COUNTRY HYDROMET DIAGNOSTICS

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

December 2023

Fiji Peer Review Report

Reviewing Agency: Bureau of Meteorology, Australia

Rerevaka na Kalou ka doka na Tui

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List of acronyms

ACCESS	Australian Community Climate and Earth-System Simulator (model)
AWS	Automatic Weather Station
CHD	Country Hydromet Diagnostics
COSPPac	Climate and Oceans Support Program in the Pacific
CliDE	Climate Data for the Environment
CREWS	Climate Risk and Early Warning Systems
ECMWF	European Centre for Medium-Range Weather Forecasts (model)
ENSO	El Niño–Southern Oscillation
EEZ	Exclusive Economic Zone
EPS	Ensemble Prediction System
FMI	Finnish Meteorological Institute
FMS	Fiji Meteorological Service
GBON	Global Basic Observing Network
GFS	Global Forecast System (model)
GTS	Global Telecommunications System
HPC	High Performance Computing
ICAO	International Civil Aviation Organization
ICT	Information and Communications Technology
JICA	Japan International Cooperation Agency
JMA	Japan Meteorological Agency
LAM	Local Area Model
NMHS	National Meteorological & Hydrological Service
NWP	Numerical Weather Prediction
RSMC	Regional Specialised Meteorological Centre
WIGOS	WMO Integrated Observing System
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting (model)

Executive Summary

Fiji (population approximately 900,000) is subject to a range of hydrometeorological and geological hazards, including tropical cyclone, riverine and flash flooding, thunderstorms and tornadoes, drought, tsunamis, earthquakes, fires, landslides, large waves and swell. The steep volcanic topography makes accurate wind and rainfall estimation challenging. Fiji is also highly exposed to climate change.

The Fiji Meteorological Service (FMS) is a leading National Meteorological and Hydrological Service in the region, with responsibility for hydrometeorological matters within Fiji and a regional role for assistance to other countries in aspects of hydrometeorology including tropical cyclone warnings, aviation and public weather forecasts. Parts of the FMS role are not well formalised (both regionally and locally), and there is no establishing legislation, which is a high priority for resolution. FMS has, however, a practical mandate stemming from departmental expectations and budgeting as well as its World Meteorological Organization (WMO) and International Civil Aviation Organization (ICAO) obligations on behalf of Fiji.

FMS's staff and budget are mostly sufficient to meet its current roles, although there is strong dependence on donor programs for service improvements (such as the implementation of impact-based warnings, expansion of quality management, and new technologies), and climate services are provided with support from a long-running regional program, the Climate and Oceans Support Program for the Pacific (COSPPac). The observations and ICT programs operate in an unsustainable fashion with too many disparate technologies and projects requiring support from too few staff, and new initiatives stalling as a result, as well as difficulties complying with global observational standards. Examples of this include the servicing of weather stations and radars donated by multiple organisations, the development of the forecasting system environment, and the aspirations towards having an internal modelling capacity, all of which cannot be sustainably supported with current resourcing. In particular, the development of the commercial (IBL provided) forecasting environment and transition away from the Australian Integrated Forecasting System (AIFS) requires additional support, and the implementation of the Weather Research and Forecasting (WRF) model as an operational model is likely not viable without a large additional staffing commitment.

The FMS has a recent Strategic Plan (2021-2024) that provides a roadmap forward through this complex landscape. Improved user relationships, clarification of legislative mandate, sustainable network and ICT practices, and continued collaboration with agencies and the international community are all vital to ensuring FMS's continued ability to serve the Fijian public and the wider region. Important initiatives such as Weather Ready Pacific and the Systematic Observations Financing Facility have potential to substantially support FMS in this work.

Summary of assessment ratings for Country Hydromet Diagnostics (CHD) elements

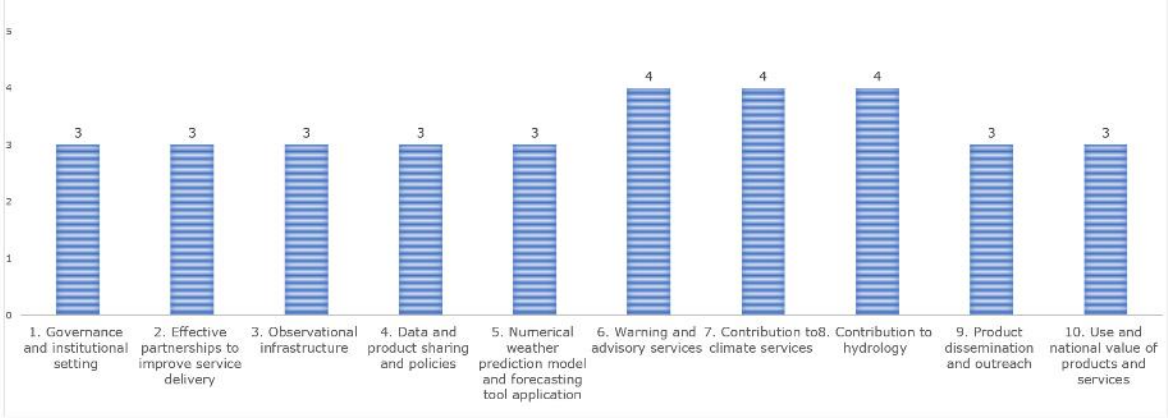

Figure 1 - Summary of assessed ratings for the ten Country Hydromet Diagnostics elements. Each rating is out of five, with five reflecting a relatively high degree of maturity.

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

Table 1 - As for Figure 1, in tabular form

Chapter 1: General information

Introduction

Fiji (population approximately 900,000) is an archipelagic country of 300 islands and hundreds of islets (Figure 2) in the southwest Pacific, about 2,100 km north of New Zealand. The majority of Fiji's islands were formed through volcanic activity. Viti Levu (seat of the capital Suva) and Vanua Levu are the major islands, with several significant smaller islands and about 100 islands in total inhabited. Fiji has a land area of 18 274 km², with an Exclusive Economic Zone (EEZ) of 1.26 million km².

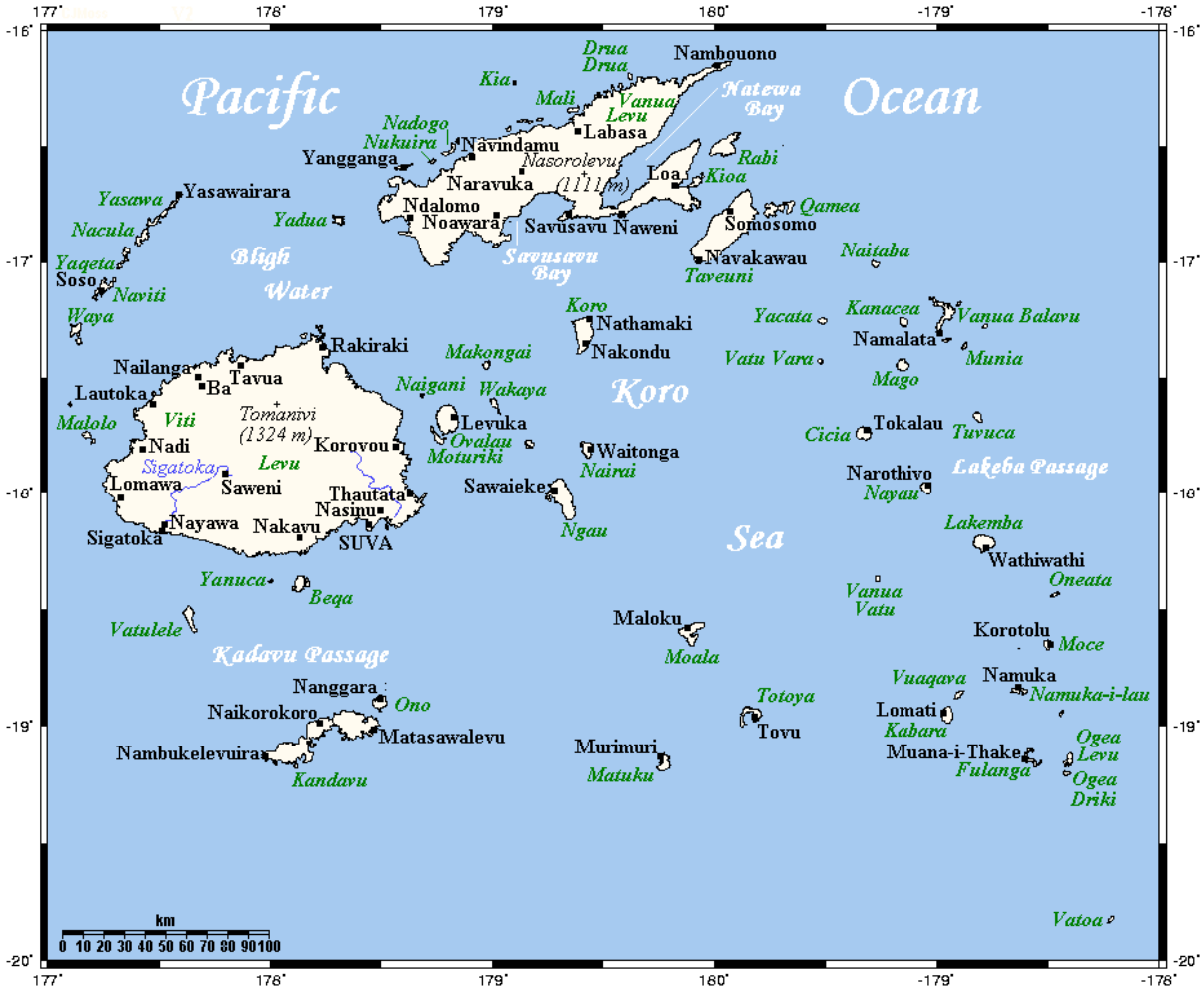

Figure 2 -Map of Fiji, with island names in green. By Kelisi at the English-language Wikipedia, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=3950526

Fiji has a moist tropical climate, with a cooler season from May to October. Rainfall is all year around, but with a peak during November – March (the Southern Hemisphere summer). The tropical cyclone season is from November to April, with cyclones also possible in October and May. Severe tropical cyclones have affected Fiji on numerous occasions, with the most severe impact from Severe Tropical Cyclone Winston (Category 5) in February 2016.

As for the wider region, variability in rainfall is strongly influenced by the El Niño–Southern Oscillation (ENSO), but topography also plays a significant role, with rainfall peaking on southeast-facing slopes. River flooding occurs most years, including occasionally in the dry season during La Niña events. The combination of topography, tropical rainfall and ocean conditions means that Fiji is frequently subject to compound hazards, with landslides, riverine and flash flooding, coastal inundation, and wind damage all possible during tropical cyclone events.

Fiji is vulnerable to climate change, with coastlines and low-lying areas exposed to sea level rise, coral reefs and ecosystems subject to ocean acidification, rising temperatures, and a range of rainfall scenarios[1].

