COUNTRY HYDROMET DIAGNOSTICS

Informing policy and investment decisions for high-quality weather forecasts, early warning systems, and climate information in developing countries.

November 2023

Samoa Peer Review Report

Reviewing Agency: Bureau of Meteorology, Australia

METEOROLOGY DIVISION M.N.R.E

Australian Government
Bureau of Meteorology

THE WORLD BANK | SOFF Systematic Observations Financing Facility | Weather and climate data for resilience | WORLD METEOROLOGICAL ORGANIZATION | Alliance for Hydromet Development

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 Dr Andrew Jones General Manager International Development Bureau of Meteorology GPO Box 1289, Melbourne VIC 3001 Australia	 Ms Peseta Noumea Simi Chief Executive Officer Ministry of Foreign Affairs and Trade P.O. Box L1859 Apia Samoa

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List of acronyms

ACCESS	Australian Community Climate and Earth-System Simulator (model)
AWS	Automatic Weather Station
BIP	Basic Instruction Package
CDCRMP	Community Disaster and Climate Resilience Management Program
CHD	Country Hydromet Diagnostics
CLEWS	Climate Early Warning System
CLiDE	Climate Data for the Environment
COSPPac	Climate and Oceans Support Program in the Pacific
CREWS	Climate Risk and Early Warning Systems
DMO	Disaster Management Office
ECMWF	European Centre for Medium-Range Weather Forecasts (model)
ENSO	El Niño–Southern Oscillation
EW4All	Early Warnings For All (a UN initiative)
GBON	Global Basic Observing Network
GDP	Gross Domestic Product
GFS	Global Forecast System (model)
GPRS	General packet radio service (a data standard)
ICAO	International Civil Aviation Organization
ICT	Information and communications technology
JICA	Japan International Cooperation Agency
JMA	Japan Meteorological Agency
NIWA	National Institute of Water and Atmospheric Research, New Zealand
NWP	Numerical Weather Prediction
PREP	Pacific Resilience Program
RSMC	Regional Specialised Meteorological Centre
SMS	Samoa Meteorological Service
SOFF	Systematic Observations Financing Facility
SOP	Standard Operating Procedure

Executive Summary

Samoa (population approximately 220,000) is a small island developing state in the equatorial southwest Pacific consisting mainly of two large volcanic islands. It has a tropical climate and is subject to hydrometeorological and geophysical hazards including tropical cyclones, severe thunderstorms, wind damage, flooding, tsunamis, earthquakes, landslides, wildfires, and volcanic eruptions. Rainfall is strongly influenced by ENSO as well as other climate drivers, leading to periods of drought or heavy rainfall. Samoa is highly exposed to climate change, with the great majority of its population living near sea level and many potentially affected by increased rainfall intensity and riverine responses as well as any change in ENSO incidence.

The Samoa Meteorology, Geoscience and Ozone Services Division (also known as Samoa Meteorological Service), part of the Ministry of Natural Resources and Environment, is responsible for weather & climate services, including warnings for hydrometeorological and geological hazards. Recent legislation has strengthened and defined the role of the Division. The Division works closely with partner Divisions for Disaster Management and Water Resources within the same Ministry, and works with other parts of the Samoan Government, the local University Sector, and international humanitarian and capacity development agencies. Weather, climate and early warning services are delivered to the public through multiple channels, including traditional and social media, a dedicated phone application, website, text messaging and emails. These services are supported by multi-agency community engagement and education programs, which engage with the strong social structures, including traditional knowledge holders, in the Samoan community.

Within this strong overarching framework, the Division faces many operational and strategic challenges. The principal issue is that it does not have the budget or ongoing staffing numbers and training to support its operations, including maintaining ICT infrastructure, observations calibration and maintenance, further development of forecasting services, vehicle procurement, training, or quality management of services. Consequently, it is largely reliant on overseas assistance for elements of its basic operations. This assistance has come from many quarters, resulting in some incompatible and unintegrated systems that create further stress on the organisation following the closure of the relevant projects. Whilst efforts to streamline and integrate these systems are underway, the underlying issues of support for ongoing operations will remain.

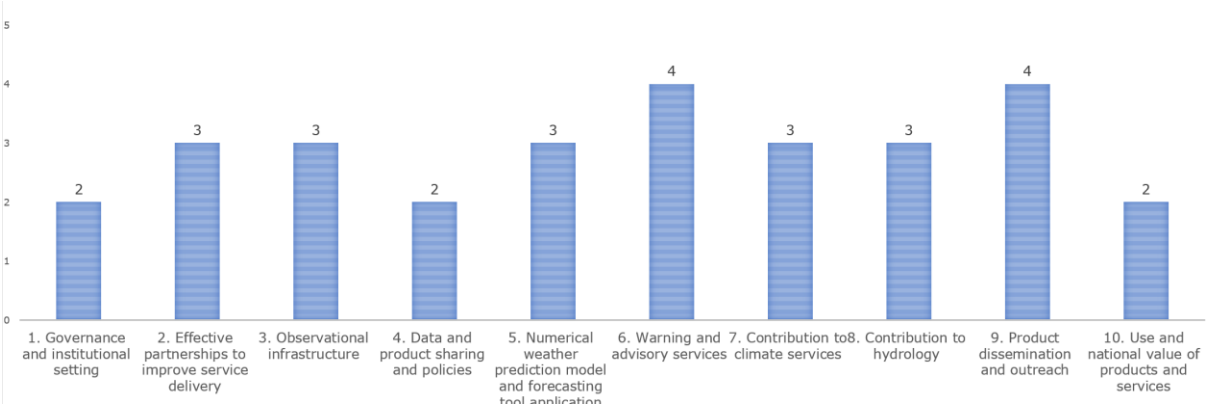
As a result of these issues, the Division's ICT infrastructure is particularly vulnerable (including its core forecasting and monitoring systems, website for service delivery, receipt and transmission of internationally required observations and other important network observations), and there is a resultant impact on service delivery. A small minority of weather observations from Samoa are internationally transmitted, meaning that the international weather models used by the Division as forecasting guidance do not 'see' actual conditions in Samoa, and are therefore hindered in accurately forecasting future conditions. These models are also of insufficient resolution for resolving the detail of extreme weather (such as heavy rainfall) of concern to Samoa. Samoa's climate records are also compromised by the quality management standards of observations and ICT system fragility. The Water Division's flood warning network faces similar challenges.

Samoa also has no weather radar or upper air observing station, both of which would bring benefits for short-term forecasting (and public decision making) and medium-term forecasting respectively, if a sustainable way of operating these facilities can be found.

The Division is currently developing its strategic plan, which will need to consider these challenges. The Division is already highly centralised, with almost all operations performed from its coastal headquarters in Apia, and there is limited immediate scope for reorganising its current workforce. Parts of its physical infrastructure are also sub-optimal (for example, many of its automatic weather stations are unsafe to climb for maintenance, and the forecasting centre has an unacceptably loud work environment), and parts of the main site are subject to coastal inundation.

To help address these issues, long term partnerships with other peer agencies, as well as capacity development agencies, are strongly recommended in preference to short-term project approaches. Where long-term partnerships exist (for example with COSPPac, the Climate and Oceans Support Program in the Pacific), they have generally been effective. Longer-term efforts could include the Systematic Observations Financing Facility, a new global initiative for improving weather observations, and Weather Ready Pacific (an initiative of the Pacific Meteorological Council). However, other areas such as ICT, governance and budget, quality management, and geohazard relationships will also require long-term attention.

Summary of assessment ratings for CHD elements



Element	Maturity level score
1. Governance and institutional setting	2
2. Effective partnerships to improve service delivery	3
3. Observational infrastructure	3
4. Data and product sharing and policies	2
5. Numerical weather prediction model and forecasting tool application	3
6. Warning and advisory services	4
7. Contribution to climate services	3
8. Contribution to hydrology	3
9. Product dissemination and outreach	4
10. Use and national value of products and services	2

These ratings are discussed below.

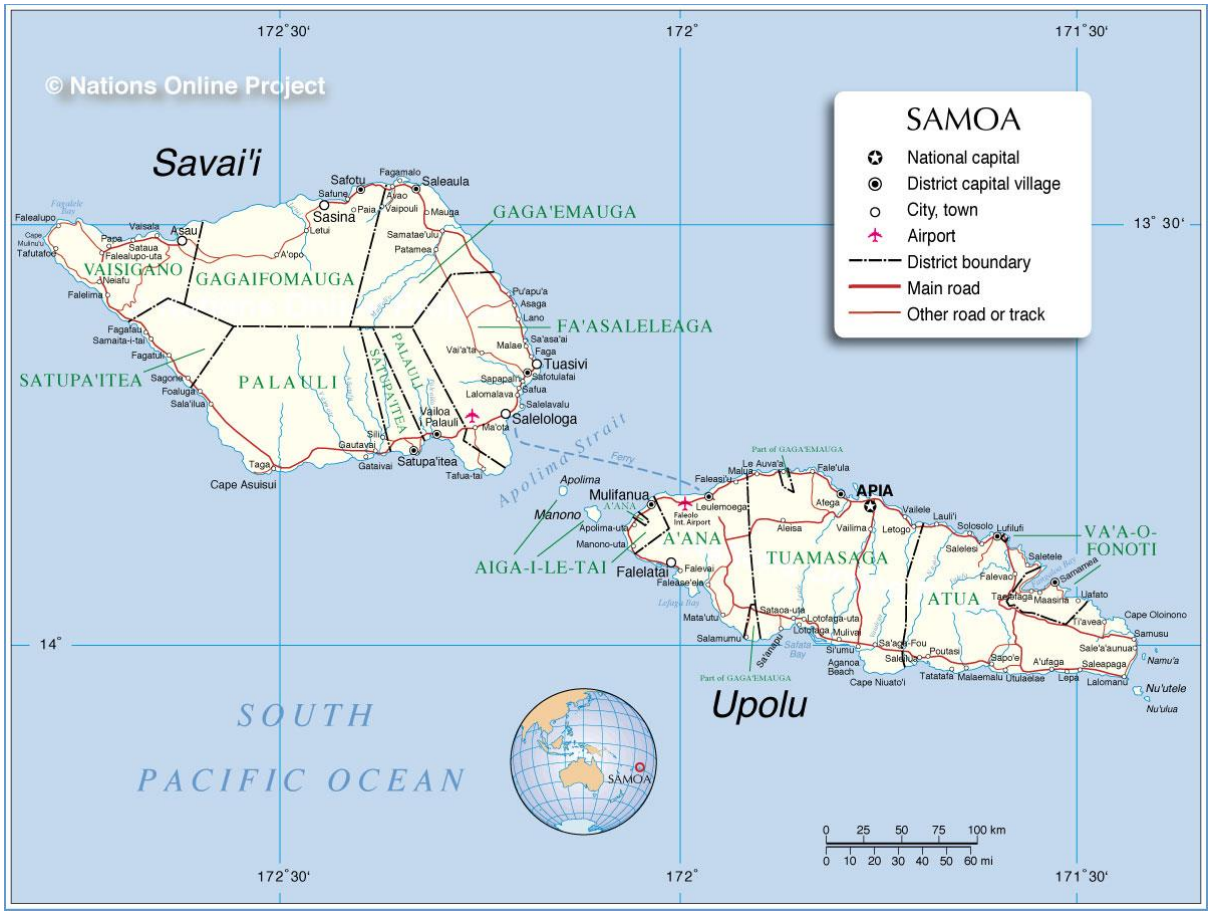
Chapter 1: General information

Introduction

Overview

Samoa consists of the western part of a volcanic archipelago south of the equator, north-east of Fiji and about halfway between Hawai'i and New Zealand. Two massive basaltic shield volcanoes, the islands of Upolu and Savai'i, make up the great bulk of the total land area of 2,842 km^2, with eight small islets making up the remainder (Figure 1). The capital, Apia, lies on Upolo, with hundreds of coastal communities on both islands, and farming and resources activities occurring in the steep, rugged and densely forested island interiors. To the east lies American Samoa, which is administered separately.

The GDP of Samoa is approximately USD 850 M and GDP per capita is approximately USD 4,000. GDP growth, inflation, and per capita GDP are all relatively high for the Pacific region[1]. The economy of Samoa has traditionally been dependent on development aid, family remittances from overseas, tourism, agriculture, and fishing. The service sector accounts for nearly two-thirds of GDP and employs approximately 50% of the labour force. Tourism is an expanding sector accounting for 23% of GDP prior to the 2020 pandemic; 163,000 visitors, most of which were tourists, arrived in Samoa in 2019. Samoa has been making good progress in addressing poverty and managing gender, health, education, and environment issues.



