, quality control, archiving, and timely access are other components that add value to those climate and agricultural data for research and direct application.

It is important to implement appropriate strategies to promote the collection and use of these data in operational climate services for agriculture. With an efficient database management system, including data collection, quality control, and analysis, it is feasible to estimate the risk of extreme events in quantitative terms, which is a crucial information in agricultural decision-making for risk management (Guerreiro, 2005).

4.2.2.3 Effective Monitoring and Early Warnings for Extreme Weather and Climate Events for Timely, Informed Decision-making by Agricultural Stakeholders

Despite the increasing recognition of the impacts of climate change on the frequency and magnitude of extreme events, current climate products and services, still fall short in providing relevant climate information for agro-advisory services. Currently, the VMGD provides climate hazard warnings elicited by extreme weather and climate events; however, the coverage is quite broad over the country level, not specific to the local community level. For timely, informed responses to the early warnings, more downscaled warnings based on each local context are needed. In addition, the early warnings should be evaluated based not only on the accuracy of the warning information but also on their understandability, recognizing actual risk from the warning information with the goal to trigger action to prevent or mitigate any damage from the extreme event. It is also important that the information produced arrives in a timely fashion, giving decision makers sufficient lead-time to formulate the necessary responses in policy or planning.

There is also a need for systematic monitoring, particularly with regard to the identification of critical thresholds that trigger early warnings. This is another component that requires close cooperation between the VMGD and the agricultural partners, to understand those critical thresholds from crop and livestock physiological/ecological perspectives, to properly calibrate trigger warnings for immediate response by agricultural communities. Proper setting of the thresholds will also help ensure effective monitoring and timely dissemination of early warnings of extreme events to the farming community.

4.2.2.4 Promotion and Use of Weather and Climate Forecasts for Operational, Tactical, and Strategic Decisions by the Farmers

Strategic planning is long-term planning that affects operations for months to years, and makes use of climate forecasts. Tactical planning, on the other hand, involves decisions that directly impact the current growing season of plants and are associated with farming practices that will be accomplished within hours to days, and make use of weather forecasts (Fig. 10).

Climate forecasts provide the information for planning agricultural practices that change on a time scale of months to years. Depending on the range of climate forecasts (seasonal to interannual and decadal), different strategic decisions can be made (Hollinger, 2009). For example, utilizing climate forecasts with the lead-time of years, long-term strategic decisions are possible, such as selection of crop or livestock species, crop rotation, size of farm, size and type of equipment, design of livestock facilities, and investment decisions, such as purchase of land, irrigation systems, and storage facilities. On the other hand, for short-term strategic decisions, climate forecasts with a lead time of months, such as seasonal forecasts, are used. These include crop cultivar selection, timing of planting and harvest, planting density and spacing, tillage practices, timing of pest and disease scouting, in-season cultivation, irrigation, fertility management, pre-season crop marketing decisions, and livestock purchase or culling for stocking of pastures or ranges.

Tactical decisions based on weather forecasts can also be divided into short- and long-term decisions in agricultural management (Hollinger, 2009). The transition from short- to long-term decisions, in some cases, is difficult to define, because the weather forecasts for both types of decisions include current weather observations and a varying forecast length into the future. A major difference is that the tactical decisions made in the short-term framework, are generally a few days into the future, rather than 3–10-day forecasts for long-term tactical decisions. Such short-term decisions can include daily routine activities for cultivation, such as fertilizer and pesticide application, timing of planting, cultivation, and harvest, irrigation scheduling and livestock movement between pastures.

The same farm management activities can be listed in both types of tactical decisions, but the change from long- to short-term tactical decisions is made through the approach of the anticipated action date. Certain agricultural practices, such as sowing of weather-sensitive high yielding crop varieties, base application of fertilizer, pesticides, efficient irrigation and planning for harvest, will require weather forecasts with a longer lead-time to enable farmers to take appropriate measures. This indicates that location-specific weather forecasts, both in the medium range (3 to 10 days in advance) and the short range (1 to 2 days), are crucial for seamless tactical decisions in agriculture.

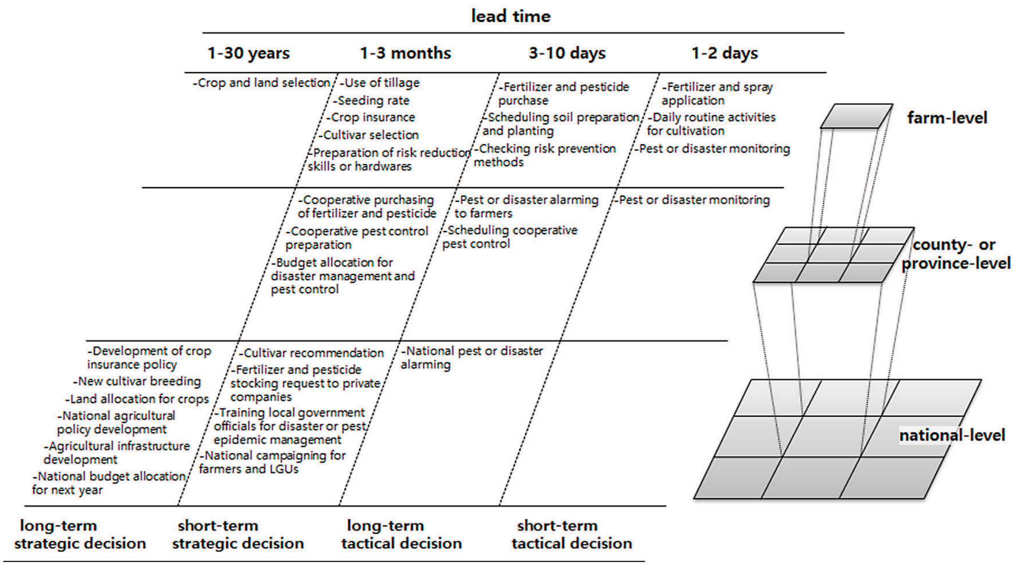

Figure 10. Agricultural decisions based on temporal and spatial scales of weather and climate forecasts

4.2.2.5 Promotion of Scientific Research and Development for Dependable, Science-based Climate Services

In order to realize effective and efficient climate services for agriculture, local, and national scale, research and development need to be targeted to urgent issues. These include capability of weather and climate forecasting for agricultural use; downscaling of weather and climate data; upscaling of agricultural models for climate service applications; ground-truth validation of the climate services developed; assessment of the economic impact of shifts in major climatic phenomena (e.g., ENSO) -depending on their frequency and strengths- and assessment of the economic value of weather and climate forecasts for agricultural systems (Kadi et al., 2011; Philips and Hansen, 2001; Singh et al., 2017).

Many climate services for agriculture involve the development and application of agricultural models that simulate the behavior of a plant or a microorganism in relation to environmental conditions, with resulting variables describing the interaction-based physio-ecological processes. For example, process-based crop models are useful to identify the optimum planting time of crops, based on soil moisture levels simulated under rain-fed conditions. The model can also be used to simulate estimated yields under low and high levels of input management practices, which provides an understanding of risk and opportunities under given weather or climate conditions. Pest and disease simulation models validated with local-specific agro-data together with weather data can provide support information for decision-making about timely control measures to avoid or prevent the damages from high-risk pest and disease outbreaks.

The analysis of historical data on climate and extreme events helps to monitor extreme event-related trends and identify the causes and effects to set priorities for coping with upcoming extreme weather and climate events in the agricultural sector. This analysis is also needed to assess the accuracy of weather and seasonal forecasts from statistical or dynamical models for Vanuatu. To elucidate the exposure of agricultural communities to climate hazards (including the location of "hot-spots'), community risk mapping is another topic for research. In addition, further scientific understanding for the linkage between climate science and traditional knowledge is required, with the goal of ensuring that traditional knowledge is incorporated with climate services wherever relevant. Promotion of research efforts in these areas can assist in developing the capacity of farmers in understanding the core relationship between climate and agriculture, and thus in integrating the findings or principles into their operational on-farm decision-making.

Therefore, it is critical to apply a bottom-up, participatory approach involving end-users of the climate services and experts in climate and agricultural sectors when research programs are designed and implemented. This will ensure that research is useful and applicable to communities and other stakeholders, as well as foster a sense of ownership over the final product, which can be critical for uptake. One of the ways of integrating users is through joint research with universities, participation in national programs, and organizing local-level climate users' groups and forums.

4.2.2.6 Improving the Dissemination of Climate Services to the Next-/End-users

For improving the dissemination of climate services, the literacy level of users, socio-economic conditions, level of technological development, and accessibility to improved technology and farming systems need to be taken into account. In fact, the literacy rate of farmers is a big challenge, resulting in a lack of connection between disseminating services and users, and could require translation of the products to local languages. The services should be timely with continuous evaluation and feedback from users. Hence, leveraging the power of Information and communication technologies (ICT) seems to be a good option for upscaling climate services in Vanuatu.

To improve the delivery of climate services, there is a need for exploiting effective and faster modes of delivery at low costs using appropriate media (radio, TV, web or mobile device-based services, text message, social networks). Since the most widespread media for delivering daily weather forecast information in Vanuatu is radio broadcasting, launching an initiative based on rural radios would be a robust idea to deliver the climate services to the very end users in rural communities. Rapid advances made in information technology, especially in audio-video integration technology, can be quickly operationalized to more effectively diffuse climate services to the user community.

Mobile devices could be an effective tool for communicating messages to poor smallholder farmers in developing countries. The two telecommunication providers in Vanuatu, Digicel and Telecom Vanuatu Ltd (TVL), provide approximately 90% coverage of the islands in Vanuatu, and approximately 80% mobile subscription level was reached in 2016 (TRR, 2017). Among them, 60,000 users are subscribed to mobile data subscriptions, indicating an internet connection through their mobile devices. At least one person with a mobile phone in a village can be designated for the role of information focal point, such that messages on the actions to be taken can be conveyed within the area.

Financial constraints and poor transport and communications are hampering efforts to reach out to rural farmers, particularly the smallholders that are in most need of climate service support. In fact, a significant challenge to the existing system of Vanuatu is the limited reach of government extension systems. Moreover, most agricultural extension workers are unskilled in climate-related knowledge.

Agricultural extension in Vanuatu is a multi-layer system of information flow, from the headquarter to the provincial agriculture office, then to the area agriculture office. However, it seems to have weak linkages between the layers. Thus, when the climate information produced by the VMGD is communicated through the DARD to the agriculture office area, it is highly possible that the information does not flow in a timely fashion. Thus, the penetration of information becomes complicated from the national level to the province, then to local village. Nevertheless, once the information reaches at the village level, it can easily be disseminated to the farmers.

Although there are bottlenecks in the existing agriculture extension structure, the extension system is a critical part of delivering climate information and services. Training agriculture extension staff and lead farmers on climate information services must be undertaken on a frequent basis to strengthen the extension system and overcome the gaps. Since the number of extension staff is very limited, engaging lead farmers within the communities is advisable. There are three major benefits associated with lead farmers. First, the dissemination of information becomes easy by involving leading farmers in the community. Next, farmers tend to rely more on a local advisor than on an outsider. Finally, it would encourage farmers to rely on scientific forecasts when told about it by their fellow farmers.

In Vanuatu, there are some NGOs actively engaged in remote islands and areas where government services are limited or completely absent. In this regard, partnership with these NGOs for delivering and disseminating the climate services to the people in remote islands on a regular basis is highly recommended.

4.2.2.7 Development of Climate Service-based Adaptation Strategies to Climate Change and Variability

Agriculture is perhaps the most sensitive and vulnerable sector to climate change and variability. Therefore, food security depends on agricultural systems that are resilient against production failure due to extreme weather and climate events (FAO, 2015; Wairiu et al., 2012). This requires a strong emphasis on sector-specific disaster-risk reduction measures, technologies, and practices. In this regard, there is a clear need to identify the climate service-based adaptation strategies for countries like Vanuatu that are recognized as being most vulnerable to the effects of climate change and variability.

Climate services can help reduce the losses associated with the occurrence of climate-related hazards, and thus provide inputs to the development of appropriate adaptation and mitigation strategies in response to climate change and variability by systematically analyzing both short- and long-term impacts of extreme weather and climate events on different crops/cropping systems. To this end, it is essential to identify and validate feasible and cost-effective adaptation options using the tailored climate services for the Vanuatu agriculture sector. A logical procedure should include: 1) expanded documentation of types of agriculture practices and agrometeorological concerns in the region, 2) stocktaking of historical and projected climate change and variability-related impacts on agriculture and food security, 3) stocktaking of indicators of the impacts identified, and 4) inventorying and upscaling of best practices on climate services and use in agriculture sector. The following sections, 4.3 and 4.4, provide good examples of the stocktaking of existing, feasible, and cost-effective adaptation options (as recommendations) identified in the context of Vanuatu using the tailored climate services.

