Guidance Document

Standardisation, Optimisation and Maintenance of Earth Observation Equipment in the Pacific Islands

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Prepared for Weather Ready Pacific (WRP) Programme

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Executive Summary

Pacific Island Countries and Territories face some of the world's highest exposure to severe weather, ocean, and hydrological hazards. Reliable Earth observation networks are essential for early warnings, climate monitoring, and informed decision-making. However, many Pacific National Meteorological and Hydrological Services (NMHSs) operate with fragmented, ageing, or unsustainable observation systems, constrained by limited budgets, small technical teams, and complex logistics.

The Weather Ready Pacific (WRP) Programme provides a decade-long, region-wide framework to strengthen multi-hazard early warning systems. This *Guidance Document on the Standardisation, Optimisation and Maintenance of Earth Observation Equipment in the Pacific Islands* directly supports WRP's strategic goals by providing the technical and operational framework needed to design, procure, operate, and sustain observation networks that are fit-for-purpose, regionally interoperable, and financially sustainable.

The Need for a Unified Approach

Historically, observation investments across the Pacific have been project-driven, leading to incompatible systems, data silos, and unsustainable maintenance burdens. Without coordinated guidance, future investments risk duplication, stranded assets, and missed opportunities for regional collaboration.

This document addresses these risks by promoting a whole-of-system, lifecycle approach, from strategic planning and procurement through to data sharing, maintenance, and eventual renewal. It ensures that national and regional investments contribute to a cohesive, resilient Pacific observation network.

A Tiered, Pragmatic Framework

Recognising that not all stations serve the same purpose, this guide introduces a three-tiered system for observation infrastructure:

- Tier 1: High-accuracy reference stations for long-term monitoring.
- Tier 2: Operational stations for real-time forecasting and warnings.
- Tier 3: Cost-effective systems for targeted, high-impact applications.

This framework allows NMHSs to match infrastructure to need, optimising resources while ensuring data quality and regional compatibility.

Key Challenges Addressed

Through regional consultation and expert input, this guide tackles persistent barriers to sustainable observation networks:

- Fragmented procurement and incompatible technologies
- Limited long-term funding for operations and maintenance
- Gaps in technical capacity and training pathways
- Weak integration of observations into forecasting and warning systems
- Logistical and environmental challenges in remote and coastal sites

Strategic Outcomes

By adopting this guidance, Pacific NMHSs and partners will be better positioned to achieve:

- **Interoperability:** Data that flows seamlessly across national, regional, and global systems.
- **Sustainability:** Networks supported by realistic budgeting, spare parts strategies, and lifecycle planning.
- **Capacity:** A skilled, confident workforce trained by recognising capacity development as a core component of any observation system.
- **Service Delivery:** Observations that directly improve forecasts, warnings, and sectoral decision-making.
- **Resilience:** Infrastructure designed to withstand Pacific environmental conditions.

Core Tools and Resources

The guide is supported by a practical Procurement Toolkit, including ready-to-use templates, evaluation criteria, and a strong recommendation for "Supply & Support" contracting models to ensure ongoing technical assistance, spare parts, and calibration.

It aligns fully with WMO standards (WIGOS, GBON, RBON), the WMO Unified Data Policy, and regional initiatives such as Early Warnings for All and the Systematic Observations Financing Facility (SOFF).

A Call to Action

This document is a foundational instrument for regional cooperation. By working together, through shared procurement, training, maintenance, and data exchange, Pacific NMHSs can build observation networks that are greater than the sum of their parts: resilient, sustainable, and ready to meet the challenges of tomorrow.

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1 Introduction

This Guidance Document aims to provide **Pacific National Meteorological and Hydrological Services** (NMHSs) and **regional agencies** a unified guide to help countries and partners coordinate the identification, design, procurement, installation, maintenance, and data management options for observing networks, in a way that is technically robust, regionally compatible, and sustainable.

It is a resource to support the structured enhancement and development of modern, fit for purpose hydro-meteorological data collection networks and infrastructure, and associated Infrastructure, Communications and Technology (ICT) systems, for the Pacific.