[1] Asian Development Bank

Figure 1 Map of Samoa (Nations Online Project).

Physical environment, climate, and natural hazards

Samoa lies near the northern end of the Tonga Trench, part of the so-called Pacific Ring of Fire, and is highly subject to earthquakes, tsunamis, and volcanic activity associated with geological processes. These are significant hazards. In 2009, an 8.1 magnitude earthquake generated a large tsunami that struck the south coast of Samoa with maximum flood heights locally over 10m. The tsunami killed 149 people in Samoa, left 3,000 people homeless and destroyed over 20 villages (Figure 2)[2].

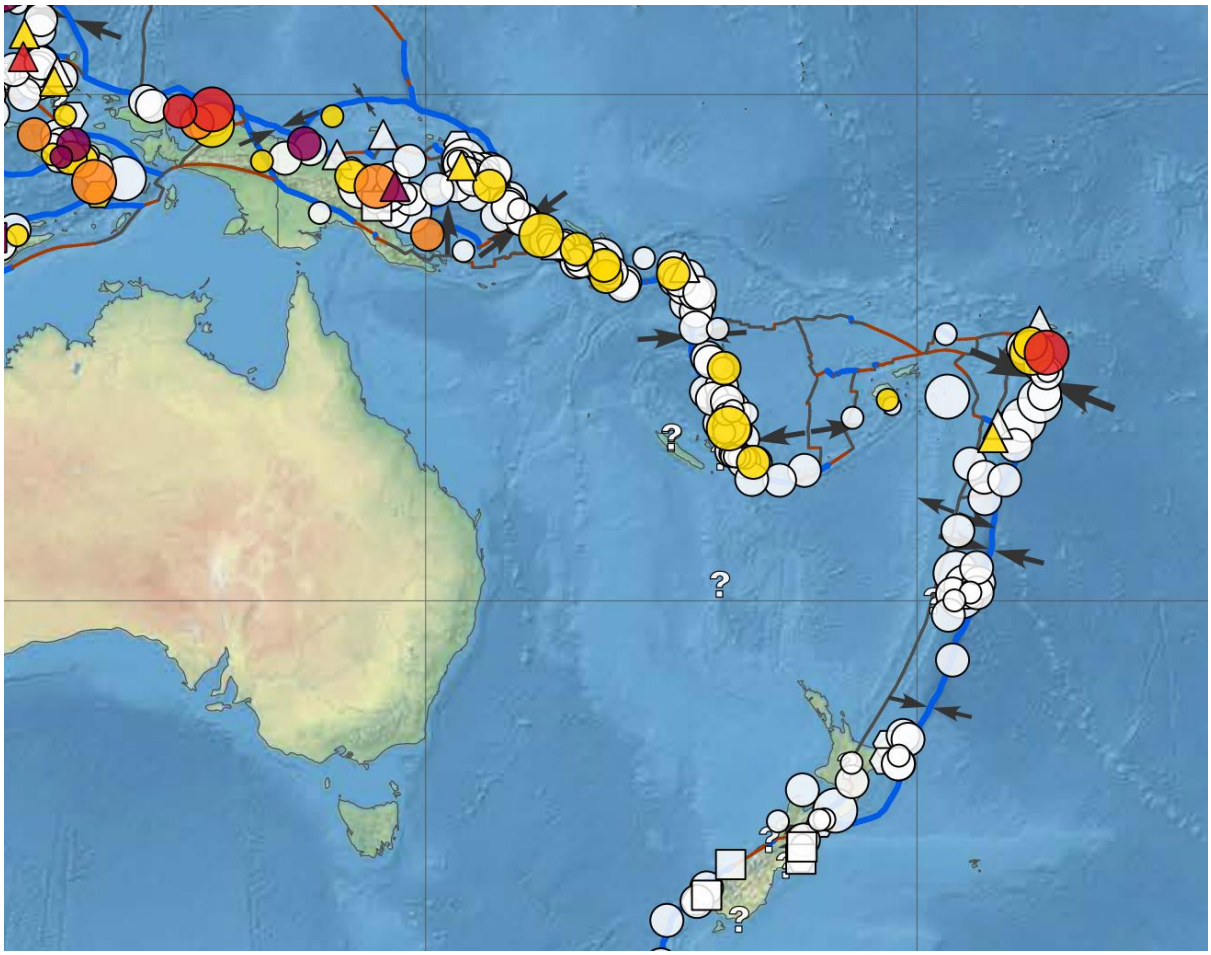


Figure 2 Detail from Tsunami Sources 1610 BC to AD 2022 poster, IOC-UNESCO, March 2022. Circles indicate earthquakes, squares indicate landslips, and triangles indicate volcanic eruptions. The location of the 2009 earthquake and tsunami is in red on the upper right of the figure. Savai'i is also marked by a white volcanic tsunami symbol immediately above. The Tonga Trench (blue line) extends southwards from Samoa towards New Zealand.

Samoan volcanic eruptions tend to be Hawaiian style, associated with lava flows and crustal hotspots, rather than the more explosive subduction-style eruptions of Tonga, although future explosive activity cannot be discounted. Savai'i remains volcanically active, with the most recent eruptions at Mt Matavanu (1905–1911) and Mata o le Afi (1902) producing lava flows along broad fronts up to about 15 km wide, destroying several villages and overtopping fringing reefs. As a result, there are solidified and exposed lava fields on Savai'i. Numerous cinder cones and lava cones dot the broad

[2] http://itic.ioc-unesco.org/index.php?option=com_content&view=article&id=1657&Itemid=3075

crest of Savai'i, which has a low-angle, dome-like profile and reaches an elevation of 1858 m.

On Upolu, the latest lava flows, at least three of which are estimated to be as young as a few hundred to a few thousand years old, were erupted from vents near the crest of the island at its centre and western side.

Volcanic eruption sites in Samoa are monogenic – the next eruption will not necessarily occur from near the location of the last eruption, meaning that a broad area monitoring strategy is required rather than a focus on a particular site.

Samoa is also exposed to off-shore volcanic hazards. During 2022, for example, there were two events of note. Firstly, the extraordinary Hunga Tonga-Hunga Hapai eruption in southern Tonga created a global tsunami through atmospheric wave coupling, with a fortunately low local death toll but widespread coastal impacts, including fatalities as distant as Peru[3]. The most recent activity in the region was from American Samoa, when a swarm of volcanic earthquakes at Ta'u Island [4]on the eastern end of the archipelago during July-September 2022 resulted in the declaration of a State of Emergency but no significant impacts.

The hazards most likely to be associated with Samoan eruptions are lava flows, volcanic gases, ashfall, ballistic ejecta, lightning, pyroclastic surges, earthquakes, lahars, and edifice collapse (potentially with associated tsunamis)[5].

Samoa has a tropical maritime climate. Temperatures are generally consistent throughout the year, tending to be cooler in July during the Southern Hemisphere winter and when the south-east trade winds are most active. Rainfall ranges from 3,000 to 6,000 mm annually[6] and is greatly influenced by the location of the South Pacific Convergence Zone, which is where surface winds converge over a broad latitudinal area to trigger thunderstorm activity. This is most active over Samoa during November to April (which is also the tropical cyclone season), during which 75% of annual rainfall occurs, but heavy rain can occur at any time of the year. Rainfall at different locations is also strongly influenced by topography, with the windward side (south to southeast) of the main islands receiving significantly more rainfall than the areas in the rain shadow in the north to northwest. This also means that the rain shadow areas have lower vegetation growth and are more subject to wildfires.

The El Niño Southern Oscillation significantly affects Samoa's climate, with El Niño tending to result in drier and hotter than average years, and an escalation of associated droughts and wildfires. Drought and fire impacts are most notable in the north-west regions of the main islands, which climatologically receive less rainfall. La Nina is more likely to be associated with heavy rain and flooding of rivers and low-lying areas.

Human-induced climate change will have impacts on weather and climate in the years and decades to come. Temperatures will continue to increase, and whilst there is expected to be little change in mean annual rainfall, extreme rainfall events are expected

[3] Global Volcanism Program, 2022. Report on Hunga Tonga-Hunga Ha'apai (Tonga) (Bennis, K.L., and Venzke, E., eds.). *Bulletin of the Global Volcanism Network*, 47:3. Smithsonian Institution. https://doi.org/10.5479/si.GVP.BGVN202203-243040

[4] Global Volcanism Program, 2022. Report on Ta'u (United States) (Sennert, S, ed.). *Weekly Volcanic Activity Report,* 28 September-4 October 2022. Smithsonian Institution and US Geological Survey.

[5] Taylor & Talia, 1999, Volcanic hazards assessment of Savai'i, Samoa, SOPAC Technical Report 295

[6] http://www.samet.gov.ws/index.php/climate-of-samoa

to increase. Tropical cyclones are projected to be less frequent but more intense. Sea levels will continue to rise and ocean acidification will increase.

Landslides and rockfalls are common in Samoa due to the volcanic origin (steep and unstable slopes) and the tropical climate (high rainfalls). They pose a potential hazard for communities and infrastructure. Rockfall and landslide scenarios in Samoa are generally associated with the presence of high angle faults, highly weathered, extensively jointed, and fractured rocks. Surface and groundwater could expand the size of the joints, and existing fault scarps trigger the rock face to become more unstable by losing its support[7].

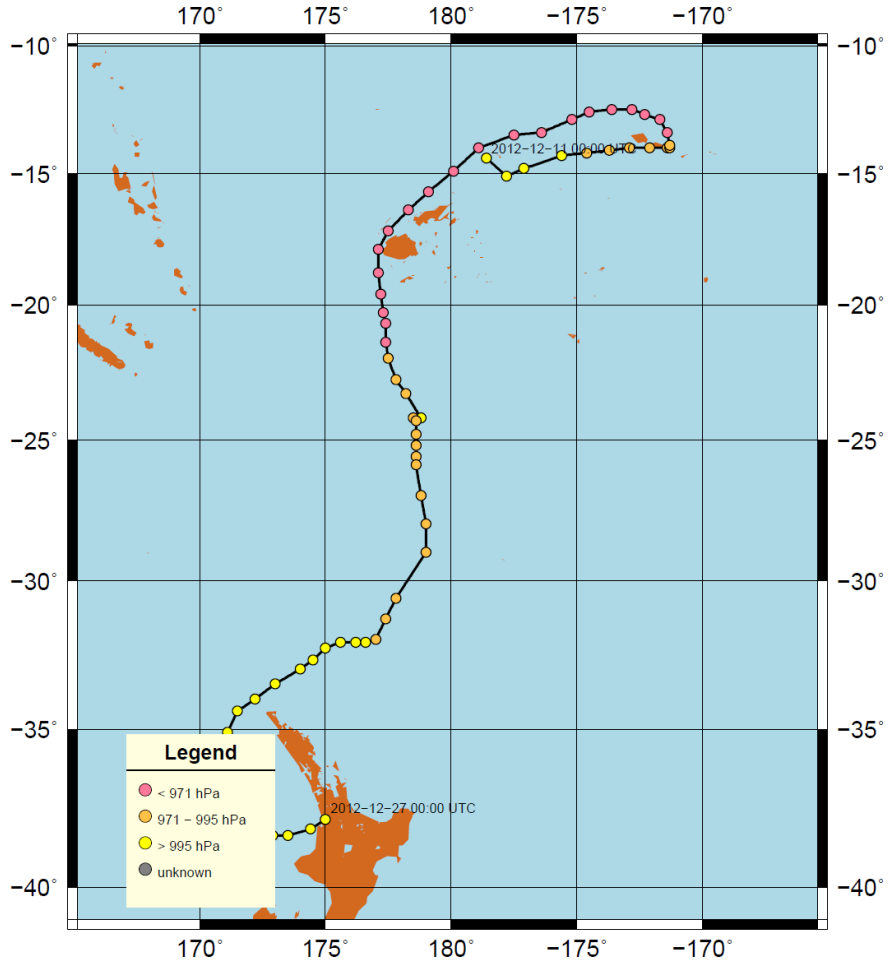


Figure 3 - Complete track of Severe Tropical Cyclone Evan, December 2012. Evan caused widespread damage in Apia, with heavy rain and wind gusts up to 210 km/h, and 14 deaths (10 at sea), as well as considerable damage in Fiji and Wallis and Futuna, and finally heavy rain and winds in New Zealand as it weakened. Improved observations and modelling can help predict these tracks and prepare communities. Bureau of Meteorology Southern Hemisphere Tropical Cyclone Portal.