For all stocktaking activities, improving awareness and understanding by local communities about the connection between climate change and variability and agricultural productions is crucial, as it will ensure that local communities and farmers do understand and appreciate the relevance of climate change to their agricultural production. Next, considering the priority given to the role of smallholders in ensuring food security in Vanuatu, it is recommended that efforts be made to increase the number of smallholders who benefit from using climate services and the climate services primarily targeted to the smallholder farmers, and provide support for their adoption of new climate service knowledge and technology in their farming.

As one of the best practices on climate services, the potential for the use of weather index-based insurance in agriculture is significant (Skees, 2003). Weather index-based insurance is a valuable instrument in many developing countries for transferring the financial impacts of low-frequency, high-consequence systemic climate risks out of rural areas. Facilitating the implementation of such insurance instruments as a climate service-based adaptation strategy to cope with extreme weather and climate events in the agricultural sector will need initial technical and financial support, in addition to the support needed for monitoring and evaluation.

4.3 Climate-Smart Practices and Technologies for Coping with Extreme Weather and Climate Events

Table 1. Climate products and services and related climate-smart practices and technologies recommended to cope with extreme weather and climate events and resulting damages.

<table>
<tr><th rowspan="2">Extreme weather and climate events and resulting damages</th><th rowspan="2">Drought</th><th colspan="2">Flood/Heavy Rain</th><th>TC</th><th>Tsunami</th><th rowspan="2">Pest & Disease</th></tr>
<tr><th>Soil erosion</th><th>Water logging</th><th>High winds</th><th>Salinity</th></tr>
<tr><td colspan="7">Climate Products and Services Required</td></tr>
<tr><td>Early-warning system</td><td>✓</td><td colspan="2">✓</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>Vulnerability mapping</td><td>✓</td><td colspan="2">✓</td><td>✓</td><td>✓</td><td></td></tr>
<tr><td>Decision support tools</td><td>✓</td><td colspan="2">✓</td><td></td><td></td><td></td></tr>
<tr><td>Dynamic cropping calendar</td><td>✓</td><td colspan="2">✓</td><td></td><td></td><td>✓</td></tr>
<tr><td>Climate information</td><td>✓</td><td colspan="2">✓</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td colspan="7">Climate-Smart Practices and Technologies</td></tr>
<tr><td>Resistant/tolerant crops and varieties</td><td>✓</td><td></td><td></td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>Deep root systems</td><td>✓</td><td>✓</td><td></td><td>✓</td><td></td><td></td></tr>
<tr><td>Shallow root systems</td><td></td><td></td><td>✓</td><td></td><td></td><td></td></tr>
<tr><td>Adjust planting dates with dynamic cropping calendar</td><td>✓</td><td></td><td></td><td></td><td></td><td>✓</td></tr>
<tr><td>Improve irrigation systems</td><td>✓</td><td></td><td></td><td></td><td>✓</td><td></td></tr>
<tr><td>Agroforestry</td><td>✓</td><td>✓</td><td></td><td>✓</td><td></td><td></td></tr>
<tr><td>Enhance ground cover with organic matter</td><td>✓</td><td></td><td>✓</td><td></td><td></td><td></td></tr>
<tr><td>Open pit</td><td>✓</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Raising beds/hilling</td><td></td><td></td><td>✓</td><td></td><td></td><td></td></tr>
<tr><td>Staking</td><td></td><td></td><td></td><td>✓</td><td></td><td></td></tr>
<tr><td>Improving land use and physical planning mechanisms</td><td></td><td>✓</td><td></td><td></td><td></td><td>✓</td></tr>
<tr><td>Removing salt</td><td></td><td></td><td></td><td></td><td>✓</td><td></td></tr>
<tr><td>Mixed cropping</td><td></td><td></td><td></td><td></td><td></td><td>✓</td></tr>
<tr><td>Biocontrol materials</td><td></td><td></td><td></td><td></td><td></td><td>✓</td></tr>
<tr><td>Integrated pest management</td><td></td><td></td><td></td><td></td><td></td><td>✓</td></tr>
</table>

4.3.1 Drought

4.3.1.1 Climate Products and Services Required

1) Drought early warning system: Knowing the probable occurrence and duration of droughts would help agricultural stakeholders to plan the amount of water to be stocked as reserve, the crops or varieties to plant, cropping measures to implement, etc.

2) Location-specific drought risk map: Based on high resolution historical data on hazard, exposure, and vulnerability, location-specific drought risk maps can be produced. These drought risk maps can be used for drought management, both proactively prior to drought occurrence together with the drought early warning information, and reactively responding to the drought after the impacts have occurred.

3) Decision support tools for climate smart irrigation: Based on measurement and forecasting of evapotranspiration or soil moisture information, climate smart irrigation can be practiced for individual crops in a specific manner. The use of decision support tools using meteorological and cultural information as inputs will facilitate climate smart irrigation practice of agricultural stakeholders.

4) Dynamic cropping calendar: A cropping calendar is a tool that provides timely information about planting, sowing, and harvesting periods of locally adapted crops in specific agro-ecological zones. It also provides information on the sowing rates of seeds and planting materials, and the main agricultural practices. The dynamic cropping calendar supports farmers and agriculture extension in taking informed decisions on crops and their sowing period based on given agrometeorological information, such as weather and climate forecasts.

5) Climate information: Historical climate analyses of past drought events at the village, province, and national levels; weather and climate forecasts for drought monitoring and outlook over the next months.

4.3.1.2 Climate-Smart Practices and Technologies

1) Drought-tolerant crops and varieties

Some crops traditionally grown in Vanuatu are relatively tolerant to drought, compared to others (FAO, 2010; 2013). Not all varieties of a crop can tolerate drought. For example, yam is quite tolerant to an extended dry period. This is especially true for wild yams that are protected by trees in a forest. Taro will not survive a prolonged dry spell, but taro Fiji, which is more tolerant to water stress, can be planted in drier areas. Kumala is reasonably drought tolerant if there is adequate rain at the time of planting; although well-distributed rain enables its harvest in three months, it requires six months to reach maturity under drier conditions. Cassava can grow at any altitude where land is cultivated in Vanuatu; abundant rain is a requirement for this crop; however, it can withstand prolonged drought, except at the time of planting. Young kava will not tolerate an extended period of drought, making the planting of kava outside the wet season highly risky. Coconut palms are relatively drought resistant, as evidenced by their ability to produce in a harsh atoll environment; however, prolonged dry periods delay drupe production. Similarly, breadfruit survives in prolonged droughts. Cocoa, with its deep root, is quite drought tolerant, but like other crops, cocoa will eventually be affected by extreme, extended drought conditions.

In Vanuatu, there is very little information on conventional crops and varieties in terms of their degree of tolerance to drought. Therefore, it is one of the priority research areas for the Vanuatu government to establish a list of drought-tolerant crops and their varieties existing in Vanuatu, and if possible, it would be beneficial to create a genetic material and nursery bank that farmers can have access to during emergency situations. Further research should investigate the magnitude of tolerance of those crop varieties. Like cocoa, deep rooted crop plants do better under drought because they are able to draw water and nutrients from deeper within the soil during water stress and dry periods (Johnson et al, 2000). Therefore, the Vanuatu government should consider breeding crop plants with deep roots (Kell, 2011). Once the information on drought tolerant crops and varieties is listed, extension workers can provide recommendations based on this information.

2) Planting date

Crop planting dates in Vanuatu are scheduled based on the onset or duration of two distinct seasons: dry (cold) and wet (hot). Planting date adjustments using a dynamic cropping calendar based on climate information can be made to coincide with the onset and duration of the dry season. Planting date should be adjusted, so that crops such as taro, yam, and vegetables take advantage of the rains at the beginning of the rainy season. The planting date of kumala can also be adjusted, such that it utilizes the dry season for tuber development and maturation.

3) Improving or building village irrigation systems

Improving existing irrigation systems or building new irrigation systems for villages is required to cope with agricultural drought. High risk areas shown on the location-specific (high resolution) drought-risk map generated based on historical climate and drought data, are normally targeted. There are two possible types of irrigation systems in the context of the Vanuatu agriculture sector.

First is a run-off rainwater harvesting system for irrigation, in which rainwater flowing on the ground is collected into a tank below the surface of the ground. The tank is constructed using bricks and cement. During storage, it is important to incorporate efficient and effective water conservation methods to reduce evaporation; similarly, it is important adopt efficient irrigation techniques to maximize water use efficiency.

Another irrigation system makes use of groundwater pumping for irrigation. In many parts of Vanuatu there are substantial amounts of underground water. This large amount of water provides a large storage buffer to sustain seasonal variations in rainfall. During severe droughts, the groundwater reservoir is expected to provide sufficient water for agricultural use, although impacts on the ecological biophysical environment should be considered. However, low lying islands are the exceptional for this groundwater pumping system because the fresh water lens is thin and salt intrusion may become a problem. In this case, the run off rainwater harvesting system can be considered as an alternative.

Community irrigation systems should be upgraded or built using an approach that enables participation of most community members in all steps of implementation, which will improve the community ownership necessary for sustainable long-term performance of the irrigation systems. Education programs, including proper use of climate products, such as drought monitoring (risk) information, seasonal climate forecasts, and ENSO forecasts, will also ensure efficient and effective water use and management by means of the village irrigation systems during future events.

4) Drought-tolerant traditional farming practices and systems

Traditional food gardens in Vanuatu, which involve small plots surrounded by forest (i.e. agroforestry), are drought resistant, being able to conserve moisture and protect crops from desiccating winds (McGregor and McGregor, 1999). The Ni-Vanuatu community have great knowledge about drought-tolerant local crops passed down over multiple generations. Although the magnitude of drought tolerance varies among species, drought tolerant crops in Vanuatu include yam (especially wild yam), taro Fiji (compared to swamp taro), kumala, coconut palm, cocoa, and cassava. On the contrary, swamp taro, kava, and vegetables are known to be drought susceptible, to avoid during prolonged dry spells.

Agroforestry combines low strata crops such as root crops, vegetables, and legumes, with trees. Leguminous trees and shrubs such as gliricidia (quickstick) and leucaena (white leadtree) can be advantageous. Agroforestry promotes efficient use of scare resources like land, soil nutrients, and soil moisture. Leguminous trees enrich soil by fixing nitrogen. In agroforestry, trees serve as wind breaker barriers that protect crops when cyclones strike. Additionally, the litter from pruning trees serves as good ground cover during the dry season preventing soil water evaporation and adding organic matter to the soil when decomposed, which in turn helps conserve soil moisture content. Well-designed agroforestry can also provide cultural and biological pests and disease control.

Ground cover systems with compost, mulch, and cover crop also reduce the impact of drought on crop performance. All three farming practices reduce direct exposure of the soil surface to sunlight or heat from the sun. The humus and organic matter produced and added to the soil will increase its (soil) capacity to retain and conserve soil moisture during drought.

Open pit is a traditional cultivation practice that functions to catch and preserve moisture during dry seasons. This practice also helps build up organic matter in the open pits as the debris filling the pit gradually decomposes. Minimum weeding is used during the dry season as a measure against loss of soil moisture.

4.3.2 Flood

4.3.2.1 Climate Products and Services Required

1) Flood (excessive rainfall) early warning system: Knowing the amount of rainfall that will occur over the next hours or days would help agricultural stakeholders decide on actions preventing possible damage from excessive rainfall and consequential floods in certain agricultural areas.

2) Location-specific flood-risk map: Based on high resolution historical data on hazard, exposure, and vulnerability, a location-specific flood-risk map can be produced. This flood-risk map can be used both, to prevent damage from flooding by the flood early warning system, and to enable timely reaction to damage from flooding after impacts have occurred.

3) Climate information: Climate information provides critical insight, including historical climate analyses for past flood events at the village, province, and national levels. Various temporal scales of weather and climate forecasts are necessary for flood monitoring and very short- to long-term predictions are needed for tactical and strategic decisions.

4.3.2.2 Climate-Smart Practices and Technologies

1) Soil erosion control plants

Floods can cause serious soil erosion and leaching. At extremely high flow during floods, underwater vortexes are formed by large volumes of rapidly rushing water, which cause extreme local soil erosion. Soil erosion (a form of degradation) will result in little or no soil left to support crop plants. Soil erosion control plants are effective in helping prevent the washing away of soil layers due to flooding in soil erosion-prone sites located in flood vulnerable areas. Forestry crops with dense and deep rooting systems can be planted at the bottom of slopes to hold soil particles together. When planted at the bottom of the slope, the dense and deep rooting system will act as a barrier preventing the soil particles from being washed down.

Bamboo species with dense rooting systems are one of the recommended plants for soil erosion control in Vanuatu. *Erythrina* has a deep rooting system also, and serves as a leguminous plant. The vetiver grass has a thick, dense rooting system, and thus, is traditionally planted in rows along slopes to reduce soil erosion. The blades of vetiver grass can be cut and laid out on the soil as mulch. Covering the soil surface protects it from directly being impacted by rain drops. Similarly, covering the soil surface with crops or weeds serves as a barrier which reduces the impact of a heavy rainfall on the soil and keeps the soil particles intact.