1.1 Background

In 2021, Pacific Leaders endorsed the proposed Weather Ready Pacific (WRP) Decadal Programme of Investment, which aims to reduce the human and economic costs of severe weather, water, and ocean events by strengthening NMHSs and their partnerships with disaster management organisations.

A key component of the WRP investment strategy is to provide access to the information and resources necessary to ensure that Pacific Island Countries and Territories (PICTs) can actively participate in and benefit from global advances in early warning technologies, contribute to improved forecast Uncertainty, geographic specificity, and lead times for global and regional systems.

The ambitions of WRP are closely aligned with complementary international and regional initiatives, including:

- the UN's Early Warnings for All (EW4ALL) initiative [2] ,
- the Systematic Observations Financing Facility (SOFF) [3] which supports Global Basic Observation Network (GBON) implementation and sustained observation networks
- the Intra-ACP Climate Services and Related Applications (CLIMSA) Program [4] supporting capacity development and climate services delivery, and
- the Climate and Oceans Support Program in the Pacific (COSPPac) [5] which has provided foundational support for ocean, tide, and climate monitoring across the region.

Collectively, these initiatives will benefit from streamlined, consistent, and regionally owned guidance that promotes interoperability, sustainability, and maximises the value of investments made at national and regional scales.

1.2 Guidance Objectives

1. Provide agreed regional guidance on the standards and principles for optimal meteorological, hydrological, and ocean observing networks and infrastructure, that is consistent with the range of station typologies that an NMHS may support to deliver its national needs.

2. Support regional and national planning, procurement, and maintenance of observation and ICT systems.

3. Wherever practical, promote interoperability principles, data sharing, and alignment with World Meteorological Organization's (WMO) Unified Data Policy [6].

4. Ensure sustainability by addressing total cost of ownership, regional capacity building, standardised spare parts, and lifecycle support.

5. Contribute to national and regional implementation roadmaps, including SOFF and other development partner investments.

1.3 Approach

This document will focus on observation systems for:

- Atmospheric (surface and upper-air), marine, freshwater, and land-based environmental variables.
- Supporting data management ICT and telemetry infrastructure.
- Calibration, maintenance, and lifecycle management systems.

1.3.1 Methodology and Stakeholder Engagement

This Guidance Document was developed using a structured and participatory process, aimed at producing technically sound, regionally relevant, and operationally practical guidance for PICTs. The methodology acknowledges the diverse operational environments, capacities, and priorities of Pacific NMHSs, and was designed to be inclusive and responsive to their specific needs.

The development process included:

- A comprehensive review and synthesis of existing international and regional standards and frameworks, including the WMO Guide to Instruments and Methods of Observation (WMO-No. 8) [1], WMO Integrated Global Observing System (WIGOS) guidelines [7, 8], National Environmental Monitoring Standards (NEMS) [9-13] from New Zealand, and relevant regional strategies.
- Stakeholder consultations through workshops and technical discussions with NMHS directors, operational staff, regional organisations (SPREP, SPC, WMO), development partners, and technology suppliers.
- Consideration of the WRP stocktake of the current state of observing networks across the region, identifying common gaps, risks, and opportunities related to procurement, maintenance, data management, and long-term sustainability.
- Peer review by a range of technical experts from the Pacific and internationally, including meteorologists, hydrologists, ICT professionals, and procurement specialists.

This collaborative and iterative development process ensures this document is a practical and adaptive resource, designed to support Pacific NMHSs in developing resilient, interoperable, and financially sustainable observation networks that enhance early warning, climate services, and community resilience.

2 End-to-End System Design and Procurement

A core principle underpinning this Guidance Document is the importance of providing the resources to enable a standardised and coordinated approach to procurement and systems integration across the Pacific region, an approach strongly advocated by WMO and other partner guidelines [14-16]. This is critical to ensure that national investments, whether made through the WRP Programme or through other bilateral and multilateral initiatives, contribute effectively to building a cohesive, interoperable, and sustainable regional observation network.