An average of six tropical cyclones affect Samoa per decade. Tropical cyclones of any strength can result in loss of life, with heavy and widespread rain from even developing systems creating the potential for flash flooding and landslides. Severe tropical cyclones also bring destructive winds and storm surges. Cyclones impacts result in the most frequent disasters for Samoa. In December 2012, for example, Tropical Cyclone Evan caused massive destruction (Figure 3) and in 2018, a series of tropical lows including the developing stages of Tropical Cyclone Gita caused floods, landslides, and widespread disruption. A large part of Apia was flooded during this event.

Like other Pacific nations, marine hazards are very important in terms of the overall risk to communities in Samoa. Most of the population lives near the coast, and fishing is a

[7] Fepuleai, Aleni & Nemeth, Karoly. (2018). Volcanic Geoheritage of Landslides and Rockfalls on a Tropical Ocean Island (Western Samoa, SW Pacific). Geoheritage. 11. 10.1007/s12371-018-0306-z.

very important economic activity. The number of instances of maritime safety incidents involving small boats has been rising (Figure 4).

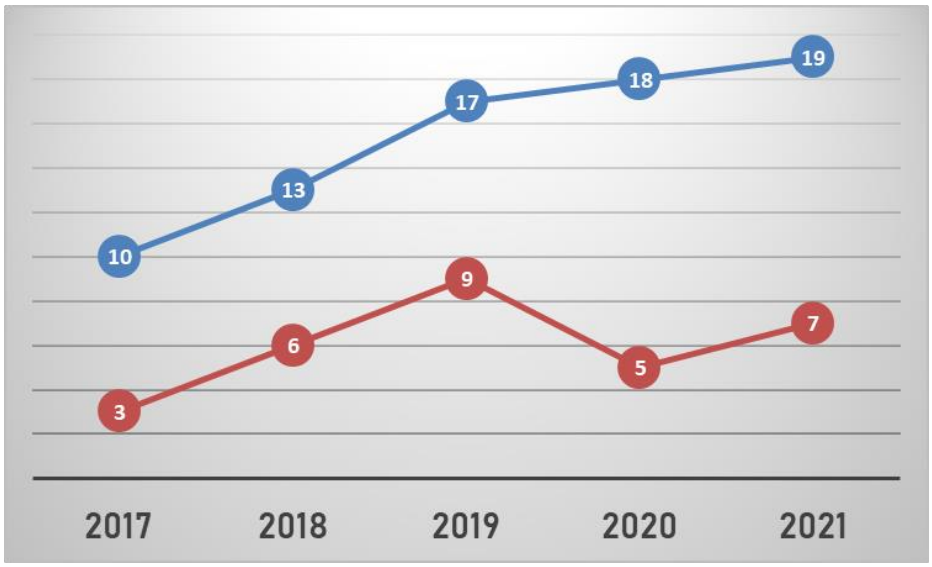


Figure 4 - Number of deaths during sea and water rescue operations (red line), and total number of rescues or attempted rescues (blue line, by head of population), 2017-2021. Courtesy Silipa Mulitalo, SMS, using data from Samoa Fire and Emergency Services Authority. Future community engagement activities have been proposed to address the rise in safety incidents.

Country Hydromet Diagnostics methodology

The Country Hydromet Diagnostics was undertaken by the Australian Bureau of Meteorology and Samoa Meteorological Service with the support of the World Bank, World Meteorological Organization (WMO), Systematic Observations Financing Facility, and Alliance for Hydromet Development.

The report was prepared using the methodology described in the 2022 update of the Country Hydromet Diagnostics. An initial desktop review was performed, using information supplied from Samoa, WMO, and other partners. Particular mention is made here of the 'Weather Ready Pacific' and the Systems Integrator Consultant activity under the World Bank-financed Pacific Resilience Program – Samoa Project for source documents, which have been extensively referred to during the process. An in-country visit was then undertaken to allow direct discussions with the Samoan Meteorological Division and necessary stakeholders, while noting the important of not creating undue pressure on local agencies due to the presence of multiple simultaneous missions in-country.

During the in-country visit, a road circumnavigation of Savai'i was performed along with many site visits in Upolu, to validate site condition, observe local communities, road conditions and inter-island ferry operations, and discuss the practical challenges encountered by staff in maintaining observation stations.

Although this report is focused on hydrometeorological aspects of the Samoan Meteorological Service's operations, efforts have been made to include relevant aspects of geohazard warning and management, which also falls within the responsibility of SMS and its parent Ministry and is highly relevant to Samoa's Sendai commitments for multi-hazard early warning systems and the UN Early Warnings For All initiative.

Chapter 2: Country Hydromet Diagnostics

Element 1: Governance and institutional setting

1.1 Existence of Act or Policy describing the NMHS legal mandate and its scope

The Samoa Meteorology Service (SMS), formally the Meteorology, Geoscience and Ozone Services Division, is a divisional branch of the Ministry of Natural Resources and Environment, Government of the Independent State of Samoa. The Ministry also includes Divisions for Disaster Management and Water Resources.

A new Meteorology, Geoscience and Ozone Services Act (2021) in Samoa provides a mandate and outlines the functional responsibilities for the Division, including Multi-Hazard Early Warning System responsibilities.

The duties and responsibilities of the Division are to:

(a) analyse and provide scientific and quality managed data and information in the areas of

(i) meteorology including weather, climate, and air quality;

(ii) geoscience including geological, geomagnetic, geophysics, oceans, which includes waves, storm surges, ocean-tides, sea-level rise, ocean acidification and astronomy;

(iii) ozone layer and space weather;

(b) control collection, analysis and dissemination of quality managed data, information and material for the purposes of the Act;

(c) provide meteorological services including data, information, warnings which may be provided by the Division for the benefit of the general public including but not limited to sectors such as agriculture, tourism, sports, education and cultural affairs;

(d) provide aviation meteorological services or weather-related information or data for the purpose of aviation in accordance with NZCAA (New Zealand Civil Aviation Authority) Part 174 - Annex 3 of ICAO;

(e) provide meteorological information for the purposes of maritime, navigation and shipping;

(f) provide a comprehensive range of meteorological related information, data, analysis, as well as other products and services, for the purposes of national, regional and international meteorological and climate change agencies;

(g) issue meteorological warnings, so as to protect and minimise the risk of harm to human life, property and the environment;

(h) provide astronomical and geo-scientific-related data, information and analysis relating to astronomy, earthquake, tsunami, landslides, volcanic warnings and other products and services, for the benefit of the general public including various sectors such as agriculture, farming, agronomy, fishing, tourism, sports, education and cultural affairs;

(i) provide oceans services including oceans information, data, products and services relating to tides and ocean related measurements;

(j) provide oceans information relating to sea-surface temperatures, currents, wave activity for the purpose of maritime transport and monitoring activities;

(k) provide data on controlled substances under the Montreal Protocol on substances that deplete the Ozone Layer, including Hydro chlorofluorocarbons and monitor consumption of ozone depleting substances and global warming potent refrigerants;

(l) develop, improve and strengthen public information protocols and systems in order to ensure the effective and comprehensive dissemination of warnings issued under this Act under the Multi Hazard Early Warning System or otherwise;

(m) incorporate and implement the detection and assessment of extreme weather or natural phenomena as part of the country's Multi Hazard Early Warning System and ensure that such remains fully operational at all times and is regularly updated and fully capable of providing the alerts and warnings necessary in order to protect the public property and any part of the country or community;

(n) promote the understanding, recognition and where appropriate, the use of verified traditional knowledge and practices, related to meteorological, geo-science, and ozone related services, through the atmospheric, oceanic and earth observation of indicators occurring in nature, or through consultation with the community and by other means;

(o) allow and facilitate the exchange of meteorological, geoscience and ozone data with the Division or their counterparts from other countries, territories and in accordance with Resolution 40 of the WMO Policy and Practice (Cg-XII);

(p) oversee and monitor the use of all meteorological, geo-science, and ozone quality controlled scientific data, collected by the Division;

(q) determine appropriate fees and charges for the provision of services by the Division, particularly where they are provided to commercial entities, or for commercial purposes, in order to recover all, or part of the cost of providing such services;

(r) approve, undertake or support research, academic or scientific studies to further the understanding of meteorological, geo-science, and ozone phenomena;

(s) support the work of other Ministries and agencies in respect of preparing and planning for climate related events and the assessment of risk to life and property from weather and climate related phenomena;

(t) support the planning, preparation and response of Samoa to climate change and its related risks through the Division's functions under this Act;

(u) raise public awareness about functions of the Division and all meteorological, geo-science and ozone related matters; and

(v) undertake and provide such other functions or services as are required by other Ministries or agencies or organisations as approved by the Minister.

This is a comprehensive and appropriate list of responsibilities, supporting a multi-hazard early warning system approach. Particularly notable is the inclusion of geohazard data and warnings, and in the Act definitions, the phrase *'including but not limited to earthquakes, landslides, undersea seismic activity, extreme wind, tornadoes, tsunami, tidal surges, volcanic activity, coastal and extreme flooding of any nature'* when describing the scope of warnings.

The Act further describes multi-hazard early warning responsibilities, which will be discussed later.

The degree to which SMS can undertake these responsibilities at present is a separate question.

1.2 Existence of Strategic, Operational and Risk Management plans and their reporting as part of oversight and management.

SMS's operations occur within broader government frameworks, such as the current Pathway for the Development of Samoa FY2021/22 – FY2025/26, and corporate planning mechanisms of its parent Department, the Ministry of Natural Resources & Environment. A key policy in this regard is the Samoa Multi-Hazard Early Warning Systems Policy 2021. Disaster planning processes under the umbrella of the Disaster Management Office (DMO) also cover the development of multi-hazard early warning systems. This plan sets out eight guiding principles for the multiple agencies involved in early warning systems to follow, together with a list of prioritised interventions.

SMS itself does not have a current Strategic Plan, and this is a priority of the current Director. A new Strategic Plan is under preparation.

1.3 Government budget allocation consistently covers the needs of the NMHS in terms of its national, regional, and global responsibilities and based, among others, on cost-benefit analysis of the service. Evidence of sufficient staffing to cover core functions

SMS's annual budget averages around USD 1.3 million[8], about half of which is spent on salaries. In 2023 it was reported as around USD 0.76 million (2,104,915 Samoan Tala), although noting that the value of the Samoan Tala has dropped against the US Dollar over recent years. Approximately 67% of the budget is spent on staffing. The budget is insufficient to meet operational costs including new observations equipment, vehicles, and other capital items. The shortfall is partially met from external project spending on new equipment.

Salaries are not generally competitive with other graduate positions in government. The Samoa Met Service has had issues with staff retention with staff leaving for regional organisations that have relatively attractive salaries. Annual staff turnover is approximately 10% per year.

No local cost benefit analysis of the SMS service is known.

1.4 Proportion of staff (availability of in-house, seconded, contracted- out) with adequate training in relevant disciplines, including scientific, technical, and information and communication technologies (ICT). Institutional and policy arrangements in-country to support training needs of NMHS.

There are 42 staff members, including 16 in total with BSc or higher degrees. As of 2023, only 5 forecasters had university level qualifications, and two of these had been formally trained at institutions that provide BIP-M[9] credentials – Bureau of Meteorology Training Centre and the Philippine Atmospheric, Geophysical and Astronomical Services Administration. There is no formal meteorological training in Samoa. Other forecasters have joined the introduction to forecasting with the Pacific Training Desk in Hawaii (National Oceanic and Atmospheric Administration, USA). All forecasters are internally

[8] Source: WMO Feasibility Study for a Pacific based WMO Regional Training Centre, 2018

[9] The Basic Instruction Package for Meteorologists (BIP-M) defines the educational requirements of those studying to become a meteorologist.

trained for about 5 years, which is useful but does not qualify them as forecasters in the usual sense.

Much of the observational training is done within Samoa and with the Fiji Met Service – the 6 month BIP-MT (Meteorological Technician) course. Six staff are designated as 'Meteorology Technician (Observations), and sit within the Weather Forecasting Department.