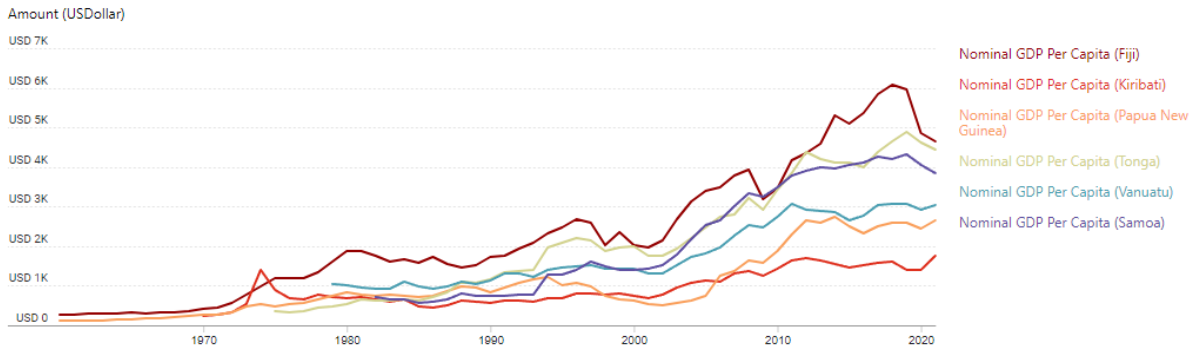

Figure 3 Fiji GDP per capita (USD), compared to Kiribati, Papua New Guinea, Tonga, Vanuatu, Samoa. Source: Datacommons.org, based on World Bank data

Fiji has the most developed of the Pacific Island economies, with tourism, fishing, agriculture and manufacturing. Its per-capita Gross Domestic Product (GDP) of around 4600 USD is relatively strong compared to other Pacific Island countries in the region (Figure 3).

The Fiji Meteorological Service (FMS) has a leading role within the region as a WMO Regional Specialized Meteorological Centre (RSMC) with a responsibility for tropical cyclones, in addition to providing other aviation and public weather assistance to some countries in the region. FMS is headquartered in Nadi, with a large office also in the capital Suva, and observations offices around Fiji as discussed later.

Country Hydromet Diagnostics methodology

This report has been prepared using the methodology described in the 2022 update of the Country Hydromet Diagnostics. An initial desktop review was performed, using information supplied from Fiji, WMO, and other partners. An in-country visit was then undertaken to allow direct discussions with the FMS and necessary stakeholders. Discussions were held in Nadi and Suva, with a circuit of Viti Levu to inspect a variety of observation station types.

[1] https://www.met.gov.fj/aifs_prods/Climate_Products/Country%20Report%20Fiji.pdf

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 Fiji Meteorological Service is part of the Ministry of Public Works, Meteorological Services and Transport, with the mission to 'observe and understand regional weather, Fiji's climate and hydrological patterns, and provide meteorological and hydrological services'. FMS was formerly part of the Ministry of Disaster Management and Meteorological Service. Both Departmental alignments are relatively common for meteorological services.

There have historically been no written laws governing meteorological and hydrological services in Fiji, and no national water policy or strategy. Following major flooding in 2012, responsibility for flood forecasting was given to the Fiji Meteorological Service.

A Meteorological and Hydrological Services Bill 2016[2] was drafted to provide for:

- the establishment and functions of the Fiji Meteorological and Hydrological Service; and
- the efficient management, control, promotion and development of sound meteorological and hydrological services, to contribute to the protection of life, property and economic development from meteorological and hydrological disasters.

The Bill also provides that the Service is 'solely responsible' for the promotion, development, management, control or provision of meteorological or hydrological services in Fiji. The draft Meteorology and Hydrology Act was submitted to the Permanent Secretary for onward submission to Cabinet in 2018 but the legislation has not yet been passed. It is currently before the Parliament Standing Committee for Natural Resources, but no recent activity concerning this Bill is evident on the website for that Committee following a call for submissions in 2016[3].

The current Strategic Plan calls for the resolution of FMS's legal position, and obliquely references the 2016 Bill. The Plan calls for further revision and consultation until 'an acceptable draft emerges'. There have been recent discussions regarding the draft, and it is believed that the long process of Bill development is nearly complete.

The National Disaster Management Office derives its authority from the National Disaster Management Act 1998, which sets out the framework for handling all phases of disaster management before during and after events.

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

A Strategic Plan was developed for 2021-24[4]. The Plan articulates five overarching strategic objectives, as shown in Figure 4. Operational plans have been developed, and each Section of FMS is responsible for identifying and managing risks. There is no formal risk management plan for FMS as a whole.

[2] https://www.parliament.gov.fj/wp-content/uploads/2017/03/Bill-No-4-Meteorological-and-Hydrological-Services.pdf
[3] https://www.parliament.gov.fj/committees/standing-committee-on-natural-resources/call-for-submissions/
[4] https://www.met.gov.fj/Fiji%20Meterological%20Service_Strategic_Implementation_plan.pdf

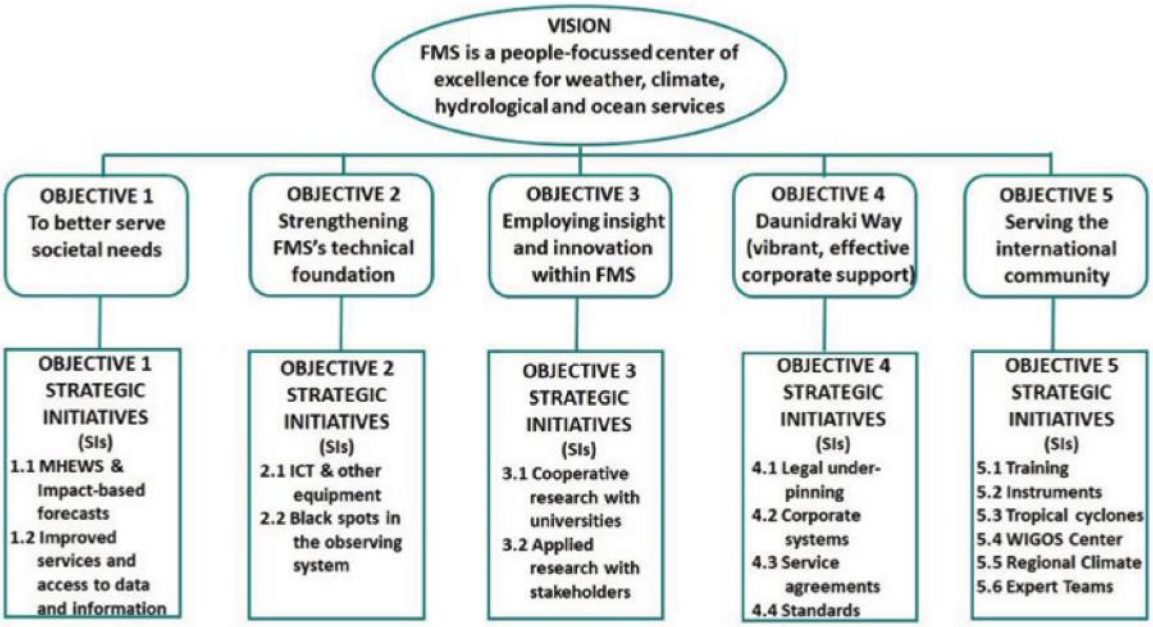

Figure 4 - FMS Strategic Vision and Objectives (FMS Strategic Plan)

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

FMS's annual budget is around USD 4.1 million, 41% of which is spent on staff costs, and 23% on operational costs. This is a relatively healthy budget when compared to other Southwest Pacific small island states. However, the budget development process appears a little unclear in terms of stability of essential operations. For example, at time of writing, no upper air observations were being performed from the sole upper air site (Nadi Airport) due to an unexpected reduction in funding for consumables (as discussed later). This may be a relatively rare situation but is a problem considering that very few radiosondes are operational in the wider region.

Around 124 staff positions are filled. Whether all core functions are adequately covered is a matter of debate; for example, it is probable that ICT functions are not being adequately covered for the current number of project responsibilities (refer later discussion under numerical prediction), and it also appears challenging to advance quality management coverage with the relevant Officer in Charge position unfilled.

A 2019 analysis by the Finnish Meteorological Institute[5] suggested that the Reporting & Facilities and Corporate Services parts of the budget were relatively underfunded (Figure 5). We would interpret this as reflecting a focus on operational prioritisation, typically found in stressed operational agencies. The same analysis also noted that, although FMS receive a fixed revenue from civil aviation, FJD 600 000 (approximately USD 266 000) per annum from Fiji Airports ltd, this revenue is relatively small compared to equivalent NMHSs that also receive aviation funding. The fixed rate approach is also inconsistent with WMO and ICAO guidance on cost recovery for aviation services.

[5] Finnish Meteorological Institute, 2019, Fiji's Hydrometeorological Observation Equipment Maintenance and Service Production – a Roadmap of Actions.

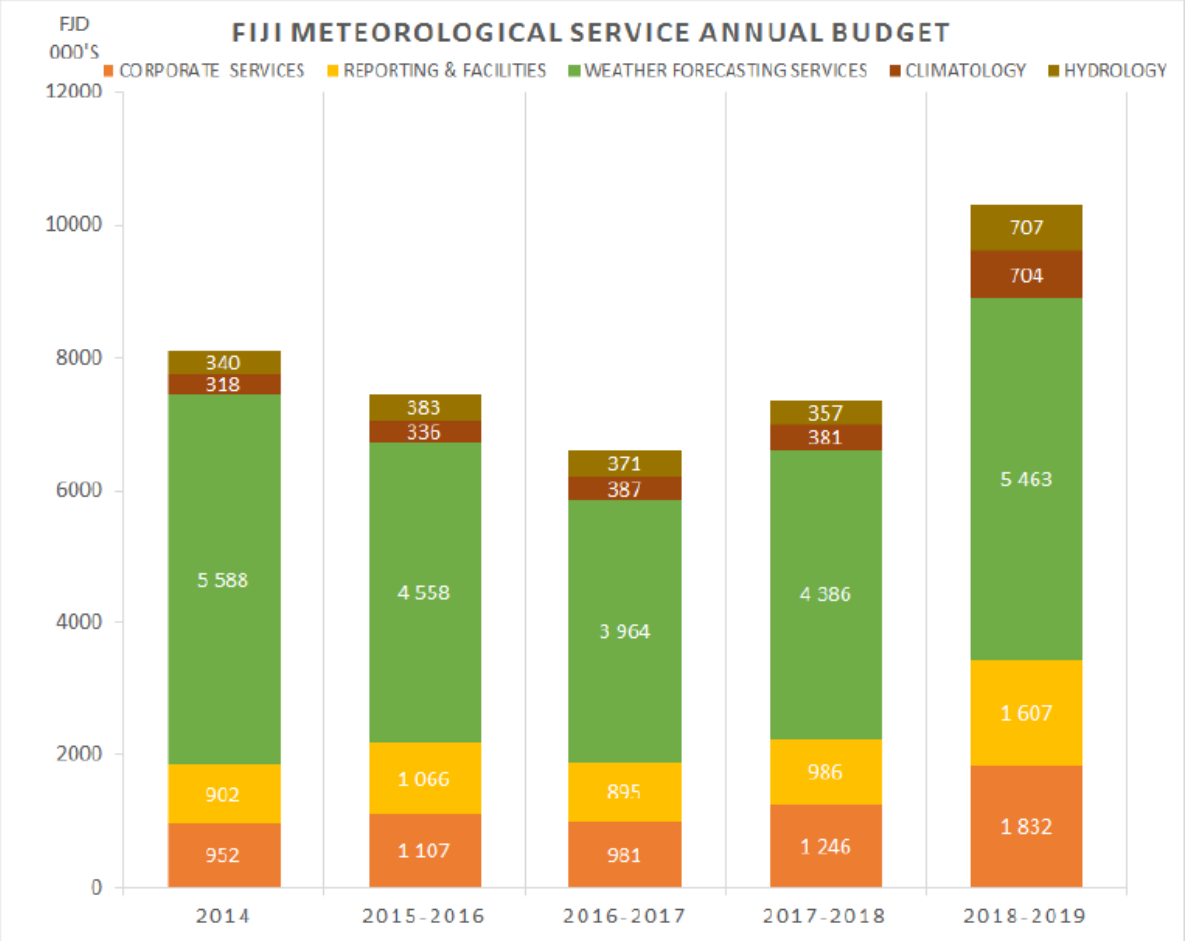

Figure 5- Finnish Meteorological Institute (FMI) analysis of budget breakdown, 2019. From top down: budget of FMS, total budget of FMS by sectors, total budget of operational Services (Weather Forecasting Services, Climatology, Hydrology) and total budget of Weather Forecasting Services by cost item. (FMI, 2019)

Donor support is also helpful in general to FMS, but has provided a wide variety of equipment types, which are not always compatible, and has also placed additional training and ICT loads on the relevant sections.