The complex and costly nature of earth observing systems in the Pacific means that poorly coordinated investments can lead to duplication, data silos, technological incompatibilities, and stranded assets. To mitigate these risks, a "whole-of-system" approach is required, one that considers the appropriate observation standards, and full lifecycle and operational context of observational infrastructure from planning to sustained operation.

Before selecting specific equipment or technologies, every Pacific NMHS must understand the complete lifecycle commitment required to operate and sustain observation systems. This section outlines the end-to-end process, from initial planning through to decommissioning, that transforms observation investments from short-term projects into long-term national assets.

The following interconnected components form the end-to-end system as shown in Figure 1.

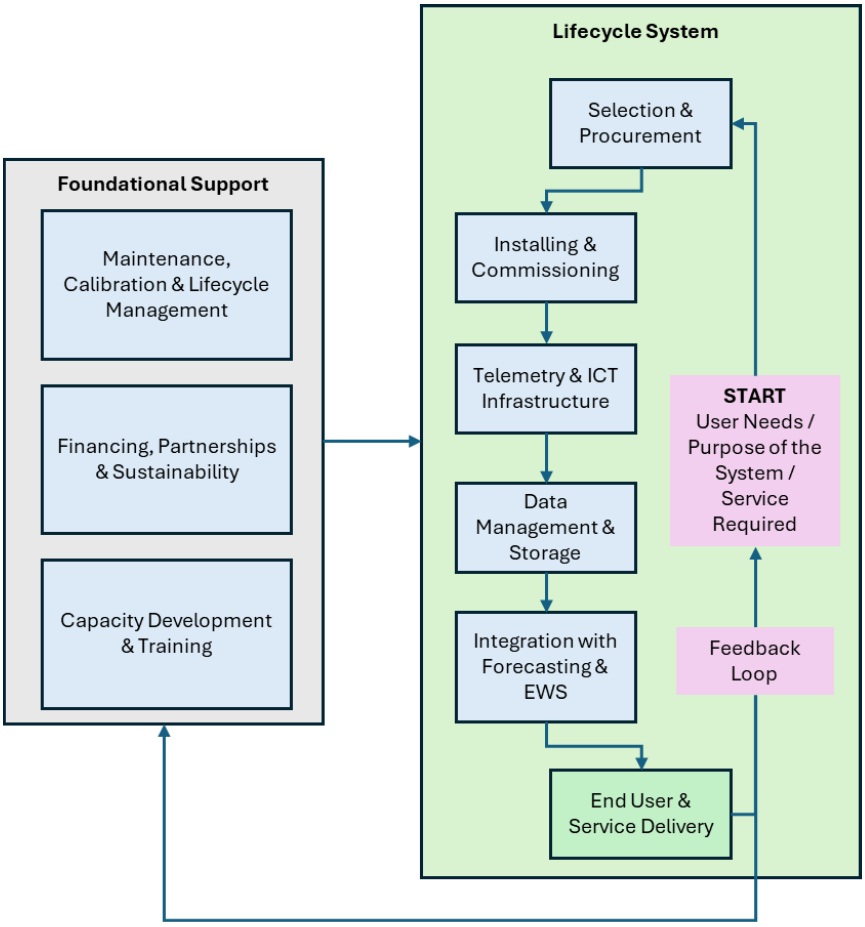

Figure 1 The End-to-End System Lifecycle. The process begins with strategic Selection and Procurement and flows through to Service Delivery, which in turn informs future procurement needs. Maintenance and Financing are not final steps but are foundational supports required for every stage of the lifecycle.

2.1 Strategic Planning & Needs Assessment

Before any procurement begins, NMHSs must clearly define:

- National and regional observing priorities aligned with service delivery goals
- Required variables, accuracy levels, and data timeliness
- Site-specific conditions and constraints
- Alignment with WMO frameworks (WIGOS, GBON, RBON)
- Long-term funding and capacity considerations

2.2 Selection and Procurement of Equipment

Ensure all investments meet agreed regional standards and specifications to maximise interoperability and facilitate regional servicing and spare part supply chains. Key considerations outlined in Table 1.