In the Geoscience Section, three of the 14 staff have BSc level qualifications, while the remaining staff have certificate level training. A similar proportion of qualifications exists in the Climate Services Department, with three of the 7 staff with BSc qualifications.

ICT staff numbers are limited, without dedicated ICT systems support. The impact of this is very noticeable in the poor degree of systems integration (particularly from multiple aid projects) and the difficulty SMS experiences in maintaining ICT systems.

1.5 Experience and track record in implementing internationally funded hydromet projects as well as research and development projects in general.

SMS have long experience working with international partners in hydromet projects, generally as a recipient of external funding. They are active in seeking or even proposing projects, and prioritise working with partners in country (specific projects are mentioned where relevant in the text).

Summary score and recommendations for Element 1

Samoa is assessed as **Maturity Level 2** on the CHD scale, reflecting *'Effort ongoing to formalize mandate, introduce improved governance, management processes and address resource challenges.'* It is particularly notable that a strong establishing Act has recently been attained, but further work is needed to establish strong operational planning mechanisms, and particularly to attain a sustainable budget that is not dependent on capacity building projects to install and maintain equipment.

This is a gradual journey, and SMS may benefit from provision of in-country advice from long term partnership programs, in addition to input from shorter term projects.

Element 2: Effective partnerships to improve service delivery

2.1. Effective partnerships for service delivery in place with other government institutions.

In-country observations validate strong relationships between government agencies, particularly including the Water Resources Division (WRD) and DMO (who have joint operating procedures). As a simple example, during the Systematic Observations Financing Facility (SOFF) country-visit, SMS staff assisted the disaster management office in setting up displays for the DMO, in support of the opening of the new building, where space has been allocated for SMS alternate operations and integrated ICT infrastructure (Figure 5). Data is shared relatively freely between the relevant government organisations, and warning protocols allow shared responsibility according to out-of-hours procedures. Recent community training in early warning systems also featured multiple departments working together. Such arrangements are not reached without a high degree of trust.

However, the physical infrastructure to support interoperability and data-sharing does not fully exist. The World Bank-financed Pacific Resilience Program (PREP) is funding an ICT refreshment to assist with this, with new systems to be procured for the Water Resources Division, SMS, and DMO (including at the new National Emergency Operations Centre).

Some relationships are still developing, for example with the marine sector. Recent WMO Marine Services Training in the Pacific has stimulated discussion and activity in this area.

Figure 5 - Preparations for a visit to the new National Emergency Operations Centre (opened in December 2020), in which space has been allocated for the Meteorology Division, 21 July 2023. Photo: Silipa Mulitalo.

2.2. Effective partnerships in place at the national and international level with the private sector, research centres and academia, including joint research and innovation projects.

Private sector partnerships are relatively limited. There is, however, active cooperation with research agencies, for example in agriculture and climate areas, and particularly where programs are externally funded to allow the collaboration to occur.

2.3. Effective partnerships in place with international climate and development finance partners.

Active cooperation occurs with a range of international partners, including WMO, the World Bank, the South Pacific Regional Environment Programme (SPREP), the CREWS project, Australia (particularly through the COSPPac program) and Japan International Cooperation Agency (JICA). SMS clearly prioritises these relationships and values the potential for improved equipment and services that result.

One major hindrance to effectiveness of these partnerships has been the short-term (less than 10 years) nature of many projects, and the resultant mishmash of incompatible and unmaintained equipment that results. This was particularly examined by the World Bank PREP project Systems Integration Consultant team, which recommended a high priority on ICT procurement as discussed earlier.

2.4. New or enhanced products, services or dissemination techniques or new uses or applications of existing products and services that culminated from these relationships.

The best example of service enhancement from research and science partnerships is probably the range of climate products. For example, Samoa's Seasonal Climate Outlook bulletin is produced with the support of COSPPac, and contributors Australian Bureau of Meteorology, Pacific Community, and APEC Climate Centre, whilst clearly being an SMS-branded product.

Summary score, recommendations, and comments for Element 2

Samoa is assessed as **Maturity Level 3** for this Element, expressed as *'Moderately effective partnerships but generally regarded as the weaker partner in such relationships, having little say in relevant financing initiatives.'* This reflects that SMS has often accepted partnerships and projects that do not produce an integrated result or ongoing maintenance funds (for example, in their observations and forecasting systems), leaving an unsustainable outcome. Samoa is seeking to avoid this in the future but has little overall power in the relationship. Other Samoan agencies are frequently in the same position. With that said, SMS is proactive and committed to improving the overall partnership and shows strong evidence of prioritising internal government partnerships. With the establishment of more long-term sustainable partnerships with donors, the situation will be expected to improve.

Element 3: Observational infrastructure

3.1. Average horizontal resolution in km of both synoptic surface and upper-air observations, including compliance with the Global Basic Observing Network (GBON) regulations.

There are 2 staffed weather stations, at Apia and Faleolo Airport, 17 automatic weather stations (AWS) and 1 sea level station. The AWS data is not transmitted outside Samoa, and technological challenges have been inhibiting transmission of the staffed synoptic station data.

The average horizontal resolution over the total land and Exclusive Economic Zone area of Samoa (approximately 133,260 km^2) is dependent on the metric used.

- In terms of GBON compliance, the resolution is undefined (zero fully compliant stations)
- For stations that report internationally, the 2 synoptic stations give a resolution of approximately 258 km.
- For all operational or partially operational stations, including stations that don't report internationally, the resolution is approximately 118 km.

If all AWSs were working and reporting, Samoa would have a relatively high network density. However, not all stations are available, with a mixture of data transmission and equipment issues meaning that the majority of the network is not being received in SMS's Apia office.

The AWSs have been primarily installed under two different projects led by JICA (Japan, 10 AWSs, Figure 6), and NIWA (National Institute of Water and Atmospheric Research, 7 AWSs, Figure 7).

NIWA and JICA AWSs have different telemetry systems, with the NIWA stations using general packet radio service (GPRS) mobile data, and the JICA stations using microwave links. There are strengths and weaknesses for each technology, particularly noting that GPRS is regarded as more reliable, but microwave links are still needed for some real-time data applications (such as seismic data). There is a general intent to transition the JICA AWS stations to using GPRS telemetry, which would solve issues being experienced with microwave transmission (Figure 6).

There is no specific funding for technicians to service AWSs and this is being done by staff when funds are available. Data from the received stations can be displayed within Samoan agencies, but not in an integrated fashion, and the AWS data may be under-used by meteorologists as a result. Data from the NIWA AWSs are ingested into the Climate Data for the Environment (CliDE) database, but the JICA data is not ingested into CLiDE. There is also a degree of double handling of data (where manual observations have to be manually retyped into CLiDE), which is inefficient and causes frustration for staff as well as delays in database updates.

Samoa has potential to have good network coverage if these issues are all addressed on a sustainable basis, whilst still noting a relative lack of stations in inland areas.

There is no upper air observational equipment but upper air observations from American Samoa are provided to Samoa. There is a low-level wind profiler at the APIA office. It was funded by JICA and it provides some upper air information for ingestion into global models, although SMS staff have low visibility of any impact of these data on model predictions. The wind profiler server is located in the forecast office, but is out of design

life, and also has loud cooling fans, contributing to an unacceptably noisy work environment for forecasters.

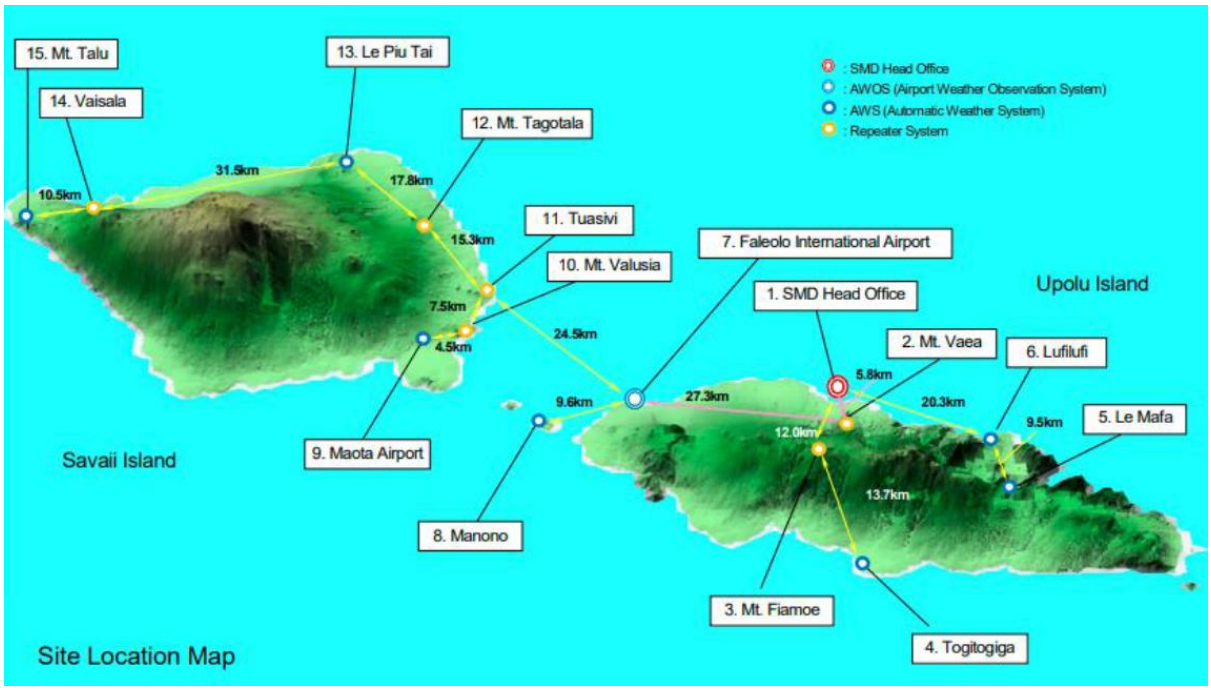


Figure 6 - Configuration of JICA AWS network (courtesy SMS). Stations are largely operational, but data from Savai'i (3 stations), Manono, and Faleolo International Airport cannot be received due a communications link interruption between Mt Vaea and Faleolo Airport.

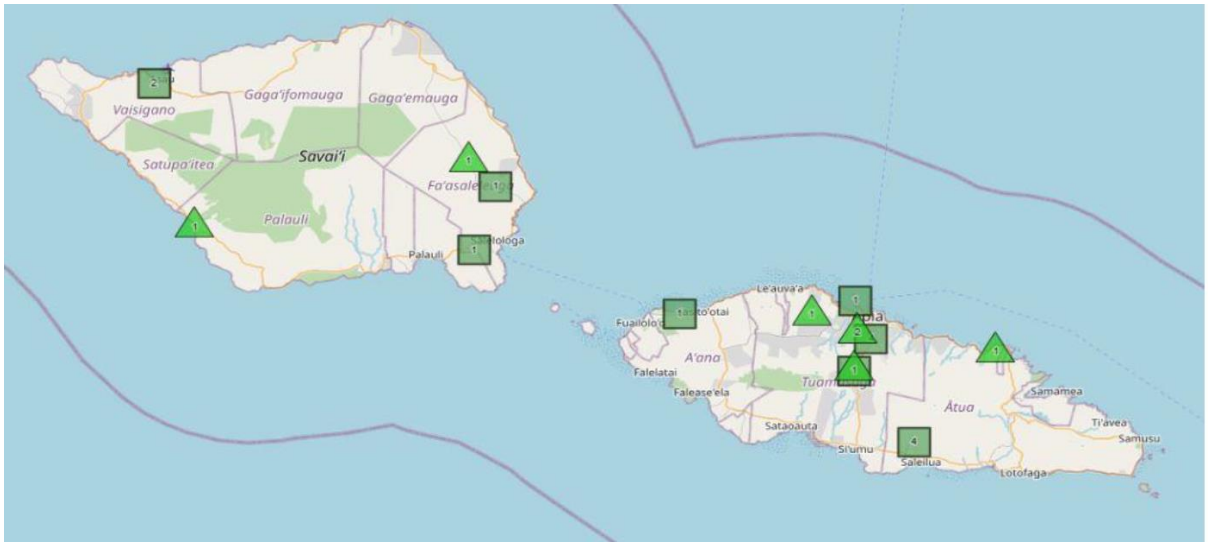


Figure 7 - Configuration of NIWA AWS network (courtesy SMS). About half of the AWS are operational, with vandalisation, battery problems, and calibration exceedance intervals all having impacts.