2) Agroforestry

Agroforestry in flood prone areas is another option to reduce potential damage from floods. Agroforestry combines low strata crops with trees. Both commercial trees and ornamental trees can help. Sandalwood, pine, and whitewood are good examples. The tap roots of the trees will hold the soil particles together and reduce the chances of being washed away by run-off water. The rooting system can also minimize and prevent landslides. The leaves of the forest trees will reduce the impact of the falling droplets of rain on the soil surface. Ornamental trees can add value to the land in addition to protecting it from soil erosion.

3) Raising beds and adding organic mulches

Flooding causes waterlogging (the saturation of soil with water), especially in heavy clay soil. Thus, if high-risk areas identified on the location-specific flood-risk map are prominently composed of heavy clay soil, waterlogging should be addressed, as it can result in root rot and crop failure. Strategies implemented include improving drainage or planting crops adapted to clay soils. Crops suitable for heavy soils in Vanuatu include ginger, cassava, kumala, and taro.

The most cost-effective strategy for smallholder famers to improve drainage in heavy clay soils is to raise beds to aid drainage and reduce waterlogging. The beds can be constructed using bamboo, wood, or sticks collected from the forest. The farmer can use a different type of soil obtained elsewhere to fill the raised bed.

Additionally, hilling or mounding allows the underground tubers of root crops to survive flooding. The hill or mount elevates the plant to heights above the flooded water level. This prevents root rots, which result from exposure to waterlogging. Yam, taro, and kumala can be hilled.

Utilizing bulky organic matter, such as manure or compost also helps improve drainage. Adding organic mulches around the stem of tree crops is another option. This is recommended for permanent tree crops. In addition to improving drainage and adding nutrients to the soil, organic matter also improves retention of soil moisture.

4) Increasing top soil after soil erosion damage

Shallow rooted crops are superior to deep rooted ones in shallow soils that were affected by soil erosion caused by flooding. The shallow rooting system allows the plants to use nutrients from decaying leaf debris on the soil surface. To improve the top soil layer of a shallow soil, cover crop, compost, and mulch can be used. Cover crops help conserve moisture as well as add humus and organic matter to the soil. Addition of humus and organic matter periodically, will gradually improve the top soil over time. The use of legumes as cover crops will also add nitrogen to the soil. Most creeping leguminous plants are good cover crops. *Dolichos lablab* and *Mucuna pruriens* are the two most commonly available creeping legumes in Vanuatu (FAO, 2013). Compost and mulch are other practices that can aid in adding soil particles to the top soil.

4.3.3 Tropical Cyclone

4.3.3.1 Climate Products and Services Required

1) Tropical cyclone (TC) early warning system: A TC early warning system generally has two levels of alerts issued by the national meteorological service

to certain national areas threatened by the imminent approach of a TC. This simply notifies the local population and civil authorities to make appropriate preparations for the TC, including evacuation of vulnerable areas when necessary. Some early warning systems include sectoral impact forecasts based on the magnitude of the TC. This impact-based forecast requires extensive knowledge of sector-specific vulnerability and exposure, which allow risks of impact forecasted and warnings issued targeting those exposed to TC.

2) Location-specific TC-risk map: Based on high resolution historical data on hazard, exposure, and vulnerability to TC, a location-specific risk map can be produced. This risk map can be used for short- and long-term practices and planning both, to reduce damage from TC utilizing the information from a TC early warning system and to timely react to resulting damage immediately after a TC has struck.

3) Climate information: Historical climate analyses of past TC events at the village, province, and national levels; weather and climate forecasts for TC monitoring and outlook over the next months.

4.3.3.2 Climate-Smart Practices and Technologies

1) Cyclone-tolerant crops

Many crops in Vanuatu are susceptible to cyclones, particularly yams, taro, and kava planted in food gardens. Nevertheless, diverse integrated cropping systems have evolved over the centuries, which provide a high degree of tolerance to natural hazards like cyclones. Therefore, it is necessary to learn from and build on the strength of traditional systems to mitigate the impact of natural hazards.

Certain crops, such as taro Fiji, are more tolerant to wind than swamp taro. Island cabbage, particularly if cut before the cyclone, will bear again within six weeks. Aboveground sections of bananas may collapse, but the main rootstock is seldom destroyed and suckers will reappear to fruit within six months. Post-cyclone pruning accelerates recovery. Traditionally, wild yams, arrowroot, and elephant yam act as disaster and hunger foods, indicating that these crops survive well during natural hazards such as cyclones. Cassava is tolerant to strong winds if the tops are cut before the cyclone. In the case of kumala, its low and spreading growth habit makes it quite tolerant to high wind. South Pacific coconut varieties have evolved in cyclone prone environments and therefore, have adapted to survive the strongest of winds.

2) Cyclone-tolerant traditional cropping practices and systems

Although annual crops such as yam, taro, and giant taro, and some fruit trees are susceptible to tropical cyclones, and get uprooted, or their leaves and branches tear off. Agroforestry practices could increase their tolerance level to strong winds, and the trees used in agroforestry would serve as windbreakers during cyclones. Upon striking the windbreaker trees, a violent gust of wind from cyclones is often reduced in velocity and intensity before reaching the crop plants.

Staking is a traditional husbandry practice used in yam cultivation in the Pacific (personal communication). Vines are trained up the stakes to keep them above the ground. This prevents the vines on the heated soil surface from getting burnt; in addition, the strong stakes would also protect the vines from cyclones. Stakes are erected 1-2 m high to prevent them from being blown over by the cyclone strong winds.

Heavy rainfall from tropical cyclones causes waterlogging. As mentioned in the previous section, drainage to avoid waterlogging can be improved by raising beds. Additionally, hilling or mounding allows the underground tubers of root crops to survive flooding. Adding plenty of bulky organic matter, such as manure or compost is another option. The organic matter or compost helps improve drainage.

Cover crop, compost, and mulch can be used to improve the shallow top soil layer caused by soil erosion due to heavy rainfall accompanying tropical cyclones. Periodical addition of humus and organic matter will gradually improve the top soil over time.

4.3.4 Tsunami

4.3.4.1 Climate Products and Services Required

1) Tsunami early warning system: A tsunami early warning system is used to detect tsunamis in advance and issue warnings to prevent the loss of lives and damage. It is made up of two equally important components: a network of sensors to detect tsunamis and a communications infrastructure to issue timely alarms to permit evacuation of the people from coastal areas.

2) Location-specific tsunami-risk map: Based on high resolution historical data on hazard, exposure, and vulnerability to tsunamis, a location-specific risk map can be produced. This risk map can be used for short- and long-term practices both, to reduce damages from tsunami, together with the early warning system, and to timely react to resulting damages from tsunami impacts.

4.3.4.2 Climate-Smart Practices and Technologies

1) Salinity-tolerant plants and cropping systems

Tsunamis can increase soil salinity by bringing salt sea water in coastal land, where farming is taking place. In this case, planting salinity-tolerant crops will help to reduce damages from the salt water inundation due to tsunamis. However, a list of salinity-tolerant crops and varieties available does not exist. The Vanuatu government is recommended to identify such crops and varieties and the magnitude of their salinity tolerance or import verified salinity-tolerant crops and varieties from other Pacific countries. Recommendations on salinity-tolerant crops and varieties can then be given to atolls and low-lying island farmers. There are several plant species known for their salinity tolerance in Vanuatu. Paw-paw and coconut trees grow in a variety of soils and tolerate salinity well. Pumpkin also tolerates salinity.

Hydroponics can be an alternative cropping system for high salinity soils on atoll islands, where salinity susceptible crop plants are difficult to grow. Hydroponics is a system that uses a liquid culture medium on which crop plants grow, physically supported in a variety of ways.

2) Removing salt from the soil

Due to sea water influx into the land during tsunamis, salts accumulate in the root zone. These salts must be removed to allow the rooting system to continue to absorb necessary nutrient ions. The salts can be flushed out by leaching and drainage. In particular, good drainage allows salts to be washed out of the soil. Although this technique is currently expensive and time intensive, it must be considered as an option in the future, when salinity in atolls and low-lying islands will increase.

3) Improving land use and physical planning mechanisms

Land use and physical planning based on accurate assessment of the possible impacts of climate change and sea level rise provides a powerful tool for reducing vulnerability to the detrimental effects of climate change. Planning mechanisms can be used to direct or regulate all new investments in infrastructure and agriculture outside hazard zones to minimize vulnerability, reduce repair costs, and decrease disruption of economic activities. This includes planning of farmland starting, at a certain minimum distance from the coastal line to fundamentally decrease the level of exposure to sea water intrusion. It also includes regulating the extraction of freshwater from coastal aquifers when the salt concentration of the fresh water exceeds a certain threshold level. Such policies would eventually reduce the vulnerability of coastal communities and reduce the need to replace infrastructure under incidences of salt water intrusion.

4.3.5 Pest and Disease

4.3.5.1 Climate Products and Services Required

1) Pest and disease early warning and spray decision support tool: A pest and disease early warning system is a decision support tool that helps agricultural stakeholders to assess the risk of outbreaks of economically damaging crop pests and diseases. Using information about the weather, the crop, and/or pathogenic agents, warning systems advise agricultural stakeholders when they need to take an action - usually to apply a pesticide spray - to prevent pest or disease outbreaks

and avoid economic losses. If the warning system uses a seasonal climate forecast, the risk of pest or disease epidemics over the next season can be predicted; this will enable the agricultural stakeholders to implement strategic management actions to control the high risk of pests or diseases.

2) Climate information: Historical climate analyses of past pest and disease outbreak events at the village, province, and national levels; weather and climate forecasts for monitoring of pest and disease epidemics, and outlook over the next months.

4.3.5.2 Climate-Smart Practices and Technologies

1) Resistant crop and varieties

Cultivation of crops and crop varieties resistant to pests and diseases incident in the locality of interest is one of the most effective ways to tackle pests and diseases. Many native plants and crops have developed resistance to specific insect pests and pathogens. An example is the resistance of giant taro to Papuan beetle. Other aroids such as taro and taro Fiji are susceptible to this pest. When there is a high risk of infestation by this beetle, farmers should be advised to cultivate giant taro rather than taro or taro Fiji. Wild lemon is observed to be resistant to diseases caused by *Phytophthora* spp. in citrus that harm the orange industry in Vanuatu. Thus, using the wild lemon root stock for grafting would benefit orange orchards and larger plantations with a natural control of the disease.

2) Dynamic Planting Calendar to avoid pest and disease favorable conditions

Pathogenic organisms require moisture as a pre-requisite to reproducing, growing, and multiplying. A dynamic planting calendar based on weather and climate information can be developed to avoid the favorable conditions necessary for the outbreak of pathogens on crops. For example, yams can be planted at the end of the dry season so that the crop is established before the rainy season; thus, mature yams will be able to tolerate anthracnose, a group of fungal disease, during rains.

3) Traditional cropping systems to mitigate pest and disease outbreaks

Mixed cropping is one of the traditional cropping systems to mitigate pest and disease outbreak. This strategy is based on the principle that most pests and diseases are crop specific (host specific). Therefore, a combination of different crops will ensure that when a pest or a pathogen strikes, non-host crops will survive. This is consistent with the belief that diversification of root crops will help in increasing the resilience of agriculture systems to climatic extremes in Vanuatu.

Crop rotation ensures that one crop species is not planted in the same field for more than two consecutive years. Breaking the continuity of monoculture removes host plants for the existing pests and pathogens for the next season; thus, reducing the likelihood of any pandemic pest or disease outbreak during the crop rotation cycles.

4) Biocontrol materials

In the Solomon Islands, seaweeds are collected, processed, and used both as an organic fertilizer and a controlling material of common insect pests. Chilly pepper is commonly found in Vanuatu. The fruits of the chilly-pepper have chemicals that repel common insect pests. The content of the coconut shell and tomato leaves are also well known for their natural pesticide activity.

5) Integrated Pest Management

Integrated pest management (IPM) is another popular technique of controlling pests with environment-friendly and thus, sustainable practices. IPM uses integrated measures to reduce the potential risk of pest or disease outbreaks. A combination of various measures, including, the use of crops and cultivars of known pest and disease resistance traits, pest repellants and trap-plants, and adopting multi-cropping and agroforestry, is a good example of IPM.

In the context of Vanuatu, IPM practices may include removing any ideal conditions for pathogenic proliferation, such as pools of water on raised beds. Well-drained soils prevent the formation of water pools after a heavy rainstorm. Regular surveillance for harmful insects, disease incidence, and weeds is another strategy. Upon detection of any of these, Vanuatu government will need to provide crop protection services, including identification of insect pests and diseases and necessary advice and recommendations on cost-effective ways to manage them, which is definitely an area requiring capacity building.