Table 1 Selection and procurement considerations for earth observations systems.

Consideration	Detail
Fit-for-Purpose Design	Select equipment that meets multiple regional and operational needs (e.g., tropicalised, cyclone-resistant, saltwater-resistant, low power draw).
Regional Standards	Align with WMO Integrated Global Observing System (WIGOS) [7] and regional minimum standards to ensure interoperability, optimisation of spare parts sharing, simplified repair and maintenance and pooled systems training.
Total Cost of Ownership (TCO)	Include all life-cycle costs: installation, training, spare parts, maintenance, verification, calibration, telemetry, software licences, and disposal [16].
Modular and Scalable Systems	Prefer modular systems that can be scaled or upgraded incrementally, reducing downtime and allowing progressive rollouts.
Vendor Track Record & Support	Identify vendors with proven service records in the Pacific and ensure training, warranty, and technical support are available locally or regionally.
Bulk procurement	Encourage the aggregation of project procurement to enable economy of scale.

2.3 Installation and Commissioning

Require technically sound and regionally informed installation practices that ensure data integrity from the outset. Key considerations outlined in Table 2.

Table 2 Installing and commissioning considerations for earth observations systems.

Consideration	Detail
Technical Guidance	Follow standard regional installation protocols to ensure data comparability, uncertainty, and system longevity.

Local Involvement	Engage NMHS staff and local technicians in installation to build familiarity and capacity.
Site Selection & Security	Choose locations with good representativeness, secure fencing, and access for maintenance.
Integration Planning	Ensure new systems link into national data pipelines, power sources, and ICT infrastructure.
Environmental Impact Assessment	Follow standard protocols to ensure negative environmental impacts are minimised.

2.4 Telemetry and ICT Infrastructure

Ensure reliable, secure, and regionally harmonised communication systems for data transmission, compatible with regional and global systems (e.g., WMO Information System 2.0 (WIS 2.0), WIGOS). Key considerations outlined in Table 3.

Table 3 Telemetry and ICT infrastructure considerations for earth observations systems.

Consideration	Detail
Data Transmission	Use reliable, redundant telemetry (e.g., GPRS, Inmarsat BGAN, Iridium, Starlink, V-SAT) suited to local conditions and bandwidth availability.
Power Supply	Include resilient solar systems with surge protection, battery backups, and local replacement options.
Data Protocols & Standards	Adhere to WIS 2.0, BUFR, and regional formats to enable real-time sharing and integration.
Cybersecurity & Data Integrity	Ensure systems are protected from data loss, hacking, and accidental deletion with robust authentication and backups.

2.5 Data Storage and Management

Prioritise systems that enable national ownership of data, while ensuring ease of regional and global data sharing in line with the WMO Unified Policy for Data Exchange [6]. Key considerations outlined in Table 4.

Table 4 Data storage and management considerations for earth observations systems.

Consideration	Detail
National Data Sovereignty	Data should be owned and controlled by NMHSs while being sharable regionally and globally.
Cloud vs On-Premises	Assess whether national servers or cloud platforms (or hybrid) offer better redundancy and affordability.
Archiving & Metadata	Implement data management systems that maintain complete metadata, version histories, and accessibility.
Data Use Cases	Systems should support end-use in forecasting, research, sectoral services (agriculture, health, Disaster Risk Reduction (DRR), and regional model assimilation.

2.6 Integration with Forecasting and Early Warning Systems

Design observation networks so that data flows directly into forecasting, nowcasting, and warning systems, both nationally and regionally. Key considerations outlined in Table 5.

Table 5 Integration with forecasting and early warning systems considerations for earth observations systems.

Consideration	Detail
Real-Time Data Ingestion	Ensure data can be ingested automatically into forecast models, warning platforms, and visualisation tools with minimal latency.
Compatibility with Models	Select sensors and data types that align with forecast model inputs (e.g., WRF, hydrological models) and ensure required variables are collected.
Forecast System Readiness	Train forecasting teams to use new data sources and integrate them into workflows, ensuring data translates into improved services.
Regional Data Sharing	Ensure national data supports regional forecasting efforts (e.g., Regional Specialised Meteorological Centres (RSMCs), Pacific Ocean forecast systems) via WIS 2.0-compliant sharing.