3.2. Additional observations used for nowcasting and specialized purposes.

There are six other manual climate stations that rely on observers in the villages/communities, and 30 manual rain gauges.

The current seismic network in Samoa consists of 4 broad band and 2 short period stations.

One of the broadband stations is an Incorporated Research Institutions for Seismology (IRIS) / United States Geological Survey station. The other 5 stations have been procured and installed in the framework of a project from the People's Republic of China. High-quality seismic instrumentation, currently housed at the northern tip of the Mulinu'u Peninsula, is itself vulnerable to tsunamis, storm flooding, and ultimately to sea level rise. The station may have to be relocated.

Currently, only three seismic stations are reporting to SMS due to various technical issues, and there is limited international exchange of these data.

There was a need expressed for more ocean observing equipment to provide better forecasts for the fisheries and tourism industries.

Currently there is no weather radar in Samoa. The addition of a weather radar would significantly improve the service offering from SMS for Samoa, and would also benefit American Samoa, which is only ~ 70 km east-southeast of Upolu. A weather radar could provide valuable data to optimise aviation and maritime operations into Samoa, nowcast short term rainfall that may lead to flash flooding, provide more accurate positioning and assessment of intensity for tropical cyclones passing close to Samoa, and assist community decision making for all relevant applications, particularly if the data were available to the public. There has been donor interest from several quarters in providing a radar, but at this stage it would require Samoan Government commitment to cover maintenance costs. It is doubtful whether SMS currently has the capacity to sustainably operate a radar without external assistance.

The WRD operates a monitoring network to support their responsibilities in water resources management (Figure 8). The network is largely complementary to the SMS field observation network, and includes inland stations, water level and groundwater gauges.

Figure 8 Hydrology monitoring stations (rainfall in red, water level stations in blue) on Savaiii and Upolu. Inland rainfall stations and water level stations are prioritised towards the more densely populated Upolu, but flooding issues also occur on Savai'i Source: based on data from SMS / NIWA.

3.3. Standard Operating Practices in place for the deployment, maintenance, calibrations and quality assurance of the observational network.

SMS and Water Resources staff maintain their networks, subject to budget and parts availability, which can result in severe constraints. On-site inspections during this

activity showed stations that were generally well-kept but where parts availability and communications issues were significantly interfering with network performance. For some stations, parts have been removed in order to service higher-priority locations. Calibration is performed, but reference sensors have not been sent to the regional centre at the Fijian Met Service for almost five years. Quality assurance is not systematically performed. Some standard operating practices exist for maintenance of stations.

Key gaps in human capacity necessary to ensure GBON compliance of observations are:

- None of the engineering, technical or observing personnel currently have Basic Instruction Package for Meteorological Technicians (BIP-MT) qualifications which are considered essential to ensuring the sustainability and quality of observations.
- The SMS personnel have no formal training in cellular and satellite communications which are critical to transmission of real-time data for GBON compliance.
- Observers require basic automatic and manual observing equipment maintenance skills to address equipment problems at stations in a timely manner to ensure reliability of observations. Given the costly and complex logistics of travel, this is much more efficient for basic maintenance than requiring reactive visits by technicians.
- SMS has no specific ICT personnel. In order to successfully implement a new Meteorological Data Management System compliant with the WMO Information System 2.0, further ICT expertise will be required in meteorological data and communications systems.
- SMS has no technical officer roles in their organization chart, and no staff currently trained in technical support. In order to ensure continuity of service for station equipment a permanent technical officer role should be created, with additional SMS staff trained to support this role to ensure back-up is available.

These are obvious and urgent needs, and have been the case for some years (in 2018 the same issue was noted by the World Bank PREP Systems Integration Consultant team). Typically, such staff need to be supported long-term through core funding rather than from short-term projects, but there also appears to be a need for a 'twinning' type partnership with another meteorological agency to plan and implement a more sustainable technology pathway. As earlier noted, a new ICT system is planned for procurement under the World Bank PREP project, which will greatly assist, but a long-term approach is still required for addressing the many technical challenges that SMS face. Meteorology is itself a field with rapidly developing technology, meaning that any agency such as SMS faces additional challenges in keeping up with innovations.

3.4 Implementation of sustainable newer approaches to observations.

As for many countries in the region, the application of new approaches to observations has not been done in a sustainable manner. Automatic weather stations have been installed without an ongoing maintenance budget. This is a significant issue and leads to large amounts of capacity development waste. For Samoa, the problem is likely solvable due to the compact nature of the country and high capacity of the staff, if ongoing budget is made available, dedicated technical staff are employed, and parts arrangements are put in place.

The NIWA-supplied AWS masts are of a design that can be lowered safely to the ground for maintenance. However, other AWSs and repeaters have to be climbed, to a height of

up to 30 metres (for repeaters), which is not safe or appropriate. Any future works should seek to correct this issue, as a sustainable approach to observations must include health and safety considerations.

3.5. Percentage of the surface observations that depend on automatic techniques.

It is difficult to give a fixed percentage of surface observations that depend on automatic techniques, as only the manual surface observations are transmitted internationally. Were the AWS networks to work as intended, over 90% of real-time observations from Samoa would be automated.

Summary score, recommendations, and comments for Element 3

Samos is assessed as **Maturity Level 3** for this Element, which is expressed as *'Moderate network with some gaps with respect to WMO regulations and guidance and with some data quality issues'* in the CHD guidance.

Samoa is relatively well instrumented, and if stations were reporting internationally and operationally maintained and an upper air station were present, the country would be rated at Maturity Level 4 *(comprehensive mostly automated network providing good traceable quality data fully compliant with WMO regulations and guidance)*. However, the lack of data integration and funds for ongoing maintenance severely compromises the network, meaning that Samoa is actually at risk of being downgraded to Maturity Level 2 (*Basic network, large gaps, mostly manual observations with severe challenges and data quality issues*).

Observational data integration and commitment by the Samoan Government to maintenance of the network is effectively required to improve the situation. In terms of international assistance for this situation, both the Weather Ready Pacific and Systematic Observations Financing Facility are potential vehicles for assisting Samoa in maintaining high observational standards and maintain a network that is both fully compliant with GBON and suitable for Samoa's national needs. International transmission of observations would also be of great benefit for supporting higher resolution operational numerical weather prediction, particularly for the purposes of more accurate rainfall forecasting.

Element 4: Data and product sharing and policies

4.1. Percentage of GBON compliance – for how many prescribed surface and upper-air stations are observations exchanged internationally. Usage of regional WMO Integrated Global Observing System centres.

No surface stations fully comply with GBON due to the observations frequency (3 hourly as opposed to hourly) at the two synoptic stations (Apia and Falelo). At time of visiting, there were also data transmission issues. There is no upper air station.

4.2. A formal policy and practice for the free and open sharing of observational data.

Samoa, as a WMO Member, participates in the global data sharing framework articulated by the WMO Unified Data Policy, and as such supports the free and open sharing of observational data. In practice, data sharing between agencies has been improving, having been somewhat limited in the past. The physical location of agencies and lack of ICT infrastructure has been a major inhibitor to data sharing. As noted earlier, this situation is expected to improve with the advent of new ICT infrastructure, including at the new Emergency Management Operations Centre, at SMS, and at Water Resources. However, ongoing efforts will be required to keep systems functional and integrated, particularly as new donor-led initiatives occur.

Samoa is also a member of the Oceania Regional Seismic Network, ORSNET, which provides a regional method for seismic data sharing.

4.3. Main data and products received from external sources in a national, regional and global context, such as model and satellite data.

SMS accesses satellite data from the Japanese HimawariCast facility, and a range of graphical format model guidance over the web using ECMWF, Bureau of Meteorology (ACCESS), US (GFS), and other data. Samoa is a participant in the Severe Weather Forecasting Programme and receives professional guidance from RSMC Wellington on the MetConnect web portal, showing areas of likely severe weather. This supplies valuable data and guidance to forecasters in SMS in the daily forecast process. However, it is still very 'broad brush', and requires significant value-add from local agencies.

SMS also receives data across the Global Telecommunications System (GTS) including surface and upper air observations and NWP data from several global models including the Japan Meteorological Agency (JMA), GFS, and UK models. This data is ingested into the IBL Visual Weather system which forms the basic platform from which forecasters conduct the daily forecast process and develop the majority of the suite of products delivered to stakeholders. Visual Weather was installed some years ago and there is no current upgrade pathway. SMS also has limited bandwidth and the Internet connection is unstable.

Summary score, recommendations, and comments for Element 4

Samoa is assessed as **Maturity Level 2** for this Element, expressed as '*A limited amount of GBON compliant data is shared internationally. The existing data sharing policies or practices or the existing infrastructure severely hamper two-way data sharing.'*

As already noted, long term support for ICT systems integration, potentially supported by external 'twinning' arrangements, would significantly improve the situation for Samoa in this area. Samoa's complex topography also means that any high-resolution models would benefit from the sharing of as much high-quality data as possible.

Element 5: Numerical model and forecasting tool application

5.1. Model and remote sensed products form the primary source for products across the different forecasting timescales.

SMS produces a suite of public and marine forecasts and warnings, and aspires to produce aviation forecasts, which are currently issued by Fiji Meteorological Service under agreement.

In support of this, SMS has access to a range of global numerical models, accessed through public weather sites, through the MetService NZ MetConnect site, and through a Himawari-cast dedicated server and (as mentioned) an installation of IBL's Visual Weather. These models include ECMWF, GFS, UK Met Office, and ACCESS. These are all global scale, operational models that have data assimilation, verification, and quality managed 24/7 operations. At the resolution these models run at (e.g. 9 km for ECMWF), Samoan topography is underrepresented. All of these models are also hindered by the limited number of local real-time observations from Samoa.

A research quality model, the Weather Research and Forecasting (WRF) model, is also operated by the University of Hawai'i, covering American Samoa and Samoa at 3 km resolution. This model is used by the WRD for precipitation insights, although without local data assimilation and verification, it may be of less operational utility than preferred. It should also be particularly noted that critical decision-making during emergencies using models that are not quality-managed is not recommended, as there is no defensible basis for life-impacting decision-making using unverified information.

Ensemble products are available through the MetConnect site, based on global ensemble models (Figure 9).

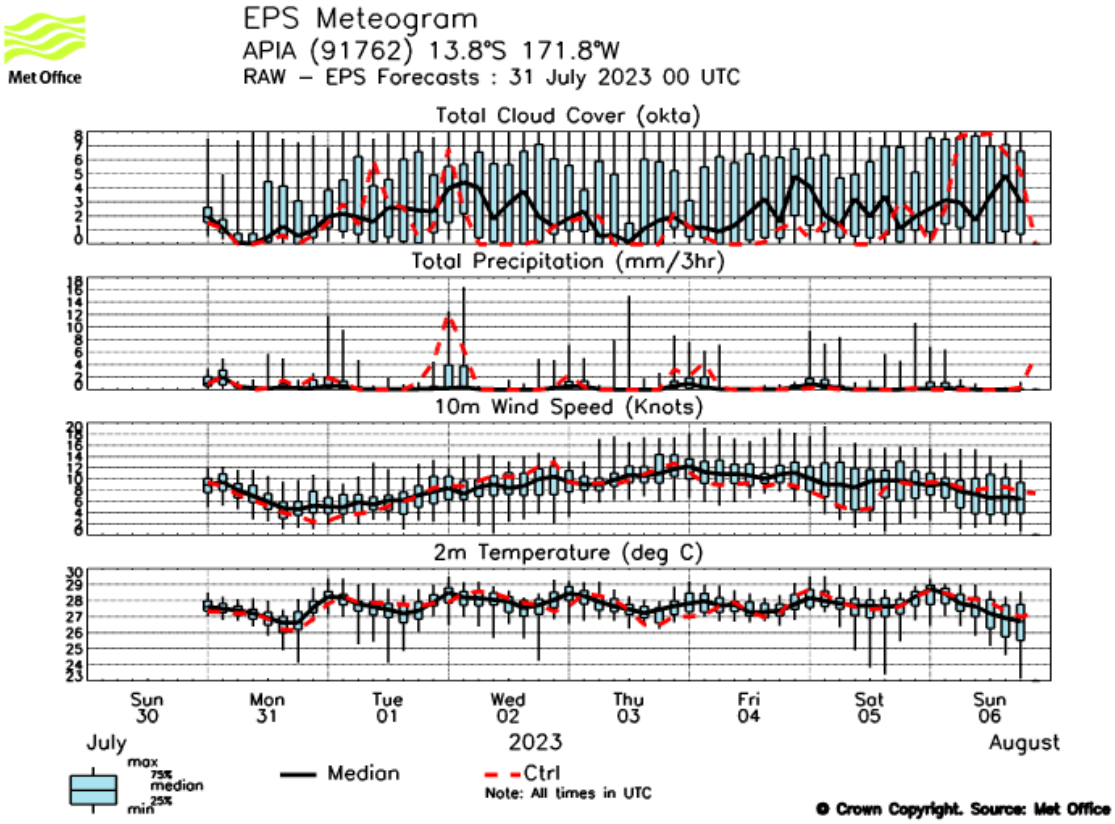


Figure 9 – Example ensemble forecast for Apia (UK Met Office)

Remote sensing satellite imagery is accessed through Himawari-cast, the MetConnect site, and other Internet sources.