No cost-benefit analysis of the service has been performed.

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.

Training (both local and overseas) is an ongoing need at FMS, as for other Pacific Small Islands Developing States. The 2018 Feasibility Study for a Pacific based WMO Regional Training Centre[6] noted some statistics for those with appropriate degrees:

[6] UNDP (Love, Mamaeva, Wilso), 2018, Feasibility Study for a Pacific Based WMO Regional Training Centre, UNDP

	Staff	Staff with degree
Administration, Management and Training	26	1
General Forecasting	40	15
Observations	25	1
Climate Services	14	5
Hydrological Services	14	3
Communications and Computing	9	3

The study considered the feasibility of implementing WMO Regional Training Centre arrangements in Fiji, concluding that there is some potential for running a post-graduate diploma in meteorology with a strong operational focus. Fiji is relatively well serviced by tertiary institutions (e.g. University of Fiji, Fiji National University, University of the South Pacific), when compared to the rest of the region, although for full meteorologist training, a substantial residency in Australia, New Zealand, or another major partner is currently required.

Staff also receive on-the job training at FMS, supported by JICA. The UNDP study noted that *"FMS does not offer accredited courses but does offer a full range of technician courses in meteorology including aviation forecasting and observing and climate data / climate services… …FMS does offer meteorological technician training and in-service courses for technicians and meteorologists."*

Like most countries in the region, Fiji Meteorological Service has a gender imbalance, with 90 male and 30 female staff.

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

FMS is very well experienced at working with international partners for capacity building projects, although this is somewhat consuming of staff time. There is no research division in FMS, and there seems to be relatively little active research collaboration with local institutions, although there are some strong relationships as described later.

Examples of projects that FMS have or have been involved in are:

- FINPAC The Finnish & Pacific project to Reduce Vulnerability of the Pacific Island Countries' livelihoods to the effects of Climate Change
- COSPPac Climate and Oceans Support Program in the Pacific
- CREWS Climate Risk and Early Warning Systems
- CIFDP Coastal Inundation Forecast Demonstration Project
- PREP Pacific Resilience Program
- SOFF Systematic Observations Financing Facility
- RESPAC United Nations Development Programme Regional Disaster Resilience in the Pacific Small Island Developing States Project

Summary score and recommendations for Element 1

Fiji is assessed as **Maturity Level 3** on the CHD scale, reflecting *'Moderately well mandated, managed and resourced and clear plans for, and sufficient capacity to address operational gaps.'*

Table 2: CHD maturity ratings for Element 1

Element 1: Governance and Institutional Setting		Description: The level of formalization of the NMHS mandate and its implementation, oversight, and resourcing.		
Level one: Weakly defined mandate; serious funding challenges; essential skills lacking; little formalized governance and future planning.	Level two: Effort ongoing to formalize mandate, introduce improved governance, management processes and address resource challenges.	Level three: Moderately well mandated, managed and resourced and clear plans for, and sufficient capacity to address operational gaps.	Level four: An effective service but with a few shortcomings related to its mandate, governance, and resourcing and in the process to address the gaps.	Level five: Strong and comprehensive mandate, highly effective governance, secure funding, and readily available skills base.

This is a mid-range ranking despite FMS having a relatively poor legal mandate. It reflects a history of service provision, practical mandate through departmental arrangements, budget and staffing levels, even if that has not always allowed FMS to provide the services that it would prefer to. To further improve this maturity level, finalisation of the establishing legislation is a high priority, as reflected in the strategic plan. This could also be paired with more formalised processes for budgetary and other assistance to help FMS achieve its legislated mandate.

Element 2: Effective partnerships to improve service delivery

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

From written and verbal evidence, the FMS clearly has solid working partnerships with partner agencies such as the Fiji National Disaster Management Office, the Maritime Safety Authority of Fiji, the Civil Aviation Authority of Fiji, and the Water Authority of Fiji. The climate team are very active in seeking to strengthen user relationships, with annual workshops and strong relationships with agriculture clients. The location of FMS's headquarters in Nadi (close to the airport) may be a mild inhibitor of strong relationships with agencies based in the capital Suva, although FMS does maintain a smaller Suva office. FMS has also had a degree of leadership instability over the past few years, due to a combination of circumstances, which can add some challenge to the fostering of high-level relationships.

Part of FMS' strategy is to formalise service agreements or equivalents with key stakeholders. For this, they need active cooperation, which can also be difficult – for example, in discussions for this report around formal partnerships, the Maritime Safety Authority of Fiji acknowledged that FMS had reached out to them to discuss Memorandum of Understanding arrangements, to which they had not yet responded. The passage of a new Act would provide an excellent opportunity to reset and strengthen partnership arrangements.

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.

FMS has developed an extensive list of current and potential partners. There is some existing engagement with the private sector, including in the agricultural, energy, and aviation areas, with specific examples noted in discussions. These partnerships include observations site hosting arrangements with organizations that are closely aligned with the FMS mission, including Fiji Airport Ltd, the Ministry of Agriculture, Energy Fiji Ltd, and the Sugar Research Institute. FMS maintains good working relationships with the research community but as previously noted have no dedicated research section. There is also no formal cost-recovery policy, making it hard to fund commercial-type relationships with clients.

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

As noted earlier, active cooperation occurs with a range of international partners, including WMO, the World Bank, the CREWS project, Australia (particularly through the COSPPac program), the Japanese International Cooperation Agency (JICA), and many others. FMS clearly prioritises these relationships and values the potential for improved equipment and services that result.

That said, managing a range of external projects, even those with funding, can be a drain on resources. FMS staff expressed frustration with the coordination load that can result, particularly as the internal communications and coordination between project partners appears to be relatively weak. This can and does result in projects that are ultimately unsuccessful or create an ongoing burden on FMS (for example by introducing new technologies that require additional load to support or are insufficiently consulted). Examples of this issue include new types of observations equipment (that require different skills and servicing to others), and recent examples of forecast delivery

software (both public domain and licensed) that have not been fully implemented and supported in a way that fully meets Fiji's needs.

It might be reasonably argued, based on our observations, that FMS has been relatively successful in managing the challenges of maintaining external partnerships, but not entirely so. Responsibility for the success of international partnerships rests not only on the recipient NMHSs, but also on the international climate and development finance partners who engage and seek to assist them.

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 examples of service enhancement from research and science partnerships are from within the range of climate products. Fiji'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 FMS-branded product.

FMS have held a series of annual Climate Outlook Forums to engage with users and documented the results thoroughly. The reports show that FMS engage in open and honest discussions with users and allow the results to challenge them to develop new or enhanced products.

A particularly notable example of new service development shows a series of interviews with stakeholders in the sugar industry, which is a major industry in Fiji, including a total of 29 structured interviews across a cross-section of stakeholders[7]. This activity, conducted with the assistance of the Australian Bureau of Meteorology and the Pacific Community (SPC) through COSPPac, demonstrates a deep research approach towards industry-specific product application in the sector.

Summary score, recommendations, and comments for Element 2

Fiji 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.'*

Table 3: CHD maturity ratings for Element 2

Element-2: Effective partnerships to improve service delivery		Description: The level of effectiveness of the NMHSs in bringing together national and international partners to improve the service offering.		
Level one: Works in isolation and does not value or promote partnerships.	Level two: Limited partnerships and mostly excluded from relevant finance opportunities.	Level three: Moderately effective partnerships but generally regarded as the weaker partner in such relationships, having little say in relevant financing initiatives.	Level four: Effective partnerships with equal status in most relationships and approaching relevant funding opportunities in a coordinated manner.	Level five: NMHS is regarded as a major national and regional role player. It has extensive and productive partnerships and is viewed as an honest broker in bringing parties together and provide national leadership on relevant finance decisions.

This rating reflects the overall effectiveness of FMS partnerships, noting some strongly positive examples as discussed above, but also the state of some national partnerships and the challenges of working with the international community. To improve this maturity level, FMS can look to have stronger coordination around partnerships, at various levels, with investment in relationships management and also strong donor coordination in support of the FMS Strategic Plan.

[7] FMS and partners, 2021, 'Better use of climate information at a community level – case study for the sugar industry in Fiji.'

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.

Fiji has an extensive network of 45 synoptic surface stations (29 Automatic Weather Stations (AWS) and 16 manual synoptic stations), as shown in Figure 6, and a relatively high resolution compared with most other countries in the region. The two main islands are relatively well served by observations, with a strong network of manual and automatic synoptic stations (Figure 7), as well as volunteer climate stations operated by third parties such as agricultural institutes. The outer islands are not as well covered, due to logistical and communications challenges. The overall resolution of surface stations is 170 km (for all stations) and 362 km (for ten synoptic stations currently reporting to the GTS), and the resolution of the one upper air observation is 1144 km.

This report was prepared concurrently with the Systematic Observations Financing Facility (SOFF) Gap and National Contribution Plans. The latter noted:

> *Issue do exist with the FMS observing network, including:*
>
> - *Challenges with reliability and quality particularly for outer island stations where logistics and travel for maintenance and repair is complex and costly.*
> - *Issues with maintenance relating to a wide array of observing equipment makes and models within the various networks (as a legacy of previous internationally financed programs), especially the AWS network.*
> - *Insufficient numbers of skilled technicians and maintenance personnel and calibration facilities, particularly given the large number of stations and wide array of equipment types maintained.*
> - *Intermittent funding of upper air consumables as well as a current lack of upper air observations in the north of Fiji, a key region of cyclogenesis.*
> - *A legacy Meteorological Data Management System that is soon to be deprecated and is not WIS2.0 compliant.*
> - *An ICT workload that is larger than feasible for the existing highly-skilled staff to simultaneously address issues with existing systems, upgrade systems and ensure reliability of reporting.*
>
> *As result of the issues above, the GBON National Gap Analysis (NGA) assessed Fiji to have only one GBON-compliant surface station, located at the FMS headquarters at Nadi. The NGA used an assessment period of Jan-Oct 2023. While there are up to seven other stations that have reported at GBON frequencies in some months in this period, due to the reliability, maintenance, ICT and resourcing issues noted above, only the one has consistently reported to GBON frequencies in at least 80% of these months.*