4.4 Seasonal Forecast-Informed Decision Making for Selected Crops

Seasonal forecasts help farmers to make informed decisions regarding their agricultural activities with sufficient lead time (from 3 months to 6 months). The same applies for ENSO forecasts, although these provides longer lead time to decision makers. In this context, translating the seasonal or ENSO forecast information into appropriate actions by farmers and other agricultural stakeholders, in a way that the potential benefits from forecasts are capitalized, is a major challenge (Hansen, 2002).

Here, we present the Decision-Making Tables based on seasonal forecasts for six selected staple crops in Vanuatu. These are recommendations for climate-smart practice based on next 3-6-month seasonal rainfall forecasts. Six major staple crops: manioc, taro, taro Fiji, giant taro, kumala, and yam, were selected because of their importance as food crops for local consumption throughout the islands of Vanuatu, and because of their economic importance as a source for income for farmers by trading at local markets. The objective of the Decision-Making Tables is to help farmers in Vanuatu to make better-informed decisions about the crops and varieties to be grown and effectively management of different rainfall conditions, based on the specific context of Vanuatu, under the changing climatic conditions that Vanuatu is currently experiencing and will continue to experience.

Basic climatic requirements for suitable growing conditions and the tolerance levels to extreme weather and climate events for each crop are referenced from interviews and communications with experts (SPC, Tonga MAFFF, Vanuatu DARD), internet web searches, and published reports and books on root crops in the Pacific and Vanuatu (Bradbury and Holloway, 1988; FAO, 2010; 2013).

In the development of the Decision-Making Tables, three climatic scenarios for rainfall are used to make the tables easily understandable and relevant to farmers: Wetter than normal; Normal; and Drier than normal. The tables offer realistic, actionable advice to agricultural stakeholders in an A-Z fashion, for each of the three climatic scenarios, beginning with the selection of crop and acreage, followed by land-preparation practices, planting material and planting, crop management and protection, and irrigation, until harvest.

4.4.1 Manioc

Manioc (*Manihot esculenta*), also known as cassava, is the most commonly grown staple crop in Vanuatu. There are numerous varieties of manioc in the archipelago, which take between 8 to 12 months from planting to harvest. The "sweet" cultivar in Vanuatu grows to a height of 2–4 m. The roots grow just below the ground and may penetrate to a depth of 50–100 cm.

The optimal temperature requirement of manioc ranges from 25 to 30°C. Manioc plant can tolerate temperatures as low as 12°C and as high as 40°C. It requires an optimal rainfall range of 1,000–2,000 mm. It can tolerate low rainfalls if it is well distributed; thus, manioc is a drought-resistant crop which may need initial watering to start growing, but once established, does not need irrigation. It is also tolerant to cyclone and waterlogging. Cyclones tend to uproot tall plants but not those of a lower status like manioc.

The manioc plant is known as the "poor man's crop". This is because it can grow and produce tubers in sub-optimal soil conditions and fertility. Hence, it is often used as a final crop in rotations prior to returning land to fallow. It competes well with weeds but is sensitive to shade. It is relatively easy to obtain planting material (manioc plant stems) from harvested crops.

– Under **Wetter than Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Depending on target market and demand, and available planting material.
Acreage Allocation	• Set according to available planting material, crop-care capability (including weeding and pest-control).
Land Preparation	• Prepare land by tractor, rotary hoe, or by hand. – land preparation may be delayed if rain is heavy and frequent because tractor ploughing is not possible in extremely wet soil. – if needed, rotary-hoes can be used to prepare thin rows for planting. After planting, the rotary-hoe can be run along both sides of the rows to mound the rows.
Irrigation	• Not required
Planting Material	• Select stalks from a crop that has been harvested and those that have not sprouted. – manioc stalks will sprout faster under wet conditions before planting. – sprouting before planting will weaken the ability of stalks to grow after the stalk is cut and planted.
Land Management	• Plant stalks 10 cm deep on the mounds.
Fertilizer Application	• Fertilizer is not normally used for manioc farming in Vanuatu.
Pest/Disease Control	• Monitor crop especially for disease symptoms during wet periods and use sprays if needed. • Monitor crop for rodents after tuber-formation and treat by spreading rat poison if needed.
Weed Control	• Monitor weed growth and weed as needed.

– Under **Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Depending on target market and demand, and available planting material.
Acreage Allocation	• Set according to available planting material and crop-care capability.
Land Preparation	• Prepare land and mounds by tractor, rotary hoe, or by hand.
Irrigation	• Not required.
Planting Material	• Select stalks from a crop that has been harvested and those that have not spouted.
Land Management	• Plant stalks 10 cm deep on the mounds.
Fertilizer Application	• Fertilizer is not normally used for manioc farming in Vanuatu.
Pest/Disease Control	• Monitor crop for disease symptoms or insect infestation and use sprays if needed. • Monitor crop for rodents after tuber-formation and treat by spreading rat poison if needed.
Weed Control	• Monitor weed growth and weed as needed. – the first weeding will be needed after 3-4 weeks. – if weeding is done using herbicide sprays, care to be taken to avoid spraying on the manioc. – a second weeding will be needed 12-13 weeks after planting – if herbicide is used, this will be the last weeding required, because the herbicide will kill all weeds and the manioc will grow sufficient number of leaves to shade the ground below and stop further growth of weeds.

– Under **Drier than Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Depending on target market and demand, and available planting material.
Acreage Allocation	• Set as large as possible according to available planting material and crop-care capability.
Land Preparation	• Prepare land and mounds by tractor, rotary hoe, or by hand. – land-preparation by tractor may be delayed under drought conditions, owing to dry and hard soil being. – if needed, rotary hoes can be used for soil/land preparation and mounding (same way as in extreme wet conditions).
Irrigation	• Prepare for hand-watering of each stalk up to 2 times – if possible, reference decision support information, such as plant physical appearance, soil moisture, or evapotranspiration.
Planting Material	• Select stalks from a crop that has been harvested and those that have not sprouted. – check that manioc stalks have not dried out and are still viable by cutting some stalks to see if the stalks are still moist inside.
Land Management	• Plant stalks 15 cm deep on the mounds. – if soil is dry at planting, water each stalk immediately after planting with at least 300 ml water per stalk. – monitor daily and if there has been no rain and the stalks do not begin to sprout after 4 days, water again with at least 300 ml per stalk. – the stalks should start growing after the first or second watering.
Fertilizer Application	• Fertilizer is not normally used for manioc farming in Vanuatu.
Pest/Disease Control	• Monitor crop for disease symptoms or insect infestation and spray if needed. • Monitor crop for rodents after tuber-formation and treat by spreading rat poison if needed.
Weed Control	• Monitor weed growth and weed as needed. – weed growth will be slower during dry times – the first weeding may not be needed until 5–6 weeks. – a second weeding will be needed 14–15 weeks after planting – if herbicide is used, this will be the last weeding, because the herbicide will kill all weeds and the manioc will then grow ample number of leaves to shade the ground below and stop growth of more weeds.

4.4.2 Taro

In Vanuatu, most varieties of taro (*Colocasia esculenta*), also known as swamp taro or aelan taro, grow best in swamps or with irrigation. It does not have a specific growing season, meaning possible all year-round farming in Vanuatu. Although the leaves of taro are edible, it is not popular among the Ni-Vanuatu population.

Although some cultivars of taro distributed by the Vanuatu government can resist drought for up to 3 months, swamp taro varieties in Vanuatu are very susceptible to water deficit and will start wilting without rain or watering for 2–3 weeks at any stage during its growing period of 8–10 months. It requires an annual rainfall of 2,500 mm or more; it grows well on heavy wet soil and does poorly on dry loose soil. The plant requires an average temperature of 21°C for normal production. Yield is poor at high altitudes. Harvesting is normally conducted one year after planting.

- Under **Wetter than Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Depending on market demand and available planting material. • Farmers need to consider: - the size of corms and overall yield both increase in wet conditions, with individual tubers growing over 2 to 3 kg; - increased supply may lead to lower market price.
Acreage Allocation	• Set as large as possible according to available planting material and crop-care capability (including weeding, mounding and leaf-picking).
Land Preparation	• Prepare land and planting trenches/holes by tractor, rotary hoe or by hand. - tractor-ploughing may be delayed if rain is heavy and frequent so the soil is too wet for tractor-ploughing - if needed, rotary-hoes can be used to prepare thin rows and trenches for planting. After planting, rotary-hoes can be run along both sides of the trenches to fill trenches as the taro grows
Irrigation	• Not required.
Planting Material	• Select only suckers plucked off harvested corms. - suckers will grow a corm with an attractive oval (rugby ball) shape which attracts a higher price in the market, even if the market is over-supplied and the price falls. - more planting material will be available in wet times, so farmers can be more selective.
Land Management	• Plant at higher density than in normal conditions because there will be sufficient water for the increase in planting. - planting density by machine-planting can be increased by up to 20% from normal conditions. - planting density by hand-planting can be increased by up to 40% from normal conditions.
Fertilizer Application	• Apply more fertilizer to match increased planting density.
Pest/Disease Control	• Monitor crop especially for disease symptoms in wet times.
Weed Control	• Monitor weed growth and weed as needed. - weed growth is faster in wet conditions so weeding may be needed fortnightly for up to 3 months, by then taro will have grown high enough to shade the soil and reduce weed growth. - mulching with plastic or organic material can be used to reduce weed-growth. - intercropping taro with kumala can be used to provide a cover crop to reduce weed-growth, and provide income from kumala after 4 months, while taro is still growing. - if weeding is done by herbicide spray, take care not to spray the taro plant - herbicide spray rate and frequency may increase by 20-50% relative to normal conditions.
Leaf-Picking	• Picking can be weekly from each taro plant. - in wet conditions, unfurled leaves and leaves that have unfurled up to 2 weeks before, can be picked for cooking and eating without causing itchiness in the mouth. - plant growth will be more vigorous under wet conditions and leaves will be larger than under normal conditions.

– Under **Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Depending on market demand and available planting material.
Acreage Allocation	• Set according to market demand, available planting material and crop-care capability.
Land Preparation	• Prepare land and trenches/holes by tractor, rotary hoe or by hand, as usual.
Irrigation	• May need some irrigation in the last month before harvesting to ensure corms grow to a minimum size of 1 kg. – the minimum preferred size of corms for the local and export markets is 1 kg, but corms below 1 kg are sold for a lower price.
Planting Material	• Select suckers plus stalks cut from the tops of harvested corms. – planting material will not be as plentiful as in wet times. – stalks cut off from the top of harvested corms will grow a corm with an oval shape, but will have an extended outcrop at the bottom end which will need to be cut off if exported. – farmers will need to choose whether to cease outcrops for market, depending on prices offered.
Land Management	• Plant according to usual practice.
Fertilizer Application	• Apply fertilizer as usual.
Pest/Disease Control	• Monitor crop for insect infestation and spray if needed.
Weed Control	• Monitor weed growth and weed as needed. – weeding will usually take place every 2-3 weeks for up to 4 months, by this time, taro will have grown high enough to shade the soil and reduce weed growth. – mulching with plastic or organic material can be used to reduce weed growth. – intercropping taro with kumala can be used to provide a cover crop to reduce weed-growth, and provide income from kumala after 4 months, while taro is still growing.
Leaf-Picking	• Picking can be done weekly from each taro plant. – under normal conditions, unfurled leaves and leaves that have unfurled up to 1 week before, can be picked for cooking and eating without causing itchiness in the mouth.

– Under **Drier than Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Plant only if irrigation is available, depending on market demand and available planting material. • Farmers need to consider: – planting material will be difficult to find during dry/drought times – farmers may need to set up their own nurseries to supply planting material or to protect and keep planting material for planting after dry/drought times (refer to setting up a nursery in the section on planting material); – local prices for taro may be higher during dry/drought times due to shortage of supply; • If irrigation is not available, switch to drought-resistant crops such as kumala or manioc.
Acreage Allocation	• If irrigation is available, set as large as possible according to available planting material and crop-care capability.
Land Preparation	• Prepare land and trenches/holes by tractor, rotary hoe or by hand. – tractor-ploughing may be delayed by the soil being too dry and hard, if there is drought. – if needed, rotary hoes can be used for soil/land preparation and trenches (in the same way as in very wet conditions).
Irrigation	• Monitor and irrigate as needed during dry/drought conditions. – if possible, reference decision support information, such as plant physical appearance, soil moisture or evapotranspiration. • Water requirement increases as taro grows. – at planting, if the soil is dry, water each taro planted with at least 500 mL. – after the taro sprouts its first leaf, if there has been no rain, water each taro with at least 1 L per week for 2 months. – between 2 and 4 months, if there has been no rain, water each taro with at least 2 L per week. – between 4 and 6 months, if there has been no rain, water each taro with at least 4 L per week. – between 6 months and up to 1 week before harvest, for 8–9 months, if there has been no rain, water each taro with at least 6 L per week.
Planting Material	• Taro and planting material will be scarce during dry/drought times. • Farmers wanting to plant commercial quantities of taro will need to find a tissue-culture nursery or set up their own nursery to grow planting material. – a simple nursery can be set up by cutting up corms (into 50 g pieces) and planting the pieces in shallow soil (5 cm deep), then watering the sprouting suckers until they are large enough (at least 20 cm high) to pick and transplant.
Land Management	• Plant at lower density than in normal conditions. – apply mulch (plastic or organic material) around the taro after planting to reduce moisture loss from the soil.