5.2. a) Models run internally (and sustainably), b) Data assimilation and verification performed, c) appropriateness of horizontal and vertical resolution.

There is no internal numerical modelling capability. No data assimilation or verification is performed.

WMO publishes Guidelines on High-resolution Numerical Weather Prediction[10] , which define six options for accessing high-resolution NWP:

> Level 1 - Use of NWP products from Regional Specialised Meteorological Centres (RSMCs)
>
> Level 2 – Enhanced use of NWP products from RSMCs through post-processing
>
> Level 3 – Downscaling regional model implementation
>
> Level 4 – Regional NWP including data assimilation
>
> Level 5 – Regional Ensemble Prediction Systems
>
> Level 6 – Regional coupled Earth system modelling or rapidly updated NWP

Importantly, the Guidelines also note that *"for many NMHSs (National Meteorological and Hydrological Services) at any level of this process, it can be beneficial to join a consortium of partners and work together to develop and implement NWP capabilities, rather than going it alone."*

Under this framework, Samoa sits at Level 1, with limited ability to post-process models in-country. *This is not inappropriate* considering Samoa's limited internal computing and science capabilities. It is *not* recommended that Samoa seeks to run its own numerical models in the future, as this would require a large technology-based overhead. There are, however, potential pathways forward that are consistent with the WMO Guidelines:

1) Engaging further with global and regional partners, for example within the Severe Weather Forecasting Programme, Coastal Inundation Forecasting Initiative, and Flash Flood Guidance System contexts, to continue to improve the applicability of global and regional models for Samoa. This should include ensuring that Samoan observations (including AWS observations) are transmitted in real-time and available for model assimilation, and that tailored model products are developed and available for use in Samoa forecasts and to the public. This would require relatively little additional resourcing beyond partnership work, user benefits verification, and the sustainment of the observations network, coupled with the transmission of observations.

2) Developing options for enhancing model output consistent with Levels 2-4 above, but in partnership with others, to develop statistically downscaled post-processed products (Level 2), dynamically downscaled products (Level 3), or regional models with data assimilation (Level 4). These options could be tackled as part of a regional approach, with a focus on countries that have similar topographic issues (e.g. Fiji, Solomon Islands, Papua New Guinea, Vanuatu, American Samoa), and the solutions implemented using either dedicated high performance computing facilities or a cloud computing approach. Whichever option is chosen, long term partnership commitments would be required, coupled with a realistic

[10] WMO_No. 1311, 2023, Guidelines on High-resolution Numerical Weather Prediction

assessment of Samoa's ability to contribute computing resources, which are at present very limited.

With each option, the guidance available for quantitative rainfall forecasting (the principal concern) would be improved. However, the success of the option chosen should ultimately be judged on user benefits, as systematically verified by SMS or external parties.

In this light, it should also be emphasised that, as rainfall in the tropics is highly dependent on convective processes that have very subtle and (to some degree) chaotic influences, even explicit representation of convection in fine resolution modelling and a high quality observation network would not give deterministic 'answers' for where rain will fall – rather, it would give a realistic range of forecast scenarios for use in emergency management planning and community response. Improvements in modelling should be matched with improvements in rainfall observation (through rain gauges and potentially a weather radar linked to quantitative rainfall estimation), river level gauging, hydrological modelling, warning systems, and community engagement. Higher resolution modelling will be helpful, but will not be a 'magic bullet' for forecasters or the community.

5.3. Probabilistic forecasts produced and, if so, based on ensemble predictions.

Ensembles are consulted as needed in formulating forecast policy, but probabilistic forecasts are not explicitly produced.

However, climate outlooks for Samoa are produced using multi-model and ensemble techniques, in collaboration with COSPPac and other supporting partners.

Summary score, recommendations, and comments for Element 5

Samoa is assessed as **Maturity Level 3** for this element, indicating *'Prediction based mostly on model guidance from external and limited internal sources (without data assimilation) and remotely sensed products in the form of maps, figures and digital data and cover nowcasting, short and medium forecast time ranges.'*

While this mid-range maturity level reflects the range of services that SMS provides using NWP, SMS and Water Resources staff strongly emphasised during consultations that the modelling guidance available does not meet user needs, particularly for quantitative precipitation.

The next higher level, Level 4, would be *'Digitized model output from internal (with data assimilation) and/or external (regional) sources and remote sensed products and data used and value-added through post-processing techniques extended into longer ranges."*

For Samoa to lift its maturity level in this area to Level 4, it is recommended that more detailed consideration be given to the partnership options outlined in Section 5.2 above, in conjunction with other improvements along the forecasting value chain as discussed above.

Element 6: Warning and advisory services

6.1. Warning and alert service cover 24/7.

Both the weather forecasting and geoscience sections are staffed 24/7, in adjacent buildings. For the weather forecasting office, only one assistant forecaster is on duty overnight during the Dry Season.

SMS issues routine public and marine forecasts every 6 hours, and standardised severe weather information every 12 hours (heavy rain, wind advisory, small craft advisory, 24-72 hours prior to impact).

As a side-note, the building premises for SMS are sub-optimal. The size of the two operational buildings does not permit for the two operational teams to be collocated, reducing the potential for efficient and flexible staffing in a multi-hazard approach. ICT equipment is housed in the same operational spaces, and (as already noted) is particularly loud in the case of the forecasting office where a server for the upper air profiler has been installed, which creates an unpleasant work environment. The site location is also close to sea-level, meaning that the site is not necessarily safe during tsunami, spring tide, heavy swell and tropical cyclone events. All of this may inhibit 24/7 operations during critical events. Alternative facilities are being developed at the new National Emergency Operations Centre, which will be usable for business continuity arrangements. On the other hand, the SMS site did prove workable during an extended 'lock-down' period during the COVID pandemic, where staff lived onsite for a considerable time.

Also as noted, the SMS ICT environment is very vulnerable, and this affects forecast processes. Although forecasters have access to a range of platforms on which to conduct the forecast process and to assemble and deliver the suite of products, these systems are not integrated. The platforms include IBL Visual Weather, SmartMet, Himawari Satellite Display and Tropical Cyclone Module.

Most of the work is conducted on Visual Weather with only limited or no use being made of SmartMet. The Visual Weather installation is no longer supported by the provider and needs further development. Forecasters are also unable to easily analyse and visualise the observations received.

6.2. Hydrometeorological hazards for which forecasting and warning capacity is available and whether feedback and lessons learned are included to improve warnings.

SMS deal with hydrometeorological and geohazards, which have considerable crossover between them, in support of an integrated multi-hazard approach and Samoa's Sendai commitments. The SMS provides the following forecast and warning products:

- Public Weather forecasts – 4 times per day for 5 districts across Samoa (two in Upolu, three in Savai'i);
- Marine forecasts
- Daily Weather Discussion for Samoa;
- A range of warnings for a variety of hazards including
    - Strong winds above 25 knots for the public and maritime sector
    - Heavy rain warnings (above 70mm)
    - Coastal Flood inundation from heavy swells (greater than 4 metres)

    - Tropical cyclones including storm surge
    - Flash flood warning siren activation to a limited extent (in coordination with Water Resources Division, and only for some catchments)
    - Landslide risk (issued by Geoscience Section).
- Tsunami warnings for potential events generated by earthquakes, particularly noting the proximity of the northern part of the Tonga Trench to Samoa. Following the January 2022 eruption of Hunga Tonga-Hunga Ha'apai, and during volcanic unrest in American Samoa, new internal procedures were developed to support the issuance of tsunami warnings resulting from volcanic eruptions.

The further development of the flood warning system is a high priority for Samoa, consistent with the mandates given in the 2021 Act for warnings of '*coastal and extreme flooding of any nature'*. A warning time of only 1.5-2 hours is possible for riverine flooding impacting the Samoan coast, but flash floods can develop more rapidly than this, with the coincidence of localised heavy rainfall and coastal high-water effects (such as high tides or a storm surge). This is discussed further under Element 8.

Systematic and independent processes for assessing and improving warning services are still under development, in line with Samoa's generally improving multi-hazard early warning systems governance. However, SMS does examine and report on significant events, including as part of their ongoing commitment to the WMO Severe Weather Forecasting Programme. For example, a detailed examination of the January 2014 heavy rainfall and flooding event associated with the development of Tropical Cyclone Ian considered the physical causes, numerical guidance performance, forecast team response, warnings issued, and emergency response, providing extensive documentary evidence of the science, impacts, and operations around the event, paired with critical analysis from the SMS perspective[11].

6.3. Common alerting procedures in place based on impact-based services and scenarios taking hazard, exposure and vulnerability information into account and with registered alerting authorities.

Samoa's warning systems shows an awareness of impact-based service principles, coupled with some limitations in service delivery. ICT systems do not yet exist to allow seamless exchange of impact-based information, but forecasting and disaster management staff are well connected to communities. Warnings are delivered through multiple media (see later discussion), through joint press conference, social media, and bilingually in an effort to reach the population. Most notably, Samoa has siren-based warning systems for areas that are most vulnerable to flash flooding and tsunamis. These sirens are the responsibility of the DMO, but can be activated by SMS at need (particularly outside office hours).

Discussions during in-country consultations suggested a strong mutual commitment from all agencies to continuing to develop and improve common alerting procedures. Another important aspect of community response is the particularly strong social fabric within Samoa.

Summary score, recommendations, and comments for Element 6

Samoa is assessed as being at **Maturity Level 4** for this Element, reflecting a *'Weather-related warning service with strong public reach and standard operational procedures*

[11] Samoa Meteorological Services, 2014, *January 2014 Heavy Rain and Flooding in Samoa,* Report, 17 pp.

driving close partnership with relevant institutions, including disaster management agencies.'

This rating is given despite the significant technological and observational challenges that SMS and partner agencies have, and reflects the strong working relationships between agencies, commitment to outreach, and public engagement of the teams. Because of these relationships, the next lower criterion, Level 3 (Weather-related warning service with modest public reach and informal engagement with relevant institutions, including disaster management agencies) was judged as being too low.

However, for Samoa to fully meet the needs of its population, and improve its early warning systems consistent with the Sendai Framework and with the United Nations 'Early Warnings For All' initiative, more work is required to address critical gaps in the warning system, integration of multi-hazard warnings, as well as improving the observations network, supporting modelling, and ICT environment.

Element 7: Contribution to Climate Services

7.1. Where relevant, contribution to climate services according to the established capacity for the provision of climate services.

For ranking climate services, the Country Hydromet Diagnostics uses a six-point rating scale, ranging from 'Not Applicable', through 'Less than Basic', 'Basic', 'Essential', 'Full' and 'Advanced'. The scale is applied across six core data points, in alignment with the WMO Checklist for Climate Services Implementation.

Governance for climate services

Samoa's weather climate services fall under a Samoan umbrella known as the *Climate Early Warning System (CLEWS),* developed in 2013, which aims to enable improved access to climate information, improved climate services to vulnerable economical sectors and to build resilience through Disaster Risk Reduction and Climate Change Adaptation inter-linkages. This is an appropriate approach, particularly in tropical countries where day-to-day weather variability can be less important than seasonal and intraseasonal considerations, although it can be difficult to fully integrate the fast-paced multi-hazard early warning system view of operations with climate services, and so CLEWS naturally favours a climate lens. The CLEWS approach foresees sector-specific approaches, focusing on agriculture, forestry, tourism, health, water, and the marine environment. So far, these have not been fully developed.