2.7 End User and Service Delivery

Ensure that observations ultimately serve users, including disaster managers, planners, mariners, farmers, and others, with timely, accessible, and usable information products. Key considerations outlined in Table 6.

Table 6 End user and service delivery considerations for earth observations systems.

Consideration	Detail
User-Centric Design	Systems should be designed with forecast and warning service needs in mind, not just data collection. Work with key stakeholders during planning stages to ensure infrastructure and data outputs meet real-world decision-making needs.
Feedback Loops	Enable user input (e.g., disaster managers, ocean users, health sectors) into system design, performance review, and improvements.
Communication Tools	Invest in the capacity to convert observations into accessible, timely, and trusted information products.

2.8 Maintenance, Verification, and Calibration

Use the TCO approach to plan for long-term maintenance, including spare parts, calibration services, training, and ICT upgrades. Key considerations outlined in Table 7.

Table 7 Maintenance, verification and calibration considerations for earth observations systems.

Consideration	Detail
Maintenance Planning	Develop national maintenance schedules and Standard Operating Procedures (SOPs), supported by trained staff and stocked spares.
Field Verification	Process of evaluating and confirming the accuracy, reliability and operational performance of measuring instruments at their

Consideration	Detail
	operational site against pre-defined requirements by comparing their measurements to reference or portable standards. This verification is carried out under actual environmental conditions to ensure that instruments continue to provide reliable, consistent, and accurate data after installation.
Calibration Infrastructure	Access to regional or national calibration laboratories, including for pressure, radiation, temperature, field verification (travelling) standards, and radar.
Inventory Management	Maintain digital records of assets, serial numbers, warranties, spares, maintenance history, and fault logs.
Environmental Protection	Regular cleaning, corrosion control, cyclone-proofing, and pest protection to extend asset life.
Asset Information System	Up to date information on equipment and maintenance status is maintained and available via an asset information system

2.9 Financing, Partnerships & Sustainability

Sustainable observation networks require long-term financial planning, coordinated partnerships, and alignment with regional standards. Investments should account for total lifecycle costs – procurement, operations, maintenance, and calibration. Leveraging regional procurement, shared services, and aligned donor support enhances cost-efficiency and system compatibility. Strong Monitoring and Evaluation (M&E) systems ensure continued relevance and performance of infrastructure. Key considerations outlined in Table 8.

Table 8 Financing, partnerships and sustainability considerations for earth observations systems.

Consideration	Detail
National Budgeting	Advocate for dedicated Operating and Maintenance (O&M) funding lines in national budgets as part of climate resilience or DRR investment.
Regional Procurement	Use regional platforms (e.g., SPREP, PIFS, WMO) for joint or bulk procurement and cost-sharing.
Donor Coordination	Harmonise donor support to avoid duplication, conflicting technologies, or unsustainable systems.
Monitoring & Evaluation	Regularly evaluate station uptime, data quality, capacity metrics, and end-user\` satisfaction to inform investment updates.

2.10 Capacity Development and Training

A sustainable observation network is dependent on a skilled, confident, and well-supported workforce [14, 15]. Capacity development in the Pacific must be strategic, continuous, and tailored to the specific roles within the end-to-end system, from technicians and forecasters to data managers and ICT specialists. A focus on standardised regional training, knowledge sharing, and succession planning is critical to mitigate staff turnover and build enduring institutional capability. Key considerations outlined in Table 9.

Table 9 Capacity development and training considerations for earth observations systems.