- Under **Drier than Normal** Seasonal Rainfall (continued)

Activity	Recommendations for climate-smart practice
Fertilizer Application	• Apply less fertilizer to match reduced planting density.
Pest/Disease Control	• Monitor crop for insect infestation and spray if needed. • Dry conditions can lead to caterpillar infestation on leaves and stalks, and aphids on roots – treat by spraying with insecticides (every 14 days for systemic insecticides and every 7 days for contact insecticides).
Weed Control	• Monitor weed growth and weed as needed. – weed growth will be slower during dry times. – weeding will usually have to be done every 3–4 weeks for up to 4 months, by then taro will have grown high enough to shade the soil and reduce weed growth. – mulching with plastic or organic material can be used to reduce weed growth. – intercropping taro rows kumala can be used to provide a cover crop to reduce weed-growth, and provide income from kumala after 4 months, while taro is still growing. – if weeding is done by herbicide spray, take care not to spray the taro plants – herbicide spray rate and frequency may decrease by 20–50% relative to normal conditions.
Leaf-Picking	• Dry conditions lead to increased calcium oxalate crystals in the leaves, which causes itchiness in the mouth when the leaves are eaten. – pick only unfurled leaves to ensure no itchiness in the mouth when cooked and eaten. – plant growth will be slower in dry conditions and leaves will be smaller than in normal conditions.

4.4.3 Taro Fiji

Similar to taro (*C. esculenta*), taro Fiji (*Xanthosoma sagittifolium*), also known as tannin, does not have a specific growing season in Vanuatu, meaning possible all year-round farming. Taro Fiji is distributed throughout the nation. Taro Fiji is described as a crop of tropical rainforest because it prefers high rainfall with soils with a good amount of moisture, indicating it is drought susceptible, although it is slightly more tolerant of drought than taro. It requires an annual rainfall of 1500–2500 mm, although it can be grown in areas with rainfall as low as 1000 mm/year. The plant roots within 15–20 cm of the soil surface and requires well-drained and relatively fertile growing conditions.

Taro Fiji is known to tolerate light shade, but will die under heavy shade, and is resistant to many pests and diseases that affect taro (*C. esculenta*). Compared to taro, it has an added advantage that, once harvested, the root can be stored in a cool, dry place for up to several months.

– Under **Wetter than Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Depending on market demand and available planting material.
Acreage Allocation	• Set as large as possible according to available planting material and crop-care capability (including weeding).
Land Preparation	• Prepare land and planting trenches/holes by tractor, rotary hoe or by hand. – tractor-ploughing may be delayed if rain is heavy and frequent so the soil is too wet for tractor-ploughing. – if needed, rotary-hoes can be used to prepare thin rows and trenches for planting. After planting, rotary-hoes can be run along both sides of the trenches to fill trenches as the taro Fiji grows.
Irrigation	• Not required.
Planting Material	• Select stalk-bases without any rot to cut up into planting pieces of usual size. – more planting material will be more available in wet times, so farmers can be more selective. – dip the planting pieces in an anti-fungal dip and dry before planting. – planting pieces will be more susceptible to rot during wet conditions.
Land Management	• Plant at higher density than in normal conditions, because there will be sufficient water for the increase in planting.
Fertilizer Application	• Apply more fertilizer to match increased planting density.
Pest/Disease Control	• Monitor crop especially for disease symptoms in wet times and spray if needed.
Weed Control	• Monitor weed growth and weed as needed. – weed growth is faster in wet conditions so weeding may be needed fortnightly for up to 3 months, by then taro Fiji will have grown high enough to shade the soil and reduce weed growth. – mulching with plastic or organic material can be used to reduce weed-growth. – intercropping taro Fiji with kumala can be used to provide a cover crop to reduce weed-growth, and provide income from kumala after 4 months, while taro Fiji is still growing. – if weeding is done by herbicide spray, take care not to spray the taro Fiji plants – spray application and frequency may increase by 20–50% relative to normal conditions.

– Under **Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Depending on market demand and available planting material.
Acreage Allocation	• Set according to market demand, available planting material and crop-care capability.
Land Preparation	• Prepare land and trenches/holes by tractor, rotary hoe, or by hand, as usual.
Irrigation	• Not required.
Planting Material	• Select stalk-bases with minimum rot to cut up into planting pieces of usual size. – planting material will be available in normal weather conditions, but will not be as plentiful as in wet times. – trim any rot from stalk bases before cutting up into planting pieces.
Land Management	• Plant according to usual practice.
Fertilizer Application	• Apply fertilizer as usual.
Pest/Disease Control	• Monitor crop for disease symptoms or insect infestation and spray if needed.
Weed Control	• Monitor weed growth and weed as needed. – weeding will usually be every 2-3 weeks for up to 4 months, by then taro Fiji will have grown high enough to shade the soil and reduce weed growth. – mulching with plastic or organic material can be used to reduce weed growth. – intercropping taro Fiji with kumala can be used to provide a cover crop to reduce weed-growth, and provide income from kumala after 4 months, while the taro Fiji is still growing. – if weeding is done by herbicide spray, take care not to spray the taro Fiji plants.

– Under **Drier than Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Plant only if irrigation is available, depending on market demand and available planting material. • Farmers need to consider: – planting material will be more difficult to find during dry/drought times – farmers may need to set up their own nurseries to provide planting material. – local prices for taro Fiji may be higher during dry/drought times due to shortage of supply. • If irrigation is not available, switch to drought-resistant crops such as kumala or manioc.
Acreage Allocation	• If irrigation is available, set as large as possible according to available planting material and crop-care capability.
Land Preparation	• Prepare land and trenches/holes by tractor, rotary hoe or by hand. – tractor-ploughing may be delayed by the soil being too dry and hard, if there is drought.
Irrigation	• Monitor and irrigate as needed during dry/drought conditions – if possible, reference decision support information, such as plant physical appearance, soil moisture, or evapotranspiration. • Water required increases as the taro Fiji grows. – at planting, if the soil is dry, water each taro planted with at least 500 ml. – after the taro sprouts its first leaf, if there has been no rain, water each taro with at least 2 L per week, until 3 months. – between 3 and 12 months, if there has been no rain, water each taro with at least 3 L per week.
Planting Material	• Taro Fiji planting material will be less-available during dry/drought times. – trim rotten parts from stalk bases before cutting up into planting pieces. – cut planting pieces bigger than usual, so the planting pieces have more vitality to grow shoots.
Land Management	• Plant at lower density than in normal conditions. – apply mulch (plastic or organic material) around the taro after planting to reduce moisture loss from the soil.
Fertilizer Application	• Apply less fertilizer to match reduced planting density.
Pest/Disease Control	• Monitor crop for disease symptoms or insect infestation and spray if needed.
Weed Control	• Monitor weed growth and weed as needed. – weed growth will be slower during dry times. – weeding will usually be every 3–4 weeks for up to 4 months, by then taro Fiji will have grown high enough to shade the soil and reduce weed growth. – mulching with plastic or organic material can be used to reduce weed growth. – intercropping taro Fiji with kumala can be used to provide a cover crop to reduce weed growth, and provide income from kumala after 4 months, while taro Fiji is still growing. – if weeding is done using herbicide spray, take care not to spray taro Fiji plants – spray application frequency may decrease by 20–50% relative to normal conditions.

4.4.4 Giant Taro

Giant taro (*Alocasia macrorrhiza*), also known as Navia, is strictly not a tuber/root crop, although it is normally grouped with root crops in the Pacific. Giant taro grows a stalk which is harvested for eating. Giant taro can be harvested from 12 months up to 3 years, depending on the variety. Giant taro can be grown in 4 different ways: 1) from the cut-off top of the stalk; 2) from off-shoot suckers growing from the stalk; 3) from small, marble-size "seed" tubers in the roots; and 4) from suckers growing from cut-up portions of the stalk. Giant taro is not grown in Vanuatu as a monocrop like other crops, but is inter-planted with other crops especially yam, taro, and banana/plantain.

Giant taro is only consumed by certain cultures in Vanuatu, although it grows throughout the archipelago. The edible stalk of giant taro can contain calcium oxalate crystals which make the mouth itchy, especially in dry conditions. In normal and wet conditions, however, giant taro does not contain these crystals and is normally sweet and delicious to eat. Depending on the variety, a single giant taro stalk can be up to 1.5 m long and weigh up to 30 kg.

Giant taro is one of the staple crops advocated as a crop capable of withstanding the impacts of climate change, such as drought and tropical cyclones. Thus, its long growing period makes it a convenient emergency food. Observation by the DARD showed that giant taro can withstand a drought period lasting up to three months, and do well in flooded area (FAO, 2013). It exhibits some shade tolerance as well.

– Under **Wetter than Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Depending on market demand and available planting material. • Farmers need to consider: – production of stalk increases in wet conditions. – increased supply may lead to lower prices in the market.
Acreage Allocation	• Set area for interplanting as large as possible according to available planting material and crop-care capability (including weeding and spraying of interplanted crops).
Land Preparation	• Prepare land for interplanting by tractor, rotary hoe or by hand. – tractor-ploughing may be delayed if rain is heavy and frequent so the soil is too wet for tractor-ploughing. – if needed, soil/land preparation can be done by hand for the rows of giant taro in the interplanted area.
Irrigation	• Not required.
Planting Material	• Select cut-off tops of stalks and suckers from stalks.
Land Management	• Plant at higher density than in normal conditions, because there will be sufficient water for the increase in planting.
Fertilizer Application	• Fertilizer is not normally used for giant taro farming in Vanuatu.
Pest/Disease Control	• Monitor crop especially for disease symptoms at wet times or insect infestation and spray if needed.
Weed Control	• Monitor weed growth and weed as needed. – weed growth is faster in wet conditions so weeding may be needed fortnightly for up to 3 months, by then giant taro will have grown high enough to shade the soil and reduce weed growth. – mulching with plastic or organic material can be used to reduce weed-growth. – intercropping giant taro rows kumala can be used to provide a cover crop to reduce weed-growth and provide income from kumala after 4 months, while giant taro is still growing. – if weeding is done using herbicide spray, take care not to spray giant taro plants – spray application rate and frequency may increase by 20–50% relative to normal conditions

– Under **Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Depending on market demand and available planting material.
Acreage Allocation	• Set interplanting area according to market demand, available planting material.
Land Preparation	• Prepare land for interplanting by tractor, rotary hoe or by hand, as usual.
Irrigation	• Not required.
Planting Material	• Select cut-off tops of stalks and suckers from stalks. – planting material will be available in normal weather conditions, but will not be as plentiful as in wet times.
Land Management	• Plant according to usual practice.
Fertilizer Application	• Fertilizer is not normally used for giant taro farming in Vanuatu.
Pest/Disease Control	• Monitor crop for disease symptoms or insect infestation and spray if needed.
Weed Control	• Monitor weed growth and weed as needed. – weeding will usually be every 2–3 weeks for up to 4 months, by then giant taro will have grown high enough to shade the soil and reduce weed growth. – mulching with plastic or organic material can be used to reduce weed growth. – intercropping giant taro with kumala can be used to provide a cover crop to reduce weed growth and provide income from kumala after 4 months, while giant taro is still growing. – if weeding is done using herbicide spray, spray as normal and take care not to spray giant taro plants.

- Under **Drier than Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Plant only if irrigation is available, depending on market demand and available planting material. • Farmers need to consider: - planting material will be more difficult to find during dry/drought times - local prices for giant taro may be higher during dry/drought times due to shortage of supply. • If irrigation is not available, switch to drought-resistant crops such as kumala or manioc
Acreage Allocation	• If irrigation is available, set the interplanting area according to irrigation capacity, available planting material and crop-care capability (including interplanted crops).
Land Preparation	• Prepare land for interplanting by tractor, rotary hoe or by hand. - tractor-ploughing may be delayed by the soil being too dry and hard, if there is drought. - if needed, soil/land preparation can be done by hand for the rows of giant taro in the interplanted area.
Irrigation	• Monitor and irrigate as needed during dry/drought conditions - if possible, reference decision support information, such as plant physical appearance, soil moisture, or evapotranspiration. • Water required increases as giant taro grows, although it is more drought tolerant than other taro plants. - at planting, if the soil is dry, water each giant taro planted with at least 1 L. - after the first week, if there has been no rain, water each giant taro with at least 2 L per week, until 3 months. - between 3 and 12 months, if there has been no rain, water each giant taro with at least 4 L per week.
Planting Material	• Giant taro planting material will be scarce during dry/drought times. • Farmers wanting to plant commercial quantities of giant taro will need to set up a nursery to grow planting material, or find planting material from other islands in Vanuatu that are not experiencing drought conditions. - a simple nursery can be set up by cutting up giant taro stalks into pieces (100 g) and planting the pieces in shallow soil (5 cm deep), then watering the sprouting suckers until they are large enough (at least 30 cm high) to pick and transplant.
Land Management	• Plant according to normal conditions. - apply mulch (plastic or organic material) around the giant taro after planting to reduce moisture loss from the soil. - irrigate as required.
Fertilizer Application	• Fertilizer is not normally used for giant taro farming in Vanuatu.
Pest/Disease Control	• Monitor crop for disease symptoms or insect infestation and spray if needed. • Dry conditions can lead to caterpillar infestation on leaves and stalks - treat by spraying with insecticides (every 14 days for systemic insecticides and every 7 days for contact insecticides).
Weed Control	• Monitor weed growth and weed as needed. - weed growth will be slower during dry times. - weeding will usually be every 3-4 weeks for up to 4 months, by then giant taro will have grown high enough to shade the soil and reduce weed growth. - mulching using plastic or organic material can be used to reduce weed growth. - intercropping giant taro with kumala can be used to provide a cover crop to reduce weed-growth and provide income from kumala after 4 months, while giant taro is still growing. - if weeding is done using herbicide spray, take care not to spray giant taro plants - spray application rate and frequency may decrease by 20-50% relative to normal conditions.