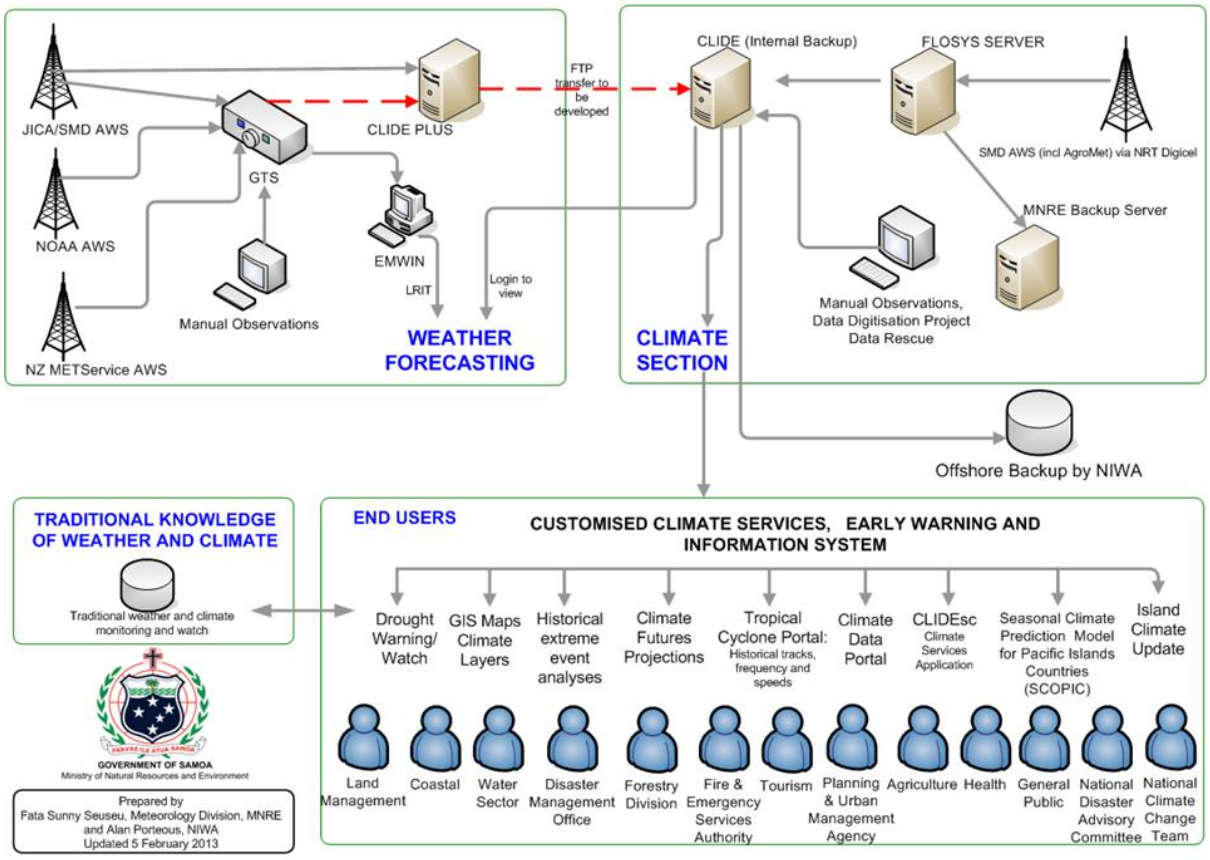


Figure 10 Samoa's CLEWS structure (SMS), as conceived in 2013 and shown on SMS's website.

The state of governance for Samoa's climate services is rated as 'Essential'.

The state of **Basic Systems** is rated as 'Basic', based primarily on the concerns around observation networks, including station maintenance and international reporting, difficultly handling data, and poor ICT systems integration.

The **User Interface** is rated as 'Full', based on questionnaire responses and also the SMS website being mostly up to date with relevant decision support products.

The **Provision and application of Climate Services** is rated as 'Advanced'. SMS have an active Climate Services team who engage strongly with user communities. User products such as climate and ocean outlooks are issued regularly, covering the next 3 months, and including coral bleaching, sea surface temperatures, sea surface heights, temperature and rainfall outlooks, along with ENSO assessments. Products are based on external modelling, including from the Australian Bureau of Meteorology as part of the COSPPac initiative (Figure 11).

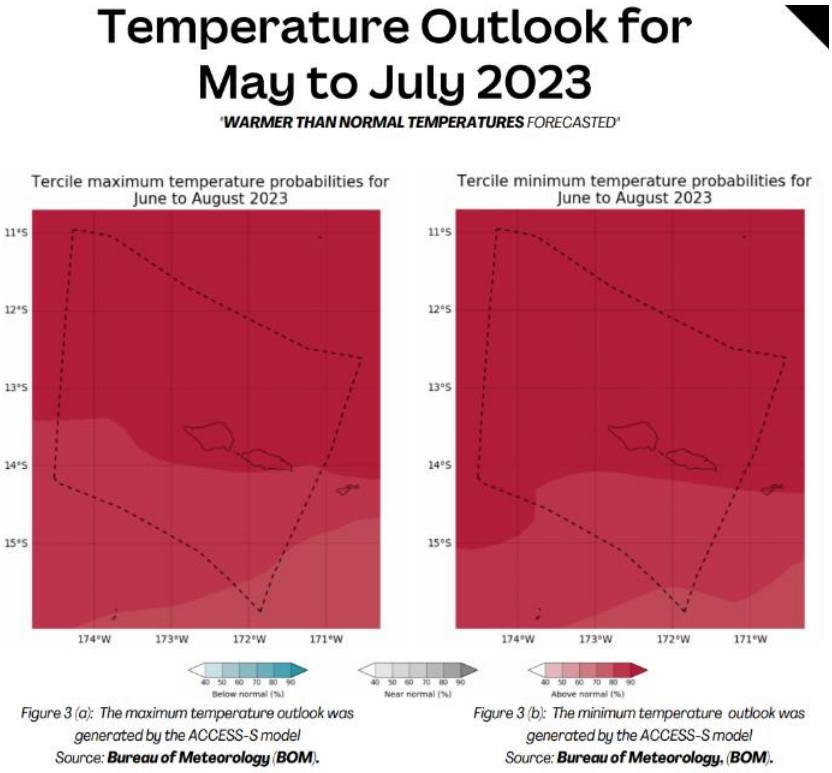


Figure 11 - Extract from June 2023 seasonal outlook.

These products are largely qualitative and don't include impact-based information.

A monthly climate summary is also issued, but the ongoing issues with observations data severely limit the amount of temperature reporting in the product. An Early Action Rainfall Watch was developed at the request of Red Cross, also funded through COSPPac. A hydroelectric power rainfall product is currently being tested in pilot phase. Further products are under development to service agriculture and health needs.

Monitoring and evaluation of the socio-economic benefits and **support for capacity development** are both rated as 'Essential', noting technical system limitations and a relative lack of evidence for services.

Based on all of the information available, Samoa's contribution to climate services is rated as a mid-range **Maturity Level 3.** This reflects that, while user relationships and commitment to services are strong, there are still strong service limitations caused by climate and observational data and system integration challenges.

Addressing the ICT infrastructure and observations issues, and providing dedicated, ongoing ICT systems support within SMS would substantially assist Samoa's climate services provision, as well as every other section within SMS.

Element 8: Contribution to hydrology

8.1. Where relevant, standard products such as quantitative precipitation estimation and forecasts are produced on a routine basis according to the requirements of the hydrological community.

There is a service requirement for quantitative precipitation and forecasts, in order to inform flood products. As noted earlier, Samoa is subject to quickly developing riverine floods, with approximately 1.5 hours between heavy rainfall on the central ranges and community flooding near the coasts. This is exacerbated in high tide and other coastal inundation situations due to the backflow of estuarine water at the river mouths, which tend to be next to communities. However, SMS are only able to provide qualitative rainfall estimates, partly due to the lack of high resolution, calibrated numerical modelling (see earlier discussion on numerical modelling), and also due to the challenging observations density required to estimate rainfall amounts in tropical convection on topography.

'Nowcasting' can be done for some areas where the rainfall network is functioning well. However, river height prediction models are in the early stages of development, and are only available for rivers that affect the capital Apia. Otherwise, flood warnings are essentially threshold-based and subject to the short lead time. There is currently no radar available for real-time rainfall estimation, so heavy rainfalls that fall outside gauges will not be detected.

As noted earlier, the rainfall and river gauge network are subject to the same issues of ongoing maintenance and parts replacement as the rest of the hazard monitoring networks.

8.2. SOPs in place to formalize the relation between Met Service and Hydrology Agency, showing evidence that the whole value chain is addressed.

The WRD is within the Ministry of Natural Resources and Environment, sitting alongside SMS and DMO. It operates under the Water Resources Management Act (2008). It has three sections: Hydrology, Watershed Management, and Policy and Regulatory.

Verbal evidence from both SMS and Water Division staff during in-country consultations was that the relationship between the two Divisions is very strong and collaborative, although formal SOPs are still under development following the passage of the new Meteorology, Geoscience and Ozone Services Act (2021). The new Act places flood warning responsibly clearly under the Meteorology Division. In practice, SMS and the WRD work very closely together, with SMS issuing warnings based on Water Division advice. WRD do not work 24/7 (and do not have the staff resources to do so) but extend their hours of coverage in potential warning situations. When they are not on duty, SMS have authority to issue warnings without consultation, due to the time-critical nature of the hazard. SMS also have authority to activate flood warning sirens, where they have been installed, during hours when the National Emergency Operations Centre is not staffed.

Other areas of activity for the WRD include river monitoring, groundwater monitoring and water quality monitoring. Water resource management is important and catchment plans have been developed with communities and policies and plans on water extraction are in place. The Division are aided by the Scientific Research Organisation of Samoa and the National University of Samoa which undertake water quality analysis of monthly samples and supply the data back to the WRD, at selected water source sites.

8.3. Data sharing agreements (between local and national agencies, and across international borders as required) on hydrological data in place or under development.

River and rainfall data are freely shared between the two Divisions, with some limitations due to observational communication challenges (if station data can't be viewed in real time, the agencies are unable to share it with each other). International transmission of data (for example, for assimilation into high resolution models) does not occur.

8.4 Joint projects/initiatives with hydrological community designed to build hydrometeorological cooperation.

The two Divisions collaborate with science research agencies as described earlier, and with capacity-building partners in multiple contexts. Weather and water data is, for example, critical for agriculture and health as well as emergency management. The key limitation in this regard is the low local capacity for Samoan-initiated projects without international assistance. In addition, when a project is finished, there is usually limited or no resourcing available to finance maintenance of assets or ongoing activities.

Summary score, recommendations, and comments for Element 8

Samoa is assessed as **Maturity Level 3** for this Element, expressed as '*There is a moderately well-functioning relationship between the meteorological, hydrological and water resources communities but considerable room for formalizing the relationship and SOPs.'*

In the case of Samoa, the relationships are strong, but the challenges are primarily in terms of maintenance of networks and the production of quantitative rainfall guidance suitable for the further development of flood warning systems. As discussed earlier, SMS could look to obtain support for improved numerical modelling and real-time weather observations, including consideration of an operational weather radar with real-time rainfall estimation (and with data available to the public for use in their own decision making). These approaches all require ongoing support but would result in a tangible improvement in flood management in Samoa, including in compounding / cascading weather situations such as tropical cyclones, where disasters can rapidly develop during conditions that life-threatening to emergency management teams.

Element 9: Product dissemination and outreach

9.1. Channels used for user-centred communication and ability to support those channels (for example, does the NMHS operate its own television, video or audio production facilities? Does it effectively use cutting-edge techniques?).

Multiple channels are used for message dissemination, including text message, radio, television, email, social media (Facebook, YouTube), and web sites. SMS does not operate its own television facilities, but regularly shares media-friendly content, and participates in joint press conferences with the DMO. Forecasters prepare a daily television video that is used by two of the Samoan stations while other stations develop their own presentations. There have been issues of consistency between the information provided through SMS and other television networks. SMS has an Android-format App with products as well.

SMS's Facebook page has 46000 followers, or around 21% of the population (noting that some of these followers will be from the broader Samoan diaspora). Posts are made regularly in Samoan and English and attract a good degree of interaction. Information from SMS is occasionally reposted on Twitter by other agencies but without significant response. Forecast weather discussions are issued on YouTube, but with a relatively small number of subscribers (maximum number of views in the 100s).