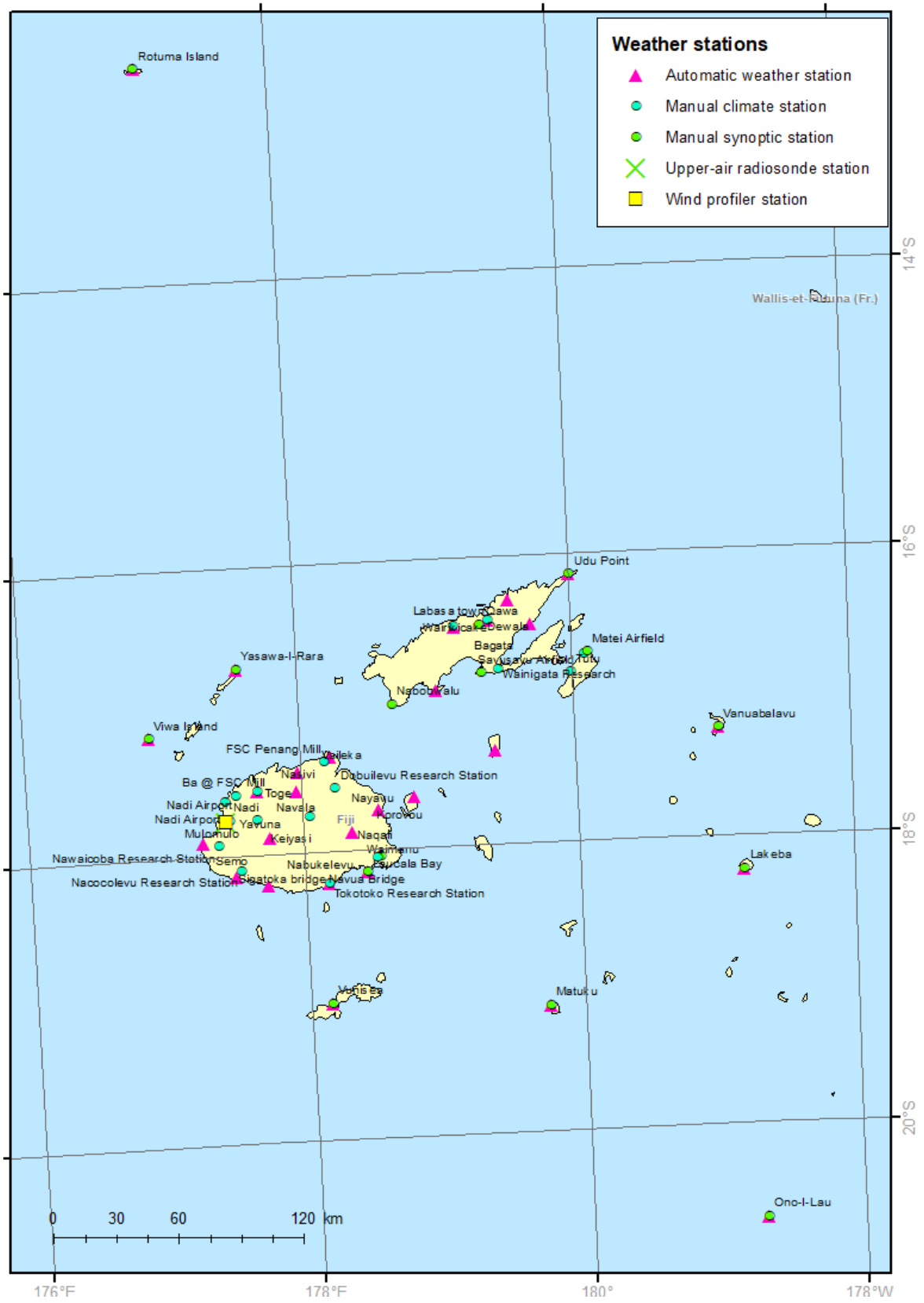

Figure 6 - Network of Fijian weather stations (excluding hydrometric and rainfall-only stations)

There is also a missed opportunity in that that many stations are not being transmitted on the Global Telecommunications System (GTS). Fiji has steep volcanic topography, and a greater network density of observations available would be very useful for current and future modelling of wind flow, convection, and topographic rainfall.

Figure 7 - An example Automatic Weather Station (AWS) and manual station setup (Rarawai Mill AWS, Ba, Viti Levu), recording rainfall, maximum and minimum air temperatures, wind speed and direction, solar radiation, humidity, station atmospheric pressure, and evaporation. The AWS is a typical installation by New Zealand's NIWA, with a tilting mast so that lofted parts can be serviced at ground level. A nearby hydrological station records river levels. Photo: Authors.

A closer examination of the network over key areas also shows physical gaps in real time observation capabilities, particularly in the interior. Figure 8 is a topographic view of Viti Levu, where the capital Suva is located (in the SE, where the rainfall is also the highest). The network density is not enough to capture rainfall and river levels in the remote interior, even if they were all reporting in real-time. This means that Fiji residents are still subject to 'surprises', particularly if rainfall has not been adequately detected on radar.

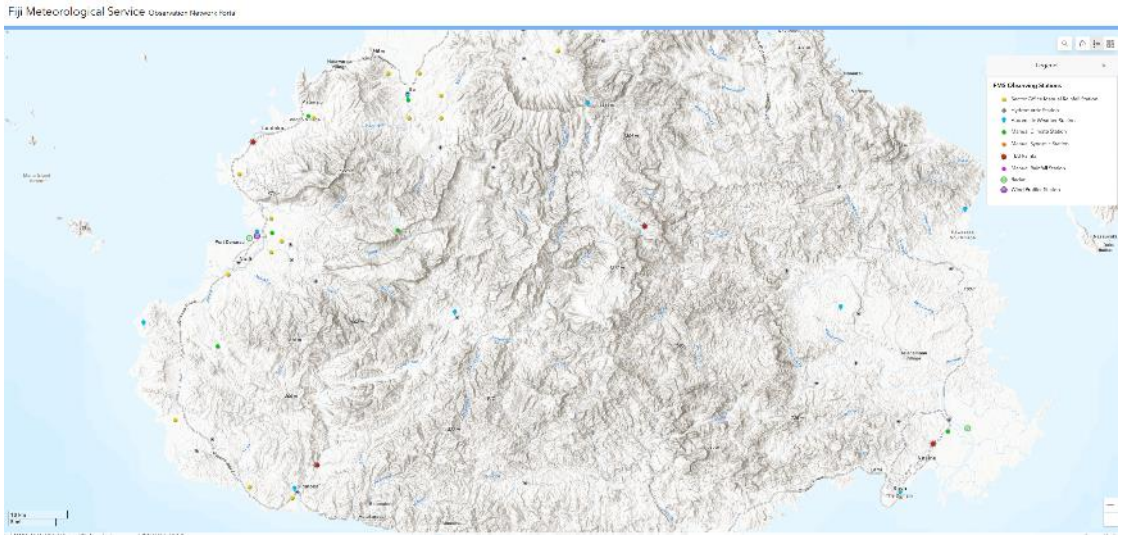

Figure 8 - Topographic view of Viti Levu, showing observations network. Courtesy FMS.

Although the upper air station at Nadi generally reports to GBON requirements, no upper air observations were being performed for a significant part of July-August 2023. Discussion with staff suggested that although this was a relatively unusual situation, it was not unique. The Nadi upper air station was therefore not assessed as GBON compliant. To meet GBON requirements, an additional upper air station is also recommended given the size of Fiji's EEZ, with Rotuma Island being a preferred location if feasible (Figure 6).

Very few upper air observations are currently performed in surrounding countries. In general terms, the upper air network over the region is quite inadequate and falls far short of GBON standards. Figure 9 shows an example for Monday 28 August 2023, with no upper air flights available for a swath of countries including Papua New Guinea, Solomon Islands, Vanuatu, New Caledonia, Fiji and Tonga, meaning that upper winds are essentially unconstrained through traditional observations in that region.

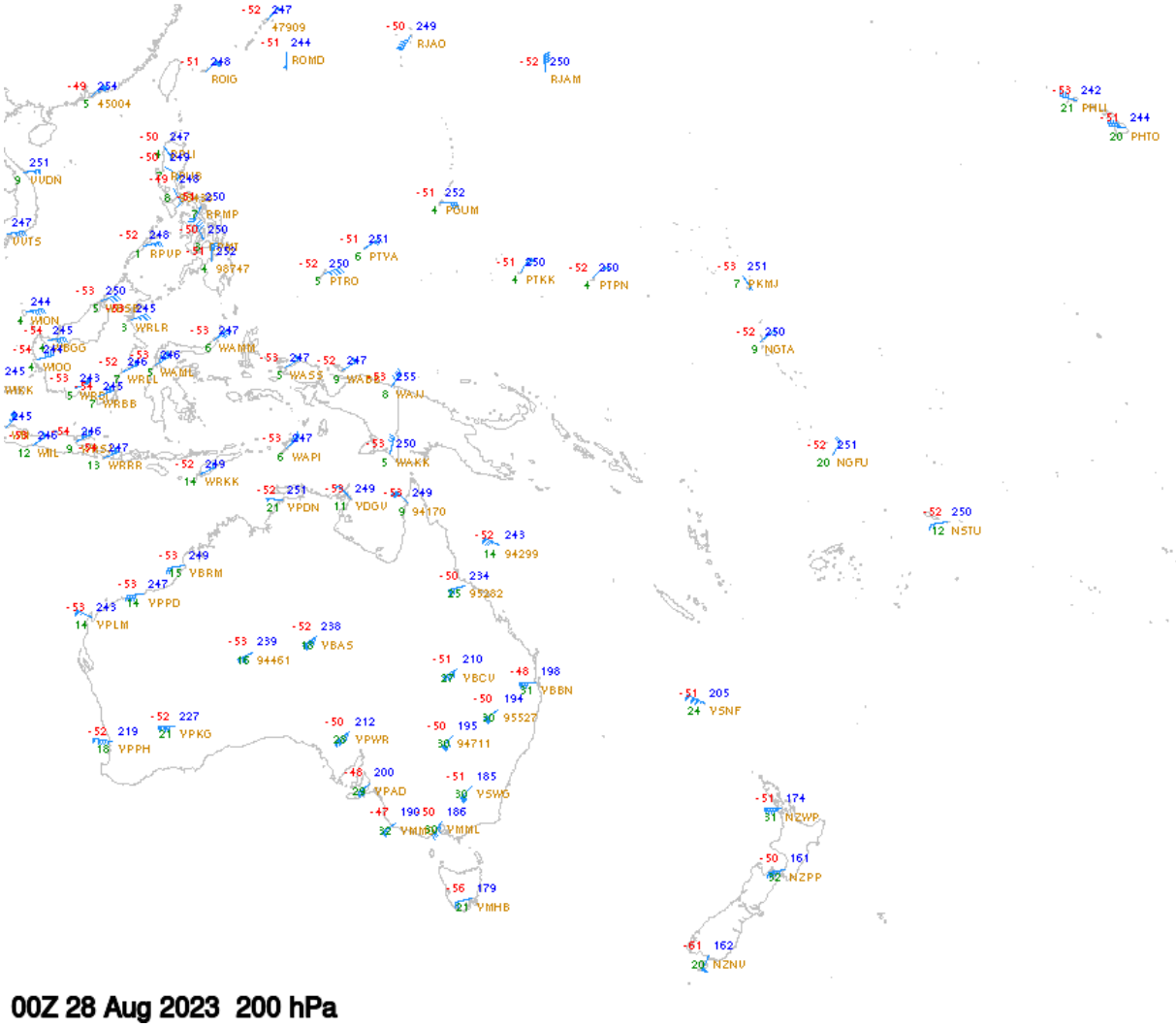

Figure 9 - 200 hPa upper air observations, 00 UTC, 28 August 2023 (coincident with project visit). The Nadi Upper Air Station was not operating for much of July and August 2023. Graphic courtesy University of Wyoming.

3.2. Additional observations used for nowcasting and specialized purposes.

Fiji has three weather radars, at Nadi, Nausori, and Labasa. At time of writing, only Nadi (upgraded in 2018) was operational, with Nausori (over 20 years old) due to be replaced later in 2023. Labasa is also over 20 years old. Weather radar lifespan can be extended

substantially through replacement of parts, but evolution of technology generally means that substantial benefits can be gained through replacement with new equipment at regular intervals.

The total surface network for Fiji consists of:

- 29 AWS
- 31 hydrometric stations
- 17 manual climate stations
- 33 manual rainfall stations
- 16 manual synoptic stations
- 8 TB3 rainfall stations

Four lightning detectors are located on Viti Levu, with the data received and processed at FMS headquarters in Nadi.

A wind profiler is installed at Nadi, sponsored by JICA.

FMS receives surprisingly few marine observations (and certainly insufficient for forecasting and verification purposes), from both local and international sources. Although local ship observations can be reported through coastal radio, it appears that in general, reports are not made or are not delivered to the forecasting centre. Inspection of the charts analysed by the duty meteorologists also showed many missing observations, including from sources thought to be reporting. This suggests a cumulative effect from gaps in observations transmission or receipt in the global system, where observations can be taken but not received by the end user through a combination of factors.