4.4.5 Kumala

Kumala (*Ipomea batatas*), also known as sweet potato, is one of the most commonly-grown staple crops in the Pacific. It grows throughout the Vanuatu islands, both, on the atoll and in the high volcanic islands. Most cultivars distributed in Vanuatu have shown good adaptation to the ongoing impacts of climate change over the last decades. Among them, there are two cultivars recommended by the DARD, which are, PNG kumala and baby kumala. The difference between the two is that baby kumala has orange flesh, while PNG kumala has white flesh; growth period to reach harvest maturity is 3-6 months.

Kumala is a drought-resistant crop that needs initial watering to start growing, but once established, does not need irrigation. Nevertheless, it grows best in high rainfall areas with approximately 1,500–2,500 mm/year. Higher rainfall may induce excessive vegetative growth at the expense of tuber growth. Thus, the planting date for kumala can be adjusted based on dynamic cropping calendar utilizing weather and climate forecasts, such that it utilizes the dry season for tuber development and maturation. It grows well in a variety of well-drained soil types, but does not tolerate shading.

Planting material (30 cm tips of vines/stalks from a growing crop) is relatively easy to obtain. Kumala vines need to be pruned approximately 2 months after planting to stimulate tuber development. If vines are not pruned, they continue growing; thereby, reducing tuber development. Almost all kumala grown in Vanuatu is consumed locally.

- Under **Wetter than Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Depending on market demand and available planting material. - Disease/pests heavier incidence occurs on all kumala varieties grown during wet seasons; thus, clean planting material (tips of stalks) without disease/pests will be more difficult to find if planting during a wet season. - if clean planting material cannot be found, farmers can pick stalks with disease/pests and spray with fungicide/insecticide immediately after planting - refer to section on planting material below.
Acreage Allocation	• Set according to available planting material, crop-care capability (including weeding, mounding and spraying for disease/pests).
Land Preparation	• Prepare land and mounds by tractor, rotary hoe or by hand. - land preparation may be delayed if rain is heavy and frequent, and thus, the soil is too wet for tractor-ploughing. - if needed, rotary-hoes can be used to prepare thin rows for planting. After planting, the rotary-hoe can be run along both sides of the rows to mound the rows - make rows of mounds wider apart (100 cm) to allow excess water to drain away between the mounds, thereby reducing disease/rot of tubers in the mounds if the soil is too wet.
Irrigation	• Not required.
Planting Material	• Select tips of stalks from an existing crop without disease/pests, if possible. - if stalks have disease/pests, spray with fungicide/insecticide immediately after planting. - pick stalks at least 1 day before planting and keep in the shade under a tree and sprinkle with water to stimulate root-development on the stalks. - in wet conditions, roots will grow faster on the stalks and the stalks need to be planted more quickly to prevent rot development.
Land Management	• Plant stalks less deep than usual on the mounds. - this is to keep tuber-formation in the drier/less-wet soil of the mound so there will be less risk of tuber rot.
Fertilizer Application	• Fertilizer is not normally used for sweet potato farming in Vanuatu.
Pest/Disease Control	• Monitor crop for disease symptoms or insect infestation and spray if needed. - wet and hot conditions can lead to disease on the leaves which can be treated by spraying with fungicides, such as benomyl, etc. • Monitor crop for rodents after tuber development begins and treat by spreading rat poison if needed.
Weed Control	• Monitor weed growth and weed as needed. - weed growth is faster in wet conditions; thus, weeding may be needed weekly until kumala runners have covered the space between rows (after approximately 4-5 weeks).

– Under **Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Depending on market demand and available planting material.
Acreage Allocation	• Set according to market demand, available planting material and crop-care capability.
Land Preparation	• Prepare land and mounds by tractor, rotary hoe or by hand, as usual.
Irrigation	• Not required.
Planting Material	• Select stalks from an existing crop without disease/pests. – pick stalks at least 2 days before planting and keep in the shade under a tree and sprinkle with water to stimulate root-development on the stalks.
Land Management	• Plant stalks according to usual practice.
Fertilizer Application	• Fertilizer is not normally used for sweet potato farming in Vanuatu.
Pest/Disease Control	• Monitor crop for disease symptoms or insect infestation and spray if needed. • Monitor crop for rodents after tuber development begins, and treat by spreading rat poison if needed.
Weed Control	• Monitor weed growth and weed as needed. – weeding will usually be needed every 2 weeks for up to 5-6 weeks; by then runners will have covered the space between rows.

- Under **Drier than Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Plant an early maturing variety to ensure that the crop matures and can be harvested before the dry season intensifies. • Depending on market demand and available planting material. - some kumala varieties are prone to insect pests eating the leaves during dry conditions; therefore, it will be difficult to obtain clean planting material.
Acreage Allocation	• Set as large as possible according to available planting material and crop-care capability. - farmers are advised to switch to growing drought-resistant crops during drier than normal conditions, to ensure food-supply and income. - kumala is relatively drought-resistant and will grow and produce a yield during dry/drought conditions, when other crops fail, e.g. taro.
Land Preparation	• Prepare land and mounds by tractor, rotary hoe or by hand. - tractor-ploughing may be delayed by the soil being too dry and hard, if there is drought. - if needed, rotary hoes can be used for soil/land preparation and mounding (same way as in very wet conditions).
Irrigation	• Prepare for hand-watering each stalk up to 3 times. - if possible, reference decision support information, such as plant physical appearance, soil moisture or evapotranspiration.
Planting Material	• Select stalks from an existing crop without disease/pest symptoms if possible. - if stalks have disease/pests, prepare to spray with fungicide/insecticide immediately after planting. - pick stalks at least 3 days before planting and keep in the shade under a tree and sprinkle with water to stimulate root-development on the stalks. - in dry conditions, roots will grow more slowly on the stalks and will not need to be planted as quickly, because rot will not develop as quickly in dry conditions
Land Management	• Plant stalks according to usual practice. - if soil is dry at planting, water each stalk immediately after planting with at least 300 mL of water per stalk. - monitor daily and if there has been no rain and the stalks begin to wilt, water again with at least 300 mL per stalk. - the stalks should start growing after the first or second watering, but continue to monitor daily and if there has been no rain and the stalks begin to wilt, water again a third time with at least 300 mL of water per stalk.
Fertilizer Application	• Fertilizer is not normally used for sweet potato farming in Vanuatu.
Pest/Disease Control	• Monitor the crop for disease symptoms or insect infestation and spray if needed. - dry conditions can lead to insect infestation of the leaves - treat by spraying with insecticides. • Monitor the crop for rodents after tuber development, and treat by spreading rat poison if needed.
Weed Control	• Monitor weed growth and weed as needed. - weed growth will be slower during dry times - weed as needed until runners have covered the space between rows.

4.4.6 Yam

Yam is an annual root crop with edible tubers high in starch content. Four edible yam species are common in Vanuatu: *Dioscorea alata*, *D. rotundata*, *D. trifida*, and *D. esculenta*. Yam is perhaps the most important socio-economic food crop in Vanuatu. It plays a major role in the cultural and traditional workings of the society of Vanuatu. Yama cultivation in Vanuatu is smallholder oriented, based on subsistence and shifting cultivation. Land clearing, land preparation, and planting are done manually.

Yam requires an optimum growing temperature of 25–30°C. It does not grow well at temperatures below 20°C. It is a tropical root crop whose shoots grow out from the tuber during the growing season (wet season), while remaining dormant during the dry season. During the growing season, the tubers die and new tuber (s) are formed. Yam requires approximately 1,000 mm of rainfall annually, but a higher amount of rainfall per year is preferred. Nevertheless, poorly drained soils or waterlogging is not suitable for yam. It is mildly drought tolerant, but does not compete well with weeds for soil nutrients.

Yam is planted at the end of the dry season and sprouting takes place during the wet season. Early planting starts in July, and ends not later than December. Most farmers carry out planting during September–October. The critical period of high water and nutrient demand is 14–20 weeks after planting, because food reserves in the tuber are almost completely exhausted during that period. The shoots grow very rapidly just before new tubers are formed. Vine breakage is often lethal during this stage of growth. Weeding throughout the growing season is important. If left unattended, weeds would take up nutrients, reducing the yield of yam crop.

– Under **Wetter than Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Depending on market demand and available planting material. • Farmers need to consider: – production of tubers in wet conditions – most varieties of yam are prone to heavier disease incidence and insect infestation in wet conditions. – increased supply may lead to lower market prices.
Acreage Allocation	• Set according to market demand, available planting material and crop-care capability (including weeding, spraying, and harvest).
Land Preparation	• Prepare land and planting holes/trenches by tractor, rotary hoe or by hand. – tractor-ploughing may be delayed if rain is heavy and frequent, thus, the soil is too wet for tractor-ploughing. • For short-tuber yam, a 600 cm/2-feet furrow can be prepared by a tractor using a rip-claw. • The furrow is then filled level again, for planting pieces to be distributed along the filled-in furrow. After planting pieces are distributed, a tractor or rotary hoe can be used to create mounds of soil over the planting pieces.
Irrigation	• Not required.
Planting Material	• Select tubers with minimum rot to cut up into planting pieces of usual size. – trim any rot from tubers before cutting up into planting pieces. – dip planting pieces in an anti-fungal dip and dry before planting. – planting pieces will be more susceptible to rot during wet conditions.
Land Management	• Plant at higher density than in normal conditions, because there will be sufficient water for the increase in planting.
Fertilizer Application	• Fertilizer is not commonly used for yam farming in Vanuatu.
Pest/Disease Control	• Monitor the crop for disease symptoms or insect infestation and spray if needed. – leaves and vines are affected by fungal diseases and insects, especially in wet conditions. – monitor daily for disease and insects, and spray as needed with fungicides and insecticides, according to approved spraying programs.
Weed Control	• Monitor weed growth and weed as needed. – weed growth is faster in wet conditions; therefore, weeding may be needed weekly for the duration of the crop (up to 6 months). – mulching with plastic or organic material can be used to reduce weed growth. • Intercropping yam with kumala can be used to provide a cover crop to reduce weed growth and income from kumala after 4 months, while yam is still growing. – if weeding is done using herbicide spray, take care not to spray yam plants – spray application rate and frequency may increase by 20–50% relative to normal conditions.
Harvest	• Harvest of yam will require intensive manual labor to dig up the tubers carefully by hand, without damage, regardless of prevailing wet, normal or dry conditions.

– Under **Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Depending on market demand and available planting material.
Acreage Allocation	• Set according to market demand, available planting material and crop-care capability (including weeding, spraying and harvest).
Land Preparation	• Prepare land and planting holes/trenches by tractor, rotary hoe or by hand, as usual.
Irrigation	• Not required.
Planting Material	• Select tubers with minimum rot to cut up into planting pieces of usual size. – trim any rot from stalk bases before cutting up into planting pieces. – dip planting pieces in an anti-fungal dip and dry before planting.
Land Management	• Plant according to usual practice.
Fertilizer Application	• Fertilizer is not commonly used for yam farming in Vanuatu; however, farmers are experimenting with fertilizers, including NPK and chicken manure.
Pest/Disease Control	• Monitor crop for disease symptoms or insect infestation and spray if needed. – leaves and vines are affected by fungal disease and insects after rain. – spray fungicides and insecticides as needed immediately after rain, according to approved spraying programs.
Weed Control	• Monitor weed growth and weed as needed. – weeding will usually be every 2 weeks for the duration of the crop (up to 6 months). – mulching with plastic or organic material can be used to reduce weed growth. • Intercropping yam with kumala can be used to provide a cover crop to reduce weed growth and provide income from kumala after 4 months, while yam is still growing. – if weeding is done using herbicide spray, take care not to spray yam plants.
Harvest	• Harvest of yam will require intensive manual labor to dig up the tubers carefully by hand without damage, regardless of prevailing wet, normal or dry conditions.