Twenty-three warning sirens are installed along the southern coast of both islands in the locations that were most severely hit by the 2009 tsunami. A network of sirens has also been constructed along the Vaisigano River in Apia for flood warning. The sirens are tested regularly.

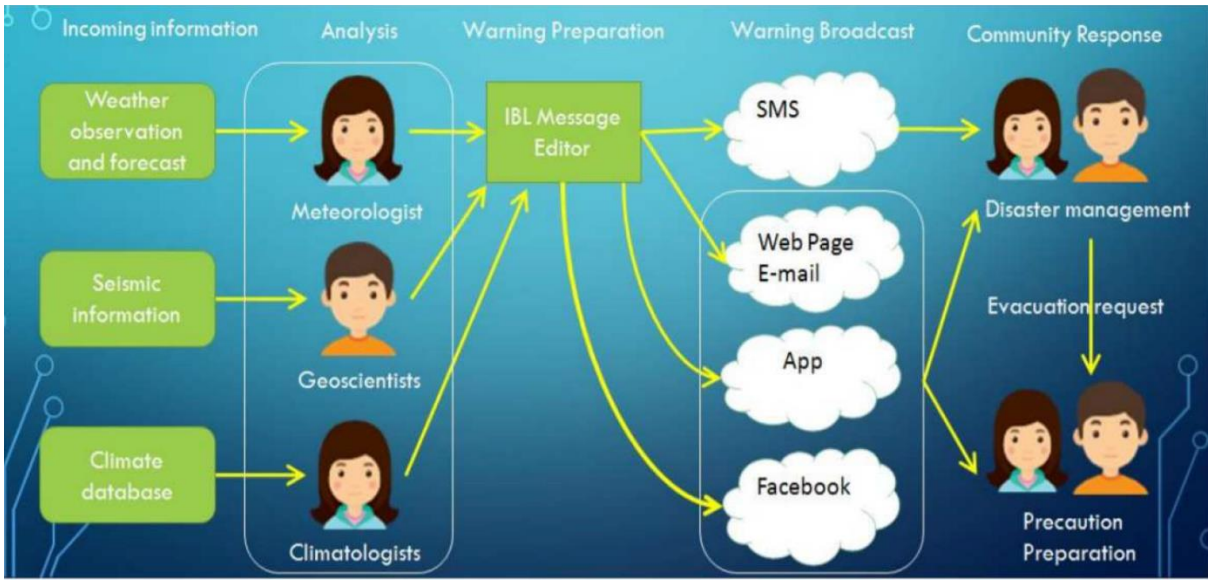


Figure 12 – Multiple channels of communication used in Samoa warnings. Extract from SMS presentation to Impact Based Forecast and Warning Services workshop, Honiara, Sept 2019, showing the warning value chain to users (courtesy SMS).

The draft Standard Operating Procedure in place for Flood Decision Support operates across WRD, Met Office and the DMO. WRD produces impact maps e.g. 1 in 5, 1 in 10, 1 in 20 flood maps. Flood warnings are disseminated by the Met Office via radio, television, email to Government agencies, Facebook and the Weather App. The Met Office provides warnings related to drought but there is insufficient capacity and

resources to support drought management and policy in terms of how to respond to droughts.

9.2. Education and awareness initiatives in place.

Climate, weather, and seismic information is included in the school curriculum. The DMO, together with partner agencies such as SMS, engages with communities and first responders such as the Red Cross. The Community Disaster and Climate Resilience Management Program (CDCRMP) is used to deliver messages to villages and provide information on how to respond as well as how to reduce risks and prepare.

9.3. Special measures in place to reach marginalized communities and indigenous people.

The CDCRMP incorporates community education, including to youth and the elderly. Over the past two years, backed by funding from the CREWS project, Samoan agencies have undertaken major community engagements to explain early warnings and hazard preparedness, covering almost 200 villages out of 365 villages in Samoa. Response agencies, including DMO, SMS, and Fire Services and Civil Society Organisations such as Red Cross worked together on the initiative. Attendances at these engagements have been high and have included community leadership as well as community members of all ages. Follow up activities have been proposed for improving marine safety.

Tropical cyclone information from SMS has been included in a recently published DMO disaster management awareness brochure, available in braille.

These community activities incorporate traditional knowledge in their planning and execution, with the Samoan agencies seeking to develop a seamless blend of traditional and scientific knowledge. Samoa has also participated in ground-breaking participatory approach research for indigenous weather and climate knowledge in the Pacific[12]. SMS services also reference both modern forecasting techniques and traditional knowledge as appropriate. Products are issued bilingually and using multiple channels.

Summary score, recommendations, and comments for Element 9

Based on the strong evidence available, Samoa is assessed as **Maturity Level 4:** *A large fraction of the population is reached using various communication techniques and platforms, in collaboration with partners, and a user-friendly and informative website and apps. Outreach and education activities occur regularly.*

There is still room for improvement despite Samoa's impressive efforts in this area. Community engagement is a never-ending task, and must be continued, which requires ongoing, core-funded resources. SMS's weather observations are not easily available to the public, meaning the loss of a routine engagement opportunity (as engagement with weather observations and forecasts leads to stronger responses during warning situations). A new ICT backbone would allow redevelopment of the SMS App to show real-time observations and warnings, and even new observation types such as radar imagery, which can directly assist community decision-making.

[12] Chambers, L.E. *et al.* (2021). Enhancing Climate Resilience in the Pacific. In: Brears, R.C. (eds) The Palgrave Handbook of Climate Resilient Societies. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-42462-6_103

Element 10: Use and national value of products and services

10.1. Formalized platform to engage with users in order to co-design improved services.

Samoa does not have a formalised national platform for user engagement and service design. Instead, SMS engages with users on a 1:1 basis or within the context of other meetings. The many externally funded projects that SMS interacts with usually have some element of user consultation. For example, the current CREWS project has documented some user needs in regard to warning communication, warning design, and support for early actions.[13] The World Bank PREP project Systems Integrator Consultant team activity (2018-2023) also included round table user consultation. WMO Marine Services Training (2021-2022) included formal assessment of marine services user needs. SMS staff participated in this training, interviewed external users, and then used the information gained to initiate follow-up activities with the marine sector.

10.2. Independent user satisfaction surveys are conducted, and the results used to inform service improvement.

Independent user satisfaction surveys are not conducted. User feedback, including community feedback during engagement activities, social media comment, and key user comment, is used to inform service improvement, although not within a formally structured process. The results of user consultations (as discussed above) are also used to guide service improvements. Recently a user survey on impact-based forecast and warning services has been undertaken (supported through the CREWS initiative and implemented by the World Bank). Analysis on the results of this survey is continuing at time of writing.

10.3. Quality management processes that satisfy key user needs and support continuous improvement.

Initial steps were taken toward introducing Quality Management, particularly in support of aviation services. So far, little progress has been made, mainly because of the turnover of key staff and resourcing constraints. The SMS website includes a section for quality management, but with no content.

When considering the overall needs of SMS, an urgent area for focus for quality management might include observational infrastructure, where there is large potential given the quality of the equipment available, but where ICT infrastructure and maintenance improvements could significantly improve the benefits to Samoa.

Summary score, recommendations, and comments for Element 10

Based on the information available, Samoa is assessed as **Maturity Level 2** for this Element, reflecting *'Service development draws on informal stakeholder input and feedback'.* A renewed effort on quality management, including for all major services (not only for aviation) would significantly lift this assessment. This will likely require long-term partnership assistance, based on the experiences of other countries in the region.

It should be emphasised that this Element does not reflect the overall value of SMS, but rather focuses on the processes around users and products.

[13] Samoa CREWS 2.0 Technical Assistance Visit report, 20-24 February 2023

Annex 1 Consultations (including experts and stakeholder consultations)

- Ms Faamanatu Molly Nielson, Assistant CEO for the Disaster Management Office, and staff
- Dr Luteru Agaalii Tuvale, Assistant CEO for the Samoa Meteorology Division, and staff
- Ms Emarosa Romeo, Water Division
- Mr Henry Taiki, WMO Representative for South-West Pacific, and Ms Tessa Tafua, WMO
- Mr Salesa Nihmei and Ms Siosinamele Lui, Secretariat of the Pacific Regional Environment Programme (SPREP)
- Mr Jian Vun (World Bank)
- Ms Lina Lannette Esera and Ms Foketi Imo Evalu (PREP Project Implementation Unit)

Note: the SOFF mission to Samoa occurred during an extremely busy period in-country, with multiple international missions in Apia seeking consultations with local stakeholders. In light of this, a decision was made to not unnecessarily add to the local burden on Samoan officials by seeking consultations in cases where well-documented contemporary evidence already existed. The assessments in this report, consistent with CHD design, draw to some extent on pre-existing material kindly made available by SMS and partners.

Annex 2 Urgent needs reported

SMS's ICT infrastructure is in urgent need of integration and repair. This is a priority of the World Bank-funded PREP project, following assessments. This situation was further highlighted by a report from PRAGMA Partners, a business consultancy, that emphasised aging, at risk technical infrastructure, poor interoperability, an insecure website, and other issues consistent with the earlier PREP findings. PRAGMA proposed a two-year mitigation plan, which might be regarded as a relatively short period to fix all issues.

SMS also need to have dedicated ICT and network engineering staff to support infrastructure on an ongoing basis. Typically, such skilled staff are highly sought after by other agencies and industries, and priority should be placed on recruiting and retaining such staff. More than one staff member will be required given the considerable load created by the demands of running a multi-hazard warning service and ensuring business continuity, quality management and systems integrity. It is highly unlikely that the systems integration, security, and service delivery risks carried by SMS on behalf of Samoa can be effectively managed without the employment of long-term ICT specialists within the agency.

At a more strategic level, SMS may benefit from consistent access to high-level advice in order to assist the Director and senior staff navigate the process of service enhancement and budget remediation within the complex Samoan environment.

Finally, at a functional level, SMS's vehicle fleet is in urgent need of updating. SMS's centralised operations model, which is efficient and appropriate for a compact country, relies on reliable 4WD vehicles able to attend remote stations, sometimes on steep topography. There have not been any recent fleet purchases, and experiences during the SOFF/CHD mission demonstrated that hire vehicles are an insufficient substitute due to inappropriate configurations and uncertain availability.

Annex 3 Information supplied through WMO

- WMO Monitoring System Data
- WMO EW4All Rapid Assessment for Pillar-2
- WMO Hydrology Survey
- Data from Checklist for Climate Services Implementation

Annex 4 List of materials used

Bureau of Meteorology, Australia, internal visit reports

Pacific Climate Change Science Program, Climate, climate variability and change in Samoa. Poster.

Pacific Meteorological Council, May 2021 Weather Ready Pacific – A Decadal Program of Investment.

Pathway for the Development of Samoa FY2021/22 – FY2025/26

PRAGMA Partners Consultancy, March 2023. Discovery Report & Mitigation Plan – Summary Pack. Slide presentation.

Samoa Meteorological Service reports for Severe Weather Forecast Demonstration Project:

- January 2014 (Heavy Rainfall Case Study)
- 16 September 2016 (Hail Case Study)
- 6 May 2018 (Severe afternoon convection)

Samoa report to Impact Based Forecast and Warning Services (IBFWS) Workshop for the Pacific Small Island Developing States, September 2019

Samoa CREWS 2.0 Technical Assistance Visit Report, February 2023 (Melanie Harrowsmith).

Samoa Multi-Hazard Early Warning Systems Policy 2021

Severe Weather Forecasting Program, South Pacific, 2022. Report No. 24

Taylor & Talia, 1999, Volcanic hazards assessment of Savai'i, Samoa, SOPAC Technical Report 295

UNDP (Love, Mamaeva and Wilson), 2018, Feasibility Study for a Pacific Based WMO Regional Training Centre, 266 pp

WMO Guidelines on High-resolution Numerical Weather Prediction (WMO-No. 1311, June 2023 Available at https://library.wmo.int/doc_num.php?explnum_id=11654

WMO Guidelines on the Role, Operation and Management of National Meteorological and Hydrological Services. 2017 edition (WMO-No. 1195). Available at https://library.wmo.int/doc_num.php?explnum_id=4221

World Bank PREP Project Systems Integration Consultant team reports, 2018-2022 (multiple reports)