Discussions with the Maritime Safety Authority of Fiji during the project visit suggested that there may be an opportunity to mandate marine reporting through government owned or chartered vessels, which would help greatly in Fiji's EEZ area.

The observations discussed above are supplemented by satellite observations, principally from Japan's Himawari series of geostationary satellites, but also from polar-orbiting satellites with data collected (with a time-lag) through third party websites.

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

Fiji has relatively good maintenance and calibration facilities and standard operating procedures compared with most other countries in the region and is developing capacity towards becoming a regional instrument centre, with support from JICA. However, as noted in the 2019 Finnish Meteorological Institute report, FMS is currently constrained in its abilities to perform a full regional role due to some missing calibration equipment and relatively cramped facilities.

In terms of its ability to services and maintain its own stations, the review team observed many well-kept stations in Viti Levu, albeit with some minor issues present on several occasions. However, the situation on the outer islands is much more difficult, with the logistics and cost of travel making station maintenance a constant struggle for the small technical team. A detailed examination of Tropical Cyclone Harold (2020) noted that the AWS network for the outer islands was insufficient, including in frequency of reporting and maintenance, recommending that AWS stations should be installed in all

outer islands for frequent data reporting, and should be maintained to WMO standards, to accurately determine wind strength and rainfall.[8]

The FMS observations team keep proper station records on paper file and electronically.

FMS' ICT team is also relatively small for the number of systems that they support, and this impacts the ability of FMS to fully utilise available observations.

3.4 Implementation of sustainable newer approaches to observations.

A number of modern observational techniques are used in Fiji, including a wind profiler, many automatic weather stations, lightning detection, and radars. Most of these are donor-supported to a degree. The sustainability of some of these technologies may be open to debate, as the underlying equipment is expensive when compared to salaries for manual observations, and there are too many different brands of equipment under current use, which requires technicians to maintain a higher level of competence and also that different spare parts are held for different systems. This was also noted by the Finnish Meteorological Institute:

"The current situation with the observation station network is very unsustainable for FMS due to the high number of different observation station manufacturers. The sensors and stations are incompatible with each other, rendering both maintenance and data collection difficult and fragmented. For example, it is not possible to replace Sutron station instruments with Vaisala instruments, and thus the spare part pool is expensive to maintain. In addition, it increases the costs of staff technical expertise and time dealing with multiple vendors and multiple incompatible technical systems."[9]

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

Approximately 50% of the Fiji surface network observations have been automated. As staff observers' salaries are relatively low compared to the cost of automatic equipment (when compared to countries with higher wages), this may be appropriate.

Summary score, recommendations, and comments for Element 3

Fiji 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.

Table 4: CHD maturity ratings for Element 3

Element 3: Observational Infrastracture		Description: The level of compliance of the observational infrastructure and its data quality with prescribed WMO regulations and guidance.		
Level one: No or limited, basic surface observations and no upper-air observations.	Level two: Basic network, large gaps, mostly manual observations with severe challenges and data quality issues.	Level three: Moderate network with some gaps with respect to WMO regulations and guidance and with some data quality issues.	Level four: Comprehensive mostly automated network providing good traceable quality data fully compliant with WMO regulations and guidance.	Level five: Comprehensive and highly automated advanced network including additional measurements and remote sensing platforms providing excellent data fully compliant with WMO regulations and guidance.

There are some relatively straightforward actions that FMS can take to improve this maturity level further.

Outer island observations are important not just for the local communities, but in order to support analysis and forecasting for Fiji as a whole as well as the surrounding region.

[8] FMS, 2020, Preliminary Report, TC Harold

[9] Finnish Meteorological Institute, 2019, Fiji's Hydrometeorological Observation Equipment Maintenance and Service Production – a Roadmap of Actions.

FMS could consider how to improve the reliability and availability of these observations, including international availability.

Reducing the diversity of instrument types (for example, by placing restrictions on acceptance of donor equipment) is important for the sustainability of automation. Negotiating mandatory ship observations from Fiji Government owned vessels would likely assist with marine observations. Discussions within the budget process may be required to ensure that funding for upper air consumables is protected, if possible, in order to maintain a reliable record of upper air flights.

The 2019 Finnish Meteorological Institute report contains additional recommendations that should continue to be considered, along with the priority actions of the FMS Strategic Plan. The SOFF programme also offers strong opportunities for Fiji and surrounding countries to improve the observations network in the region.

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 WIGOS centres.

As noted in the previous section, Fiji was not assessed as meeting GBON compliance when considered over an extended assessment period of January-October 2023. Only one station (Nadi) was judged as compliant, giving 16% compliance when compared with the target of six stations. At time of the project visit, the single upper air station was not compliant, although it has since begun reporting again. In that sense, Fiji's upper air compliance is assessed as 0% in terms of stations that are fully compliant. To meet the recommended number of upper air stations for GBON requirements, another upper air station should be established.

Regional WIGOS centre arrangements are developing, with Fiji actively planning to play a role as a regional centre.

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

Fiji, as a WMO Member, participates in the global data sharing framework articulated by the WMO Unified Data Policy, including the free and open sharing of observational data. Twenty-eight surface stations are reporting meteorological data on the FMS website at time of writing.

Discussions with FMS staff suggested that they are actively planning to share more observations internationally, with the issues being around systems configuration and process workload rather than any policy barriers.

External stakeholder discussion also suggested a readiness to share observational data, although this does not always happen in practice.

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

FMS 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. Fiji is a participant in the Severe Weather Forecasting Programme[10] and receives professional guidance from RSMC Wellington on the MetConnect web portal, indicating areas of likely severe weather. This provides valuable data and guidance to forecasters in FMS in the daily forecast process. However, it is still very 'broad brush', and requires significant value-add from FMS.

FMS also receives data across the GTS including surface and upper air observations and numerical weather prediction (NWP) data from several global models including the JMA, GFS, ECMWF and UK models. This data is ingested into IBL Visual Weather, although at this stage the system is mostly used for satellite data display and needs further investment and training to become more operational.

FMS also has good Internet bandwidth, and the connection is considered stable.

[10] https://community.wmo.int/en/activity-areas/severe-weather-forecasting-programme-swfp

Summary score, recommendations, and comments for Element 4

Fiji is assessed as **Maturity Level 3** for this Element, expressed as 'Moderately well mandated, managed and resourced and clear plans for, and sufficient capacity to address operational gaps.'

Table 5: CHD maturity ratings for Element 4

Element 4: Data and Product Sharing and Policies		Description: The level of data and product sharing on a national, regional and global level.		
Level one: No observational data is shared internationally, either because not available to be shared or due to the lack of data sharing policies or practices, or the existing infrastructure does not allow data sharing.	Level two: 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.	Level three: Moderately well mandated, managed and resourced and clear plans for, and sufficient capacity to address operational gaps.	Level four: Fully meeting GBON data sharing compliance with a data policy and practices and infrastructure in place. These support free and open sharing of data nationally and, for some products, regionally or internationally as well as the in-house use of external data.	Level five: Exceeding GBON data sharing compliance and additional data (marine, radar, etc.) contributing to regional and international initiatives with policies that promote free and open two-way sharing of data and products

In order to meet the next higher maturity level (expressed as 'Fully meeting GBON data sharing compliance with a data policy and practices and infrastructure in place. These support free and open sharing of data nationally and, for some products, regionally or internationally as well as the in-house use of external data'), FMS could focus on processes to ensure that upper-air observations are available all-year around and continue to build its data sharing and management capabilities.

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.

FMS produces a suite of public and marine forecasts and warnings, including some products that assist neighbouring countries.

In support of this, FMS 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, although this is not fully configured. Most of these models are viewed as image files rather than gridded data. The models include ECMWF, GFS, UKMO, 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), Fijian topography is under-represented.

Ensemble products are available through the MetConnect site, based on global ensemble models.

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

In order to quality-manage model output and available observations, FMS meteorologists perform hand-drawn analysis (Figure 10), incorporating wind, pressure, satellite and rainfall observations from various sources to cross-check for consistency and refine their own meteorological understanding. This is an appropriate method for quality control, particularly in the moist tropics where subtle influences can be missed in model output and where observations deserve close scrutiny.

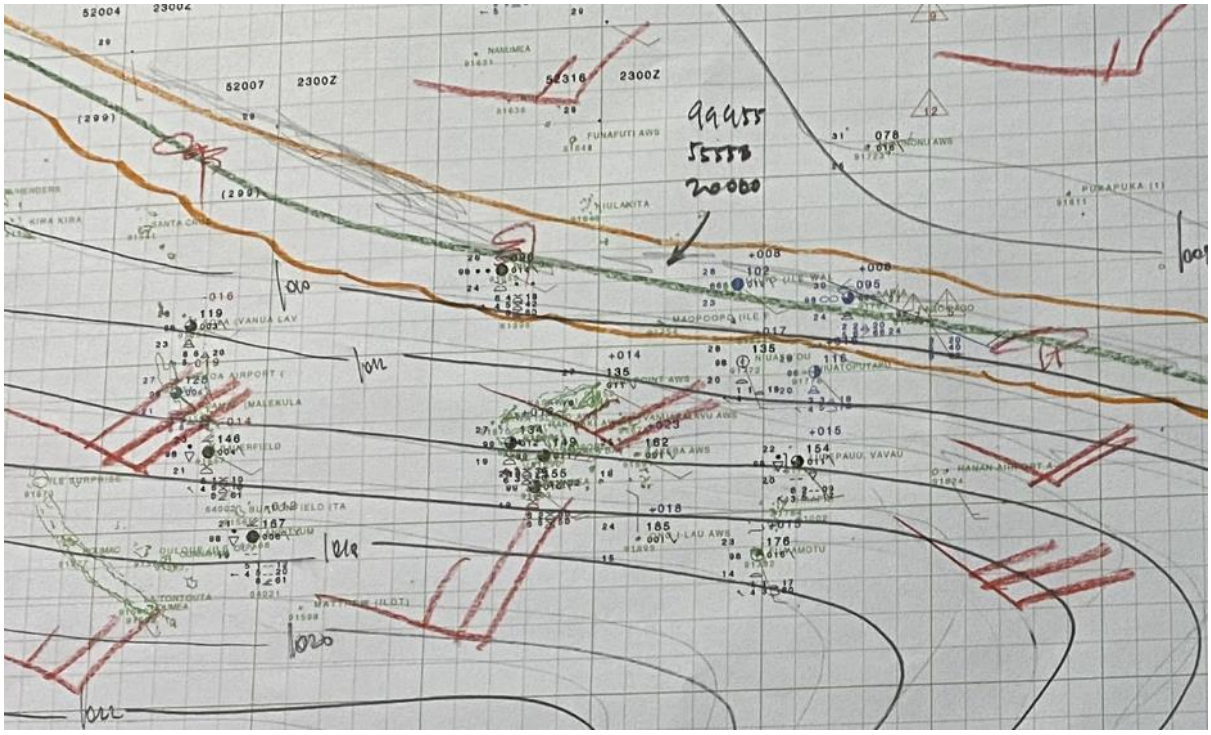

Figure 10 Detail from hand-drawn mean sea-level pressure analysis for 28 August 2023 with annotations and calculated gradient level winds from isobar spacing. This method is valuable for independent analysis of the meteorological situation and cross-checking of models and observations. Source: Authors, with kind permission of FMS

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

Figure 11 - Recently installed HPC server (Photo: authors)

FMS has recently installed a high-performance computing server (Figure 11) in order to permit the running of the Weather Research and Forecasting Model[11], in two configurations – a 9 km regional model (Figure 12), and a 3 km local model (non-convection resolving). ICT staff have received training, including a substantial training course at BMKG Indonesia's training facility in Citeko, Indonesia, and the project has been supported by CREWS in addition to the in-kind support from Indonesia. At this stage, no local data assimilation or verification is performed, and the model is not yet considered operational. At time of visiting, the model was not running due to some configuration issues. The High-Performance Computing (HPC) server is reported to be running well after installation through a local provider, although there is little spare capacity for more intensive computing tasks in the future.