– Under **Drier than Normal** Seasonal Rainfall

Activity	Recommendations for climate-smart practice
Select Variety	• Plant an early maturing variety to ensure that crop matures and is harvested before the dry season intensifies. • Farmers need to consider: – planting material will be more difficult to find during dry/drought times. – local prices for yam will be higher during dry/drought times due to shortage of supply. • If irrigation is not available, switch to other drought-resistant crops such as kumala or manioc.
Acreage Allocation	• If irrigation is available, set as large as possible for the high price yam according to available planting material and crop-care capability (including weeding, spraying and harvest).
Land Preparation	• Prepare land and planting holes/trenches by tractor, rotary hoe or by hand. – tractor-ploughing may be delayed by the soil being too dry and hard in case of drought. • For short-tuber yam, a 600 cm/2-feet furrow can be prepared by a tractor using a rip-claw. • The furrow is then filled level again, for planting pieces to be distributed along the filled-in furrow. After planting pieces are distributed, a tractor or rotary hoe can be used to create mounds of soil over the planting pieces. – farmers may consider minimum-tillage by mowing or disking the planting area, and using rotary hoes or hand-tools to prepare rows for planting, without ploughing the whole area. – a weed-killer spray with glyphosate over the area, one week before planting, will kill growing weeds.
Irrigation	• Monitor and irrigate as needed during dry/drought conditions – if possible, reference decision support information, such as plant physical looking, soil moisture, or evapotranspiration. • Water required for irrigation increases as yam grows. • At planting, if the soil is dry, water each mound planted with at least 1 L per week until rain falls or the yam sprout appears from the mound. – after yam sprouts, if there has been no rain, water each yam with at least 1.5 L per week, until rain falls. – for small-scale yam plots, watering can be carried out using empty plastic bottles (1.5 L or larger) – make a small hole in the cap of the bottle with a nail, fill the bottle with water and screw on the cap, then poke the full bottle upside-down into the mound leaving half the bottle visible. The water will drip slowly to provide sufficient water for up to a week. Then refill the bottles and put back in the mounds.

– Under **Drier than Normal** Seasonal Rainfall (continued)

Activity	Recommendations for climate-smart practice
Planting Material	• Tubers will be less-available during dry/drought times. – trim rot from stalk bases before cutting up into planting pieces. – dip planting pieces in an anti-fungal dip and dry before planting. – cut planting pieces bigger than usual, so the planting pieces have more vitality to grow shoots.
Land Management	• Plant at lower density than in normal conditions. – apply mulch (plastic or organic material) around the yam after planting to reduce moisture loss from the soil.
Fertilizer Application	• Fertilizer is not commonly used for yam farming in Vanuatu, but farmers are experimenting with fertilizers, including NPK and chicken manure.
Pest/Disease Control	• Monitor crop for disease symptoms or insect infestation and spray if needed. – despite dry conditions, leaves and vines will still be affected by fungal disease and insects after rain. – spray fungicides and insecticides as needed immediately after rain, according to approved spraying programs.
Weed Control	• Monitor weed growth and weed as needed. – weed growth will be slower during dry times. – weeding will usually be every 3–4 weeks for the cropping duration (up to 6 months). – mulching with plastic or organic material can be used to reduce weed-growth. • Intercropping yam with kumala can be used to provide a cover crop to reduce weed-growth and provide income from kumala after 4 months, while yam is still growing. – if weeding is done using herbicide spray, take care not to spray the yam plants. – spray application rate and frequency may decrease by 20–50% relative to normal conditions. – if minimum tillage has been used, weeding will be limited to between the rows and 300 cm/1 foot outside each row.
Harvest	• Harvest of yam will require intensive manual labor to dig up the tubers carefully by hand without damage, regardless of prevailing wet, normal or dry conditions. – farmers will need to ensure they have careful workers to dig up the tubers.

5. Way Forward

5.1 Climate Information Services for Resilient Development in Vanuatu

Climate change and variability and extreme weather and climate events are exerting increasing pressure on Vanuatu. Considering the current baseline of climate products and services and the national capacity and needs identified thus far, there must be concrete, practical, and sustainable interventions that need to be built on the identified baseline in Vanuatu.

Impacts of climate change and extreme weather and climate events on agriculture are now influencing the livelihoods of the Vanuatu people in various temporal and spatial scales. Although there are currently many vulnerabilities and high risks, Vanuatu has shown to have the potential to adapt to the climate risks if the government can proactively apply and mainstream the climate products and services in decision-making for resilient planning and implementation. Therefore, based on the gaps and needs and potential capacity identified, a selection of concrete, actionable recommendations for climate services for agriculture in Vanuatu was prepared within the boundary of the recently established Vanuatu Framework for Climate Services.

To facilitate a major shift for climate services both in paradigm and in practice for stakeholders, the VMGD and the SPREP, in partnering with APCC, BOM, and CSIRO, proposed a GCF funded four-year national project in Vanuatu (approximately 2018-2021).

The proposed GCF project, Climate Information Services for Resilient Development in Vanuatu (Van CIS RDP), will feature the development and use of best-available climate information service (CIS) designed to facilitate enhanced adaptation pathways, with emphasis on creation of "actionable" knowledge within a strategic, logic-based (theory-of-action) framework (i.e. data-information-knowledge-action-outcome-impact value chain) customized to the needs of target sectoral and community end-users in Vanuatu (SPREP et al., 2017). The priority sectors identified were agriculture, fisheries, water, tourism and infrastructure.

The project will focus on the delivery of a set of highly interlinked activities to achieve the project outcomes, including training and capacity development; development of practical CIS tools and resources, supporting coordination and dissemination of tailored information; and building the requisite information and technology infrastructure. Furthermore, a key feature of the project is the support it will provide for the application of CIS to real-time existing and or emerging sector-specific development policy, planning and project processes (particularly climate adaptation and disaster risk management initiatives), or 'case studies'. Through the application of CIS to sector specific development priorities, the project will ensure efficient and effective demand driven development and application of CIS. Thus, this approach will provide demonstration case studies to build awareness and appreciation for the practical value and methods for the application of CIS for resilient development. The sectoral case studies will also serve as a focal point for much of the (sector specific) training, resource development, capacity support, etc., to be delivered as per the project components described below. The case studies will be aligned with relevant adaptation and associated disaster risk-reduction strategies and sectoral priorities in Vanuatu.

Synergies will be created in developing and applying CIS for priority case study sectors where applications can be made more broadly across other relevant sectors. This will be achieved through undertaking integrated project-level communications, capacity development and outreach on a collaborative and participatory basis with all relevant sectoral stakeholders in Vanuatu and the region, in generally. Indeed, through appropriate stakeholder engagement it is expected that the utility of many CIS will have broad application across multiple sectors beyond just the immediate case study focus. The case studies will be variously delivered over the four-year term of the project through project-based multi-disciplinary research and development activities. Such an approach involving simultaneous "top down/bottom up" engagement is expected to create valuable synergies for realizing expected project level outcomes and impacts for Vanuatu.

The main activities and associated outputs planned for the national project in Vanuatu have been designed specifically to address the priority CIS needs of Vanuatu and the specific target sectors (as discussed elsewhere in this proposal), in a manner that is sustainable. This will reduce and avoid mal-adaptation, and will permit the realization of relevant outcomes and on-ground impacts for target Next/End-Users in Vanuatu. The project will feature direct engagement with and among all stakeholders, from providers to end-users of CIS; whereby, it will be developed and implemented to demonstrate and evaluate best practice approaches to incorporating CIS in development and decision-making. This is a major shift from doing business as usual to the application of CIS to underpin adaptation priorities for implementation supported by enabling policies and appropriate institutional arrangements.

The key categories of Project Outputs are:

- **Output Category 1:** Multiple Next/End-user engagement and capacity development activities including new sector specific CIS action plans, guidance materials and databases, technical training, advisory and assessment workshops, mentoring and attachments and other miscellaneous in-country exchanges.
- **Output Category 2:** Suite of sector specific CIS development case studies (at least one per sector for term of project), which provide the platform for development, delivery, application and demonstration of CIS tailored to the adaptation needs and resilient planning and development roles of target Next/End-Users, based on tailored H/R/V assessment and associated climate and weather data.
- **Output Category 3:** Suite of customized communication, capacity development and outreach resource materials, including communication and media products, training materials, climate management tools, portals and Decision Support Systems, hands-on expert technical support, and full suite of documentation and web-based capability and content for building capacity, for raising awareness and visibility, and for improved adaptation and resilience planning and development
- **Output Category 4:** New weather and climate infrastructure for enhancing development and delivery of CIS in Vanuatu, including new IT and observational infrastructure for the VMGD (including Doppler radar installation), new

sensors and associated measuring instruments for fine spatial scale data collection in and around designated climate (vulnerability) hot spots, and new communications infrastructure for real-time delivery and outreach of CIS to local communities (including Community Climate Change Centers).

- **Output Category 5:** Digitized and quality controlled observational and related/ancillary socio-economic data secured and accessible within functional CDMS (including appropriate analysis/report applications) and/or other relevant databases ready for uptake and application by climate adaptation and disaster risk-management planners and policy makers.
- **Output Category 6:** Down-scaled and/or regionally specific CLEWS, sub-seasonal/seasonal forecast and long-term projections data and information tailored to sectoral Next/End-user adaptation and disaster risk-management policy development and planning needs and roles.

Deliverables from each component for the Vanuatu Project fall within one or more of these six Output categories and are specifically designed to address the priority CIS gaps and priority needs of target Next/End-users for the five key sectors. The expected Project Level Outcomes to be achieved by delivery of the integrated set of Outputs include:

- Strengthened institutional and regulatory systems for climate responsive planning and development
- Increased generation and use of climate information in decision making [for prioritized adaptation based on assessed needs and gaps (reducing and avoiding mal-adaptation)]
- Strengthened adaptive capacity and reduced exposure to climate risks
- Strengthened awareness of climate threats and risk-reduction processes

5.2 Climate Services for Agriculture Components in the Van CIS RDP

The Van CIS RDP project will directly support generation of and application of climate products and services in decision-making in the agriculture sector through key development policies, planning and project processes. A comprehensive suite of tailored climate products and services will be developed in partnership with target Next/End-users, and deployed in real-time operational situations for the agriculture sector, as part of the case studies. These case studies will provide the framework for ensuring that climate services are mainstreamed into the decision-making process by the key decision-makers themselves.

To produce desired climate services to impact decisions of agricultural stakeholders it is crucial to guarantee a productive coordination among and within the organizations involved. Thus, strengthening the existing units is important to ensure that climate products and information is integrated in their coordination mechanism. The strengthened coordinating unit should have representation from all potential stakeholder groups, which will be identified to facilitate development of potential tailored content of climate, agriculture and allied sector information and advisory.

For example, within the coordinating unit, the role of the VMGD should be to produce seasonal downscaled forecasts; while, the Ministry of Agriculture needs to ensure that advisories issued to farmers are reached in user-friendly manner. Local universities need to collaborate with the Ministry of Agriculture to package the content in a comprehensive fashion. Media and research organizations must work on communicating information on the seasonal forecast advisory. Research organizations need to develop the capacity of the met agency and extension systems to ensure delivery of tailored information. NGOs must provide information from the ground-up on whether the seasonal forecast was accurate and useful to farmers. They also need to encourage confidence in scientific information among farmers. Farmers' organizations need to mobilize farmers to use advisories.

The project will support the capacity of agricultural communities to plan for and make decisions on the best adaptation pathways, via training and resource support, such as climate services and planning decision-support tools. The project will develop a suite of new climate services delivered through multiple formats/platforms tailored to the specific needs of target Next/End-users in the agriculture sector. The combination of targeted climate service support for these key Next/End-users will facilitate enhanced awareness of the risks of climate change and increase broad adoption of climate services at different levels of government and within local communities to make better "climate-smart" decisions in relation to climate adaptation and disaster-risk reduction.

The scope of the proposed activities for the climate services for agriculture under the Van CIS CDP project addresses the baseline condition in Vanuatu and priority climate products and service gaps and needs identified. These activities reinforce delivery of key climate services for agricultural decision-makers at all levels in Vanuatu (from national and provincial government to local community scale). The proposed set of activities will be delivered by the APEC Climate Center under the supervision by the two Executing Entities (SPREP and VMGD), according to a detailed Work Plan as follows.

☐ Work Plan for Climate Services for Agriculture in Vanuatu under the Van CIS RDP

Output 1. Development and delivery of web-based, mobile device-compatible DSS to inform the agricultural sector, where feasible using remote recorded agro-meteorological data and near real-time weather and climate data from VMGD weather stations

1. **Development of an agro-met information portal, the VaCSA (*Va*nuatu *C*limate *S*ervice for *A*griculture), including related IT infrastructure and software:** VaCSA is an agriculture specific interface where agricultural stakeholders get tailored weather/climate information, agromet services, climate smart agriculture practices and knowledge, and manage agro-data in relation to climate data. VaCSA also plays a critical role in producing agro-advisories for the Ag-Extension purpose, which will be managed directly by the Ministry of Agriculture.