Preliminary evaluation from FMS forecasters is that the WRF model gives comparable results to other models and will be welcomed when it becomes operational. Because the 3 km implementation is not convection-resolving, it will not necessarily identify convective developments of interest to forecasters and users, but it will better account for topography than the 9 km resolution models such as ECMWF.

However, concerns have been expressed that resourcing is not in place to maintain, develop, or verify the model operations.

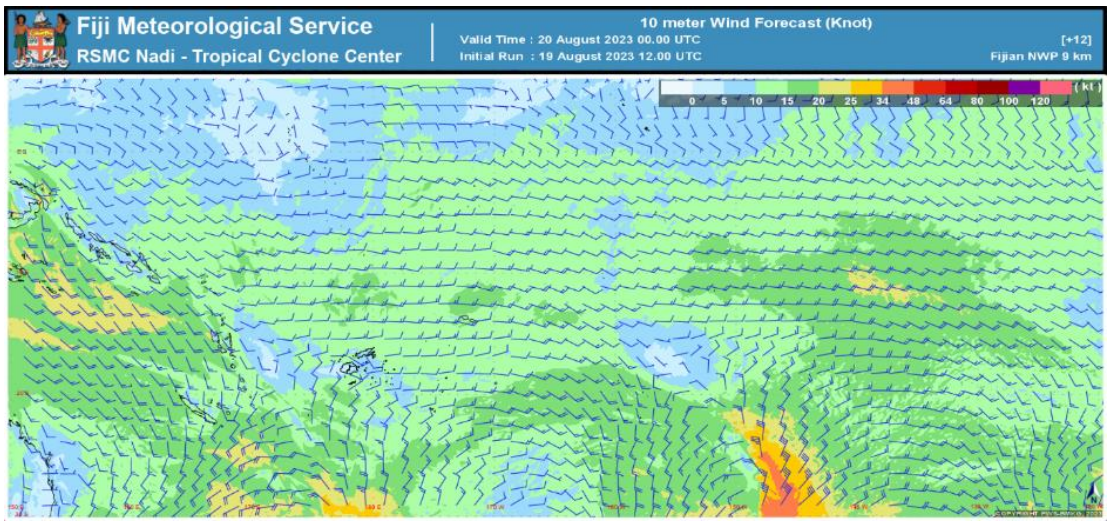

Figure 12 - Example of 9 km resolution output from WRF, regional domain

[11] https://ncar.ucar.edu/what-we-offer/models/weather-research-and-forecasting-model-wrf

Discussion on sustainable modelling approaches for FMS

WMO publishes Guidelines on High-resolution Numerical Weather Prediction[12] , 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 (EPS)

Level 6 – Regional coupled Earth system modelling or rapidly updated NWP

The Guidelines also note that *"for many NMHSs 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."*

A WMO expert mission examined Fiji's situation in 2018 and discussed possible options at length.

"In terms of NWP Local Area Model (LAM) capability, the mission team concluded that FMS/RSMC Nadi is currently at Level 1 - "Use of NWP products/EPS from global/regional centres" and it may gradually improve its capacity from Level 1 to Level 2 - "Best use of NWP/EPS products from global/regional NWP centres", and then further improve to move on to Level 3 –"Downscaling regional model implementation" which requires more skills and tools. The mission team recognized that FMS need to have access to NWP high resolution products including for potential NWP LAM implementation at FMS for its application in hydrology and flash flood forecasts and to improve its services for Fiji and Small Island Developing States in the sub-region. However, this will require strong commitment from FMS and the government of Fiji for provision of national resources, in addition to donors' support…

"The mission team developed a road map for FMS suggesting a set of recommendations and follow up actions for moving FMS from level 1 to level 3. To assist in this process NMHSs of Australia and Indonesia will run NWP LAM (i.e. ACCESS-Fiji and WRF-Fiji respectively) and provide data to FMS, and WMO through CREWS funding and with technical support from advanced NMHSs will arrange a training for FMS staff in Fiji to make best use of the global and regional NWP data in developing value added products by FMS and to gain sufficient experience including for NWP LAM data application in hydrology and flash flood forecasting during 2018-2020 before implementing NWP LAM at FMS during 2020-2021."[13]

The same report noted the resourcing requirements estimated for each Level, as shown in Table 6:

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

[13] WMO Joint Expert Mission to Fiji (20-25 May 2018), Final Report

Table 6 - Estimated requirements for difference sustainable levels of local NWP operation (WMO)

Levels/ Resources	**Minimum Human Resource**	**Computer Resource**	**Communication Network**	**Post Processing**	**Service & Products**
Level 1 – Use of NWP & EPS products, from NWP centres	NWP, Soft Engineer (SE): 1-2 full time experts (FTEs) ICT: 1-2 FTEs	Workstations	Broad enough to obtain graphical products.	None	Fundamental met. information to support forecasting operations and to provide guidance of severe weather.
Level 2 – Best use of NWP/EPS products from NWP centres	NWP: 2-3 FTEs SE: 1-2 FTEs ICT: 1-2 FTEs	Workstations	Broad enough to obtain global/regional NWP grid data sufficient for post-processing	Diagnostic variables Site-specific bias correction	Same as above
Level 3 – Downscaling regional model implementation	NWP: 3-5 FTEs SE: 1-2 FTEs ICT: 2-3 FTEs	HPC Cluster with performance to produce T+36 hour forecasts within two hours.	Broad enough to obtain NWP grid data for initial and boundary conditions within one hour.	In addition… Grid-point bias correction	Enhanced support to forecasting operations and services to users. Specialized customer products

These guidelines would suggest that, for local WRF implementation, *6-10 additional staff* would be required for FMS to sustainably operate the system to meet WMO guidelines, which are expressed in more detail in the WMO Manual on GDPFS (WMO-No. 485) and Guide on GDPFS (WMO-No. 305)[14]

To date, no extra staff have been acquired by FMS for these efforts, and staff have articulated that they are not able to sustain the workload of making and maintaining the model in operations.

Based on this, it is difficult to avoid the conclusion that the WRF implementation as it stands is unsustainable and will fail without a sustained injection of local resources. This would be unfortunate given the very positive efforts made so far, and the needs of the Fijian community for higher resolution modelling.

[14] Further detail on the Global Data Processing and Forecast System (GDPFS) , now renamed as the WMO Integrated Processing and Prediction System (WIPPS), can be found at https://community.wmo.int/en/activity-areas/wmo-integrated-processing-and-prediction-system-wipps

The issue is alluded to in the FMS Strategic Plan, alongside a note regarding difficulties of WRF implementation for convection-allowing modelling, and without a clear direction given resolve the sustainability issue of using WRF operationally.

In this context, it should be noted that the Weather Ready Pacific proposal[15] outlined a plan for additional investment in numerical prediction capacity in the Pacific, including 3 NWP modelling staff and 4 IT staff for that purpose for the combined Wellington, Nadi and Darwin RSMCs. These staff would not necessarily be located in FMS, but there might be an opportunity through the proposal to add to any support the Fijian Government is able to give.

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

Probabilistic forecasts are used in forecasting and climate prediction, sourced through global modelling centres. Generally, forecasts are expressed deterministically, but with probabilistic elements as appropriate (for example, for tropical cyclone maps or climate predictions). Ensembles are not produced locally.

Summary score, recommendations, and comments for Element 5

Fiji 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.'*

Table 7: CHD maturity ratings for Element 5

Element 5: Numerical Weather Prediction Model and Forecasting Tool Application		Description: The role of numerical weather prediction model output and other forecasting tools in product generation. Whether local modelling is sustainably used to add value to model output from WMO Global Data-processing and Forecasting System (GDPFS) centres.		
Level one: Forecasts are based on classical forecasting techniques without model guidance and only cover a limited forecast time range.	Level two: Basic use of external model output and remote sensed products in the form of maps and figures, covering only a limited forecast time range.	Level three: Prediction based mostly on model guidance from external and limited internal sources (without data assimilation) and remoted sensed products in the form of maps, figures and digital data and cover nowcasting, short and medium forecast time ranges.	Level four: 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.	Level five: Optimal combination of global, regional and local models, remote sensed data, post-processing techniques and automated probabilistic product generation over weather and climate time scales with minimal human intervention supported by up-to-date verification statistics.

The key issues for FMS here are around the sustainability of the WRF pathway. At the moment, it is not clear that the implementation of WRF will unambiguously succeed. In the absence of additional funding, it might be better to divert the resources currently devoted to the WRF implementation to other workstreams that will realise NWP benefits, such as further progressing the IBL Visual Weather implementation so that forecasters can work with global model data more effectively. On the other hand, further investment, including from the Fijian Government, could lead to an operationally successful WRF implementation, which would be a major step forward for FMS.

A related issue for further consideration for FMS might be around improved investment and cooperative arrangements with the other RSMCs in the region (Wellington, Darwin, Melbourne) and World Meteorological Centre Melbourne, particularly around the possibility of convection-allowing modelling for Fiji.

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

Element 6: Warning and advisory services

6.1. Warning and alert service cover 24/7.

Warning and advisory services do cover 24/7 operations. FMS is relatively well staffed for forecasters compared to many Southwest Pacific countries, and also has one media officer in support of communication strategies. As in any country, the readiness of the population to receive and act on warnings varies with the hour and day, for which reason, advance warning is important where at all possible.

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

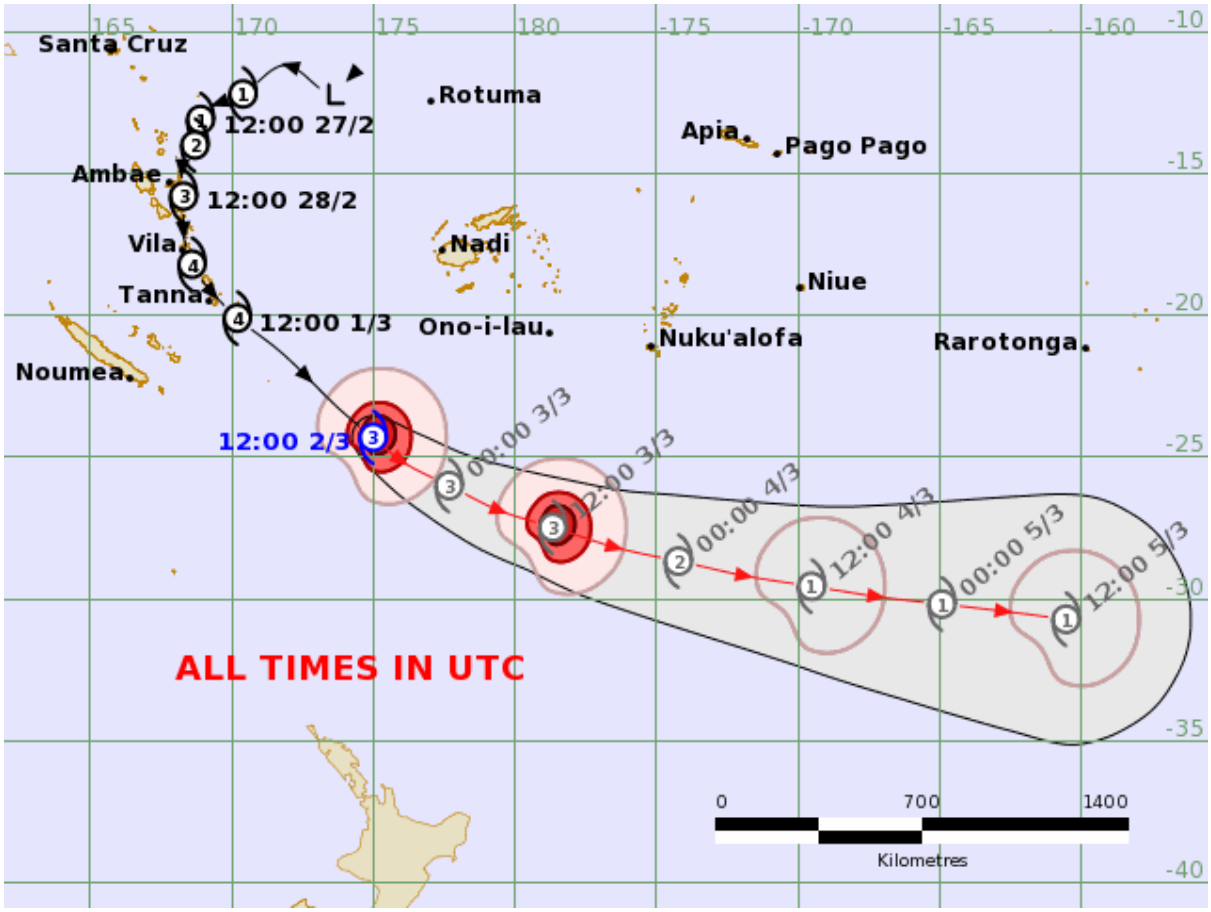

Figure 13 - FMS produces tropical cyclone warnings using the Australian-provided Tropical Cyclone Module, which provides ensemble based threat areas for the future path of the system. Image: FMS, for Severe Tropical Cyclone Judy in March 2023 (graphic legend not shown here).

Services are available for storm surges and coastal floods, fog, drought wind, volcanic ash (for aviation purposes), tropical cyclones (Figure 13), thunderstorms, marine warnings, rain, lightning, hail, riverine and flash flooding. Tsunami (a mixed geological / hydrometeorological hazard) and earthquake (a geohazard) information is issued from the Ministry of Lands and Mineral Resources. The 2022 eruption of Hunga Tonga-Hunga Ha'apai in Tonga showed the challenges of coordinating warnings for joint hydromet-geohazard events[16], and further development is needed in that area. Landslide early

[16] https://earthjournalism.net/stories/i-thought-there-was-a-war-happening-a-fijian-perspective-on-the-tonga-volcanic-eruption-and

warnings (also a multi-disciplinary hazard) are currently inadequate, which is a concern given Fiji's steep topography.[17]

Tropical cyclone is a specialist area for Fiji given that FMS also has an RSMC role in the region for providing advisory information for other countries. Tropical Cyclone warnings are created using the Tropical Cyclone Module developed by the Australian Bureau of Meteorology, which is widely used through the region.

Post event reports are prepared for major events. Examination of reports provided to the Severe Weather Forecasting Program shows reflective reports for heavy rain, tornado, large waves and tropical cyclone events, with lessons learned and recommendations (particularly in terms of observations, forecasting and warnings) given on occasion. Input from external stakeholders is not necessarily sought for every event, but major events are carefully post-analysed.

Fiji regularly hosts training events for other countries in the region, which also advantages their own staff as it improves their own ability to attend training.

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.

Warnings are generally issued in plain text format, accompanied by media and social media support where possible. Common Alerting Protocol (CAP) format warnings are not yet implemented. Standard operating procedures are used.

Impact-based warnings are not formally implemented, although FMS and other agencies are moving in that direction (as expressed in their Strategic Vision), including through a 'Weather Ready Nation' workshop in August 2023, following an earlier workshop in November 2022. This activity has been supported by the US National Weather Service International Activities Office and the U.S. Agency for International Development/Bureau for Humanitarian Assistance. In addition, FMS staff already informally take impact and vulnerabilities into account in their communications strategies and policy making.

Summary score, recommendations, and comments for Element 6

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

[17] Ram, Arishma & Stephens, Mark & Brook, Martin & Cronin, Shane. (2019). Landslide Early Warning System in Fiji: Prospects and Challenges. AOGS 16th Annual Meeting, 28 Jul to 2 Aug, 2019 At: Singapore

Table 8: CHD maturity ratings for Element 6

Element 6: Warning and Advisory Services		Description: NMHS' role as the authoritative voice for weather-related warnings and its operational relationship with disaster and water management structures.		
Level one: Warning service not operational for public preparedness and response.	Level two: Basic warning service is in place and operational but with limited public reach and lacking integration with other relevant institutions and services.	Level three: Weather-related warning service with modest public reach and informal engagement with relevant institutions, including disaster management agencies.	Level four: Weather-related warning service with strong public reach and standard operational procedures driving close partnership with relevant institutions, including disaster management agencies.	Level five: Comprehensive, impact-based warning service taking hazard, exposure and vulnerability information into account, with strong public reach. It operates in close partnership with relevant national institutions, including disaster management agencies and registered Common Alerting Protocol alerting authorities.

The actions outlined in the FMS' strategic plan will further improve this maturity level. It will be important to continue the impact-based forecasting journey in close partnership with other key agencies such as the National Disaster Management Office, to continue to improve community engagement, including through media and social media strategies, and also to work with the Ministry of Lands and Mineral Resources to further enhance the seamless multi-hazard approach for geohazard and hydrometeorological warning services.

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.

In terms of *Governance*, Fiji has a **Full** rating due to the overall strong climate services presence and involvement in government processes, with an impressive degree of community and stakeholder engagement. The Climate Services Division participate strongly in the Climate and Oceans Support Program in the Pacific (COSPPac), which supports climate database management (through Climate Data for the Environment (CliDE) software[18]), analysis and forecast products, and user interactions. As noted in the FMI analysis:

"The climate services produce different kinds of analysis and products from the observations as well as seasonal or climate forecast products either regularly or on demand. The product portfolio is rather comprehensive, and the main products are updated regularly and disseminated via the website http://www.met.gov.fj/index.php?page=climatedatalatest , which is publicly accessible. The products may consist of different elements such as text, analysis maps, tables, graphs etc. These are not limited to discussing or displaying strictly the weather or climate; some of them also include climate impact analysis, which is standard practice for modern climate services."[19]

FMS is included in national governance mechanisms to a large extent, and leads much of the relevant national discussion, including through the annual National Climate Outlook Forum, which has been held since 2018. Each Forum has been well documented, including with user feedback on forum content and format.

FMS' *basic systems* for monitoring climate are not as strong, and an **Essential** rating is given. The climate services team would prefer to have more functionality than what is currently available to them. Quality control is a manual process. The state of Fiji's observations network, including supporting infrastructure and ICT capacity, is also a concern for Fiji's national climate record, and results in a weakness in climate data provision (also noted in the FMI report), offset to some extent by the use of CliDE, which although an imperfect tool in terms of FMS' complete climate data management needs, has many useful features. Fiji have negotiated with the CliDE development team for additional CliDE functionality, such as ingestion of volunteer climate station data through an FMS-developed interface.

A concerning situation is the current state of FMS' data-rescue project, in which approximately 270,000 historical documents have been scanned over five years, but FMS has no current access to these documents due to software issues. This needs to be resolved as soon as possible.

For the *user interface and climate services* aspects of FMS climate operations, a **Full** rating is given.

[18] http://www.bom.gov.au/climate/pacific/about-clide.shtml

[19] Finnish Meteorological Institute, 2019, Fiji's Hydrometeorological Observation Equipment Maintenance and Service Production – a Roadmap of Actions.

The products produced include:

- Climate Outlook (covering the next six months)
- Climate Summary (a concise summary of recent conditions
- Sugar Outlook (targeted at helping the sugar industry)
- Monasavu Outlook (for hydro-electric generation)
- ENSO Outlook (a discussion of climate drivers)
- Annual Climate Summary (a summary of the past year's climate)
- Early Action Rainfall Watch (for the Fiji National Disaster Management Office and others)
- Fiji Ocean Outlook (focusing on ocean conditions, including coral bleaching and other parameters)
- South Pacific Tide-Calendars (provided through Australia)
- Fire Danger Class (current fire dangers)
- Days Without Rain (a simply measure of the length of dry spells)
- Rainfall Amount Last 30 Days (recent cumulative rainfall, with a quality control marker to show missing data)

In support of these products, FMS use a range of inputs including the ACCESS-S model from the Bureau of Meteorology in Australia, along with statistical methods, expert discussion from other countries, and their own expertise. An audit of products on FMS' external website showed that nearly all were up to date, with a possible issue around the Days Without Rain product not showing any data. User satisfaction surveys are conducted.

The *monitoring of social-economic benefits* of the product set is less well developed than the product set itself, with no quantitative assessment performed, but user feedback is regularly collected. Recent (2021) interviews with sugar industry show a range of feedback, validating the importance of sugar industry products but giving many suggestions for improvements in products, training and communications[20]. Feedback from the Ministry for Fisheries indicates that the Fiji Ocean Outlook, including coral bleaching information, is very helpful. FMS is rated as **Full** for this area.

FMS works collaboratively and productively with donors and other countries in the region to assist with regional capacity building, as well as with in-country users as described above. FMS is also rated as **Full** for this area of activity.

Summary score, recommendations, and comments for Element 7

Based on all of the information available, Fiji's contribution to climate services is rated as a **Maturity Level 4,** expressed as 'Full Capacity for Climate Services Provision'. This rating reflects the degree of user engagement and the range of services provided by FMS.

Table 9: CHD maturity ratings for Element 7

Element 7: Contribution to Climate Services		Description: NMHS role in and contribution to a national climate framework according to the established climate services provision capacity.		
Not Applicable: Climate Services provided by another party Level one: Less than basic Capacity to provide Climate Services	Level two: Basic Capacity for Climate Services Provision	Level three: Essential Capacity for Climate Services Provision	Level four: Full Capacity for Climate Services Provision	Level five: Advanced Capacity for Climate Services Provision

[20] FMS and partners, 2021, 'Better use of climate information at a community level – case study for the sugar industry in Fiji.

This relatively high rating does not mean that action on high priority issues is not required. Further improvement can be gained by resolving the data-rescue issue and any related database problems, alongside the more public-facing actions outlined in the FMS Strategic Plan.

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.

Flash floods and riverine floods ranks as the second and third-most important natural hazards in Fiji, following tropical cyclones. FMS is responsible for flood forecasting following a 2012 merger, and has a well-functioning hydrological team with a network of river height gauges and rainfall stations, which are part of the wider FMS network. Qualitative rainfall alerts are given by the forecasting team, and then threshold-based warnings issued to communities when river heights reach defined levels. Radar information is used to supplement the surface-based observations network where possible.

Forecasters are unable to provide sufficiently precise quantitative precipitation estimation and forecasts, due to the combined effect of Fiji's topographic and convective-driven rainfall, insufficient network resolution, and insufficient numerical prediction resolution and model forecasting skill. This is not at all unusual in similar situations.

River height rise is not modelled. This, together with quantitative rainfall estimation, is the next priority step for improving flood warning services.

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

FMS is responsible for operational flood warning in Fiji and has flood warning procedures, with the operational value chain covered mainly within FMS operations until the point of community engagement and response. Other agencies (for example the National Disaster Management Office and community-based organisations) are involved with warning response in particular, and FMS works actively with these agencies.

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

Data is shared openly between agencies, including the Ministry of Waterways and the Mineral Resources Department. Memorandum of Understanding arrangements are under development with the Water Authority of Fiji.

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

FMS continues to work with other agencies and community groups involved in water matters. A significant project in 2018 under the CREWS initiative developed the Fiji Flash Flood Guidance System (FFGS). Currently, FMS is involved in the Nadi Flood alleviation project, which will develop flood models and assessments of watershed conditions in the upper Nadi catchments. The Australian Water Partnership is also underway, with the Pacific Community (SPC) involved in various activities to improve flood warning services. This includes project work to improve stream gauging, exploring remote camera approaches amongst other activities. This project work will be complete in 2024.