1.1 Historical/forecasted weather and climate information

1.1.1 Near real-time weather and climate data from agro-meteorological stations and VMGD weather stations

1.1.2 Visualization and analysis of the historical data from the stations

1.1.3 Weather and climate forecasts from VMGD

1.2 Agro-met information, including crop phenology and yield and optimal farm management, based on agro-met index and/or agro-model simulation

1.2.1 Visualization of agro-met indices for each station using historical and forecast data

1.2.2 Crop phenology and yield and optimal farm management information based on agro-met index and/or agro-model simulation

1.3 Agricultural database, including digitized agricultural data, knowledge products, such as climate-smart agriculture practices and agricultural policies and plans, and agro-data collected from the Crop-Climate Diary app.

1.3.1 DB management, including agro-data storage, and upload and download of all files

1.3.2 Agro-data statistics from the Crop-Climate Diary, linked with agro-met indices

1.4 Weekly and/or monthly agro-met advisory in English and local language

1.4.1 Weather and climate information, including forecasts, warnings, and past climate verification

1.4.2 Agro-met information

1.4.3 Climate smart advisories based on the given weather and climate information

1.4.4 Advisory issued via various methods such as pdf download from the VaCSA, text message to a cell phone, push-alarm from smartphone app, etc.

1.5 IT infrastructure (a server system) and software are provided

1.6 Relevant training on system maintenance is provided

2. **Development of a mobile device application (Crop-Climate Diary) customized for agro-data collection, including mobile devices provided for field data collection:** Crop-Climate Diary App is a mobile device-based tool to collect agro-data, including GIS information on the map, which is synchronized with the VaCSA system for further data management and analysis. This App is a critical part of the climate information service for connecting agro-data with climate data, thereby, increasing data management capacity in the agriculture sector.

2.1 Development of Crop-Climate Diary

2.1.1 GIS-based location and area information

2.1.2 Farm diary for farming activities

2.1.3 Offline collection of agro-data and online sync with the VaCSA server

2.1.4 Agro-data management and further analysis with the meteorological data through the VaCSA system

2.2 10 Tablet PCs (Galaxy Tab) and relevant training on the agro-data collection with the Crop-Climate Diary are provided for agro-data collection in the field surveys and trials

Output 2. Installation of new automated weather stations in selected provinces/islands, including sensors for solar radiation with sunshine, air temperature, soil moisture, precipitation, relative humidity, wind speed and direction, and a data logger and GSM antenna for automatic data transmission to a server

1. **Installation of new automated agro-met stations and new automated rain gauges:** Agromet stations will be procured by the VMGD. APCC will provide advice on site selection. The agromet stations provide agromet data necessary for smart irrigation, dynamic crop calendar, agromet indices monitoring for every day decision-making. The weather data, in combination with existing VMGD weather stations data, will be used to verify (downscaled) weather/climate forecasts information for agricultural use.

1.1 Select sites for the installation of agro-met stations and rain gauges based on multiple review and discussion with the Ministry of Agriculture (MofA) and VMGD

1.1.1 Reach an agreement for the maintenance and the use of data of agro-met stations and rain gauges between MofA and VMGD

1.1.2 Sites determined based on target crops in the major agricultural area of each province/island, easy access for regular maintenance, security, and distance to other weather stations

1.2 8 agro-met stations installed for selected provinces/islands

1.2.1 10-year sensor replacement and maintenance warranty for the agro-met stations

1.2.2 Installation will be done only in land free of any ownership issues (e.g. government-owned land)

1.3 10 rain gauges installed for selected trial sites

1.3.1 10-year sensor replacement and maintenance warranty for the rain gauges

1.3.2 Installation will be done under the permission of the land owner (either private or public)

1.4 Intensive training of the VMGD staff for sustainable agro-met station operation and maintenance

1.4.1 Training of designated VMGD staff from the installation and every regular maintenance of the equipment by the AWS service company

1.4.2 Detailed maintenance manual and maintenance checklist will be provided

1.4.3 The company will conduct regular maintenance with training at least once a year during the project period, and then at least every other year within the warranty period

2. **Data interface to CliDe and VMGD data portal and VaCSA system:** Agromet station data will be transmitted to existing CliDe and/or VMGD data portal via a data interface gathering all agromet station data.

2.1 Development of a data interface to VaCSA system

2.2 Development of a data interface to CliDe and VMGD data portal

Output 3. Develop and apply agro-met services utilizing climate information for climate smart decision-making in agricultural sector at a provincial- or national- level to be incorporated into the web-based DSS

1. **Comprehensive analysis of Vanuatu agriculture and its resilience to climate variability, such as caused by the occurrence of tropical cyclones and drought:** Comprehensive information analysis will help to identify critical issues and problems that need to be tackled by the climate information service for agriculture developed under the project. Some information will be part of the solutions to the identified problems and will serve as a basis for the

development of climate services. Expert knowledge will be critical in some information analysis.

1.1 Vulnerability assessment of the agricultural sector in Vanuatu to climate variability

1.1.1 Historical damage of the agricultural sector by climate variability

1.1.2 Governance mapping of the main players and ongoing projects in the agricultural sector

1.1.3 Major crops for food security and major cash crops, and their tolerance to climate variability

1.2 Collection of traditional knowledge, measures to counter climate variability, and state-of-the-art skills in climate-smart agriculture through stakeholder surveys, literature reviews, and expert consultation

1.2.1 For a short-term strategy, focus on countermeasures and skills in case of drought and tropical cyclone

1.2.2 Climate-smart practices to improve agricultural resilience against climate change as a long-term strategy

1.3 Undertake quality control of the collected information and analyze them to generate climate-smart agriculture knowledge-products for VaCSA

2. **Agro-data collection from selected survey and trial sites:** Agro-data collection is fundamental for the development of agromet services. Without sufficient samples of agro-data, all the agro-models developed in the project will have a weak logical basis for accurate simulation or prediction. Therefore, more quality data will assure more robust agromet service. Data collection in survey sites should takes place in existing farms by agreement with the owner. If the data is not sufficient enough or quality-assured in the survey sites, trails need to be conducted for better control of data collection.

2.1 Develop an agro-data collection plan and manual for selected crops and survey sites, and appoint data collectors

2.2 Conduct field trials for agro-data collection and agro-model development if necessary

2.3 Collect agro-data by the appointed data collectors through hand-writing and/or Crop-Climate Diary, once it becomes available

2.3.1 First data collection takes place near existing VMGD weather stations

2.3.2 Second data collection near newly installed agro-met stations or new rain gauge sites

3. **Development and validation of new algorithms and models:** New agro-models will be developed using the agro-data collected from Activity 2.3. Based on Activity 3.1, in addition, it will be decided which agro-models to be prioritized in the project. For now, smart irrigation, dynamic crop calendar, crop phenology and yield prediction using agromet indices, climate-smart farming models will be developed through this project.

3.1 Development of new algorithms and models by analyzing the agro-data collected from multiple field surveys and trials for individual crops and the meteorological data from near weather stations

3.1.1 Crop phenology and yield estimation

3.1.2 Optimal farm management, including planting, harvesting, and irrigation

3.2 Development of tailored weather and climate data to feed the algorithms and models developed

3.2.1 Tailoring or downscaling methods of weather and climate forecasts if necessary

3.2.2 Feeding methods of the weather station-monitored data to the algorithms and models

3.3 Validate the algorithms and models via field trials

3.3.1 Design location-specific field trials to validate the algorithms and models developed for selected crops

3.3.2 Conduct field trials for validation to predict crop phenology and yield

3.3.3 Conduct field trials to validate the optimal farm management options generated from the algorithms and models

4. **Ground validation of the agro-met services and final outreach with/to target Next/End-users:** Ground-validation is a final output of the agromet service development. The agromet services need to be ground-validated for the stakeholders to adopt the agromet services for their decision-making. Most behavioral changes are only possible through the evidence-based uptake by the stakeholders. This result will be a success indicator and will ensure the sustainability of the project outputs.

4.1 Select champion farmers and extension officers to participate in the ground validation of the agro-met services developed

4.2 Conduct trials with the champion farmers and extension officers

4.3 Development of agro-advisory for VaCSA

4.4 Farmer field schools for target Next/End-users

4.4.1 Share results of the ground validation of the agro-met services

4.4.2 Champion farmers and extension officers serving as trainers and exemplary pioneers in the region

4.4.3 Training on the use of agro-met services and climate smart practices via various training materials

4.4.4 Roundtable discussions based on the agro-advisory information from VaCSA

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Appendix Technical Specifications – Automatic Weather Stations

The automatic weather stations (AWSs) and the surrounding enclosure must meet:

1. Agro-meteorological requirements
2. VMGD weather and climate monitoring requirements
3. WMO standards and guidelines

In regard, the recommended technical specifications for automatic weather stations are:

Item	Description/specifications required
General AWS Requirements;	The AWS equipment for the Vanuatu Meteorology and Geo-Hazards Department (VMGD) will meet the World Meteorological Organization (WMO) standards and specifications as per the Guide to Meteorological Instruments and Methods of Observation (WMO CIMO Guide 2014). The purpose of the stations is to provide near-real-time observations of key climate parameters to enable the generation of Climate early warning products as detailed in the project scope. Measurements will include wind speed and direction, cloud height and visibility, relative humidity and air temperature, precipitation, atmospheric pressure, soil moisture, soil temperature profile and leaf wetness. The AWS should include capacity to support the measurement of other parameters such as sea level. The AWS should include a programmable data logger that provides local data storage in “first in first out” (FIFO) storage and remote telemetry. The remote telemetry should be capable of using the Vanuatu government wireless broadband network as a primary data path and Satellite communications as a secondary path. The AWS should include solar power supply and be able to sustain operation for a minimum of 2 weeks without solar charge. The AWS should include a 10 m guyed and lowerable station mast, a small Stevenson screen for air temperature observations and be of a robust and durable construction suitable for use in tropical environments. The general specification for each item is detailed below:

AWS Sensor:	Model	Range/ Specification
Wind Speed/Direction:	Vector A101m wind speed	0 – 75m/s, +/- 1%
	Vector W200P wind direction	0 – 360°, +/-3°
Air Temperature and Relative Humidity:	Vaisala or equivalent HMP155A temperature and Relative humidity	Temperature: -80 – +60℃, +/- 0.1℃ Relative humidity: 0 – 100% +/- 1%@20℃
Precipitation:	Hydrological services TB3 tipping bucket rain gauge	0.5 mm/tip, 0-250 mm/hr, +/- 2%, 200-300 mm/hr +/-3%.
Atmospheric Pressure:	Vaisala or equivalent PTB 110	500 – 1060 hPa, +/- 0.3 hPa.
Solar Radiation:	Licor LI200SZ-50	0 -3000 w/m^2, +/-5%
Soil Moisture:	Acclima Digital TDT	0 – 100%, +/-2% VWC
Earth Temperature:	Unidata LM34	-18 to +100℃, +/-0.3℃
Leaf Wetness Sensor	Decagon dielectric leaf wetness sensor	250 – 1000 mV
Ceilometer and Visibility		OPTIONAL
Data Logger	All data recording to be undertaken using the Unidata NRT Ethernet dual communications module that should combine an 8 MB data logger with modern IP capable Satellite and Cellular data modems. The data logger memory is configured for FIFO storage with the oldest data eventually over written by the newest. The 8-MB NRT data memory will provide local storage for 〉2 years. The data logger should include capability for expansion of the measurements to include other data type such as Sea Level. The NRT is a small self-contained unit which connects to sensors, records readings from them and transmits the data to a central server with a cellular telephone network. The data logger should include IP data communications and be compatible with Unidata's NEON IP telemetry system. The NEON system should include integration with VMGD CliDE climate database and CliDEsc the CLEWS product reporting system.	
Communications	The AWS should include dual IP based data communications capability. Primary communications should utilize the Vanuatu government national broadband network and to provide backup communications the system should automatically transfer operations to a local Inmarsat BGAN IP satellite or cellular options	
Power Supply	The AWS shall be solar powered with sufficient capacity to enable at least 2 weeks operation	

AWS Sensor:	Model	Range/ Specification
Station Mast and Site Hardware	Each AWS shall include all hardware to enable mounting of all sensors, including: - A 10 m guyed folding tubular mast to deploy the wind sensors. Wind speed and direction to be measured at 2 m, 4 m, and 10 m for agro-meteorological purposes. - A secondary lattice mast to locate the equipment enclosure and locate the solar panel - All station cabling and sensor mounting hardware - The equipment enclosure should be stainless steel, lockable and double skinned to provide solar isolation to reduce equipment heating - A small Stevenson instrument screen and stand will be required for RH/T observations All AWS station will be fenced.	
Warranty	All equipment should include a warranty against poor workmanship for 12 months beginning from the date of commissioning.	

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