Summary score, recommendations, and comments for Element 8

Fiji is assessed as **Maturity Level 4** for this Element. The Country Hydromet Diagnostics template expresses this as *'The meteorological, hydrological and water resources sectors*

have a high-level formal agreement in place and an established working relationship and data sharing take place, but institutions still tend to develop products and services in isolation.'

Table 10: CHD maturity ratings for Element 8

Element 8: Contribution to Hydrology		Description: NMHS role in and contribution to hydrological services according to mandate and country requirements.		
Level one: No or very little meteorological input in hydrology and water resource management.	Level two: Meteorological input in hydrology and water resource management happens on an ad hoc basis and or during times of disaster	Level three: There is a moderately well-functioning relationship between the meteorological, hydrological and water resources communities but considerable room for formalizing the relationship and SOPs.	Level four: The meteorological, hydrological and water resources sectors have a high-level formal agreement in place and an established working relationship and data sharing take place, but institutions still tend to develop products and services in isolation.	Level five: The meteorological, hydrological and water resources sectors have robust SOPs and agreements in place to work closely in developing new and improved products and providing seamless and advanced services.

This full description is not strictly applicable in Fiji, but the rating is the most appropriate of the ratings available. The rating reflects that flood warning services and relationships are quite well developed but there are barriers to further flood warning system improvement without the leap to quantitative rainfall estimation and flood modelling.

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?).

FMS uses many channels for communication, including simple 'Green screen' videos (Figure 14) issued on social media, television, radio, newspapers, email, and SMS. Unusually, FMS employs a qualified journalist to help drive engagement, who does the bulk of the day-to-day work.

The communications approach has developed strongly in recent years, with support from FMS partners and donors. Communication during major events may need further improvement, with FMS' Nadi location making joint national press conferences and 'joined at the hip' type engagement with disaster management authorities more difficult. Training in media presentation also needs further reinforcement with some staff, given that it is a sometimes a difficult skill to learn, including for those from a more scientific or technical background.

Social media engagement in Fiji has improved following recent efforts, with 140K followers on the FMS Facebook page and much interaction with social media posts.

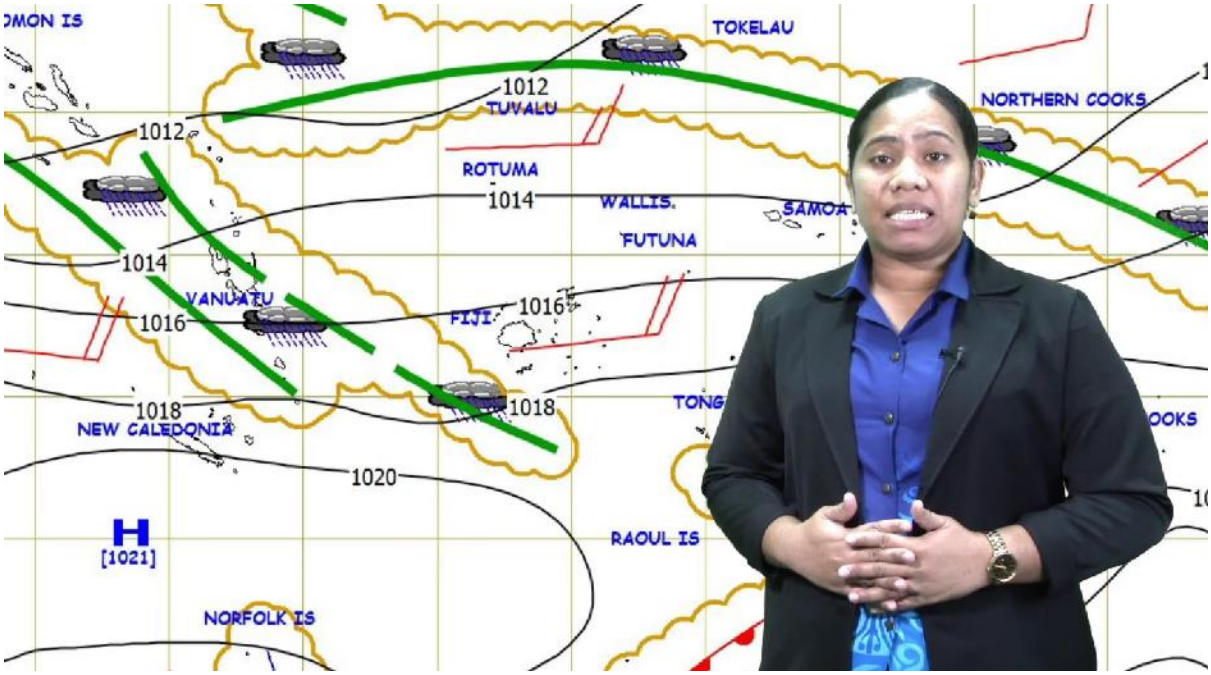

Figure 14 - example of simple 'green screen' video produced at FMS headquarters and distributed via social media, September 2023 (courtesy FMS).

9.2. Education and awareness initiatives in place.

FMS engages with schools and communities where possible, including hosting many school visits (Figure 15), participating in broader initiatives such as climate and weather education, and through social media. The FMS website includes educational videos and brochures on weather and related topics. FMS staff on outer islands also engage with the community as respected community members.

The FMI report notes that FMS' customer liaison activities are currently fragmented between sections. This is likely to also be affecting the unity of education and awareness

initiatives, which can be segmented when specialist staff focus on their area alone instead of the total message.

Figure 15 - School visit to FMS (courtesy FMS)

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

Traditional weather knowledge is respected, and FMS makes efforts to engage with it, particularly through climate programs and supported by organisations such as COSPPac and the Pacific Community. For example, the Pacific Community support included *'field missions to connect with communities and to understand the gaps and success in communicating weather information, training on digital communications, the redevelopment of Fiji MET Services brand online and the development of an FMS communications strategy'*. [21]

Reaching the outer island communities is probably the most challenging in terms of communication for FMS, due to poorer communications networks and isolation. According to FMS staff, portions of the community (for example mariners, traditional farmers) are also likely to be more resistant to including modern techniques in their decision-making processes. However, these communities are also likely to hold deep traditional knowledge, and so there are good opportunities to enhance overall outcomes by bringing traditional knowledge and more recent techniques together.

Summary score, recommendations, and comments for Element 9

Based on the evidence available, Fiji is assessed as **Maturity Level 3:** expressed in the CHD guidelines as 'a *moderately effective communication and dissemination strategy and practices are in place, based only on in- house capabilities and supported by user-friendly website.'*

Table 11: CHD maturity ratings for Element 9

Element 9: Product Dissemination and Outreach		Description: The level of effectiveness of the NMHS in reaching all public and private sector users and stakeholders.		
Level one: Dissemination using only limited traditional channels such as daily newspapers and the national broadcaster and with little control over messaging and/or format.	Level two: Traditional communication channels and a basic dedicated website is used to disseminate forecasts and basic information.	Level three: A moderately effective communication and dissemination strategy and practices are in place, based only on in- house capabilities and supported by user-friendly website.	Level four: 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.	Level five: Advanced education, awareness and communication strategy, practices and platforms in place using various technologies tailored to reach even marginalized communities and in close cooperation with several partners.

[21] https://www.spc.int/updates/blog/blog/2023/02/reshaping-weather-information-for-communities-in-fiji-0

Further improvement to this maturity rating can come from developing a stronger joint communication approach in severe weather with other key agencies, and continuing to develop media strategies and measures to reach vulnerable communities.

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.

Fiji does not have a single unified platform. The closest to this platform is the annual climate outlook forum, which chooses focus areas to explore different services and impacts.

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

Independent user satisfaction surveys are not conducted. However, user feedback, including community feedback during engagement activities, social media comment, and key user comment, is used to inform service improvement, most notably for climate services where the process appears to be more formalised than for other areas. The results of user consultations (as discussed above) are also used to guide service improvements.

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

Fiji has climate and aviation services certified to ISO 9001:2015. There is a general intent to continue to certify FMS operations areas, including for public weather services (including warnings), hydrology and marine services. However, the Quality Management Section has only one staff member, there is little discussion of quality management in the Strategic Plan, and without external support it is difficult to see how this will be progressed quickly.

Many FMS observations and products are verified for their formatting and timeliness, through a manually intensive process as there is little automated error-checking available in product preparation systems. Results are reported monthly and corrective measures taken. There is however no verification of accuracy of routine forecasts due to a lack of resources and observations, so accuracy-based service improvements are limited to consideration of special cases such as severe weather events where careful evaluations may be made.

Summary score, recommendations, and comments for Element 10

Based on the information available, Fiji is assessed as **Maturity Level 3** for this Element, reflecting *'Services development draws on regular dialogue with major stakeholders.*

Table 12: CHD maturity ratings for Element 10

Element 10: Use and National Value of Products and Services			Description: Accommodation of public and private sector users and stakeholders in the service offering and its continuous improvement.	
Level one: Service development lacks any routine stakeholder feedback practice.	Level two: Service development draws on informal stakeholder input and feedback.	Level three: Services development draws on regular dialogue with major stakeholders.	Level four: Service development draws on survey data and regular dialogue based on formal relationships with major stakeholders to ensure continuous improvement.	Level five: Strong partnerships, formal and objective survey and review processes exist with all major stakeholders enabling service co-design and continuous Improvement.

Further improvement to the maturity level in this area can be obtained through building formal, national consultations around non-climate issues, regular high-level engagement with key agencies and stakeholders, implementation of independent user-satisfaction surveys, and more priority given to quality management processes.

Annex 1 Consultations (including experts and stakeholder consultations)

The CHD process initially drew heavily on other recent consultation reports provided by FMS, and was followed by a week in-country with in-person discussions. At the time of visit, Fiji had just had weeks of intensive meteorological discussions with the hosting of the Pacific Meteorological Council and also a Weather Ready Nation consultation meeting. In order to reduce the load on stakeholders, external meetings were limited to areas where extra detail was required. Particular thanks are extended to the Fiji Maritime Safety Authority for additional perspectives on marine observations and safety (Capt. Sesoni Komaisoso, Officer in Charge, Capt. Viliame Kotobalavu, Deck Surveyor, and Ms. Miriama Latianara, Legal Officer), and also to Cpt Rufus D'Cruz for his personal insights.

Annex 2 Urgent needs reported

No urgent needs were reported, although many important issues were raised for discussion. These are reflected in the report.

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

FMS and partners, 2021, 'Better use of climate information at a community level – case study for the sugar industry in Fiji.

Fiji Meteorological Service reports for Severe Weather Forecast Demonstration Project:

- 5-7 Dec 2020 – Heavy rainfall
- 8 April 2020 – Tornado event
- 20-22 November 2020 – Heavy rainfall
- 22 January 2021 – Large waves
- April 2020 – Tropical Cyclone (TC) Harold Preliminary Report
- December 2020 – TC Yasa
- February 2021 – TC Ana

Fiji Meteorological Service, 2019-2022 National Climate Outlook Forum reports

Fiji Meteorological Service, 2021 Strategic Plan 2021-24

Fiji National Tsunami Warning Centre, 2022 Post Event Brief 3, Update of the Hunga-Ha'apai Tonga Eruption Event and Tsunami.

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

Finnish Meteorological Institute, 2019, Fiji's Hydrometeorological Observation Equipment Maintenance and Service Production – a Roadmap of Actions.

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

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

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

Ram, Arishma & Stephens, Mark & Brook, Martin & Cronin, Shane. (2019). Landslide Early Warning System in Fiji: Prospects and Challenges. AOGS 16th Annual Meeting, 28 Jul to 2 Aug 2019 At: Singapore

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

WMO Joint Expert Mission to Fiji (20-25 May 2018), Final Report