Consideration	Detail
Needs-Based Training Strategy	Develop and regularly update national and regional training plans based on systematic skills gap analyses, aligned with WMO competency frameworks [15] and the specific technology tiers (1, 2, 3) in use. Training must be specific: ● Technicians: Equipment-specific maintenance and repair, field verification, grounds maintenance, basic telemetry troubleshooting. ● Data Managers: Data QC procedures, metadata standards, use of data management systems (e.g., CliDE). ● Forecasters: Interpretation and application of new data streams in forecasting and warning workflows. ● Upper-Air Specialists: Radiosonde system operation, maintenance, and data handling.
Leverage Regional Centres	Prioritise and utilise WMO Regional Training Centres (RTCs) like RTC Nadi and RTC Melbourne, and partner with regional institutions (e.g., USP, SPC) for foundational and advanced training, fostering a cohesive Pacific expertise base.
Hands-On and Localised Training	Ensure training curricula include substantial practical, hands-on components relevant to Pacific conditions (e.g., cyclone-proofing, corrosion control, vegetation management, troubleshooting in remote settings).
Integrate Training with Procurement	Mandate that equipment suppliers provide comprehensive initial training and detailed documentation as a core requirement of all procurement contracts, especially under "Supply & Support" models.
Continuous Professional Development	Establish programs for ongoing learning beyond initial installation, including workshops on new technologies, data quality control, maintenance Standard Operating Procedures, and the use of observations in service delivery (e.g., for early warnings).

3 The Tiered Framework – A Pacific Solution

With a clear understanding of the observation lifecycle, NMHSs can make informed decisions about the appropriate level of investment and commitment for different observation needs. To ensure practicality and cost-effectiveness, this Guidance Document adopts a three-tiered approach to Pacific Earth observation system standards (shown in Figure 2).

This framework emerged from stakeholder feedback highlighting the need for flexible, purpose-driven standards that match varying national capacities, priorities, and resources. The tiered system is not about creating a hierarchy of importance, but rather a hierarchy of purpose and sustainability. It is a pragmatic and strategic tool that enables Pacific NMHSs to build resilient, fit-for-purpose, and financially sustainable observation networks that directly serve national priorities and contribute effectively to regional resilience. The tiered system ensures that limited resources are strategically allocated. Not every station needs to meet the highest international standards for climate benchmark monitoring. This approach allows NMHSs to design a cost-effective network tailored to specific applications.

Tier 1	Tier 2	Tier 3
Summary: Stations meeting the highest accuracy standards for long-term monitoring, serving as national. These stations require the highest specification instruments and most rigorous maintenance schedules. ***Purpose:*** To establish and maintain definitive, long-term climate records across the atmosphere, ocean, and land; and to contribute to global climate assessment and forecasting systems.	***Summary:*** Stations designed for operational weather forecasting and warning. They meet all WMO Regional Basic Observing Network (RBON) requirements and provide high-quality, reliable data for models and nowcasting. ***Purpose:*** To provide real-time, reliable data for daily forecasting and severe weather warnings, including cyclones, storm surges, floods, and high seas.	***Summary:*** Stations deployed for specific, high-impact applications (e.g., rainfall in flash-flood prone catchments, soil temperature and moisture monitoring for agriculture, etc.). The focus is on robustness, reliability, and cost-effectiveness for a targeted purpose, potentially relaxed accuracy specifications for non-critical parameters. ***Purpose:*** To address specific, local risks or sectoral needs with a practical, cost-effective solution.

Figure 2 Tiered system for Earth observation infrastructure in the Pacific, categorised by purpose, accuracy, and sustainability requirements into Tier 1 (Reference), Tier 2 (Operational Forecasting), and Tier 3 (Targeted Applications).

3.1 The Three Tiers Explained

TIER 1: REFERENCE STATIONS

Purpose: To establish and maintain definitive, long-term records across the atmosphere, ocean, and land; and to contribute to global climate assessment and forecasting systems. Key characteristics and specification outlined in Table 10.

Important Note: This document uses the terms Tier 1, 2, and 3 to define operational categories of observing stations. In regard to atmospheric observations, this is distinct from the WMO Measurement Quality Classifications (A, B, C, D) defined in WMO-No. 8 ADDIN EN.CITE <EndNote><Cite><Author>WMO</Author><Year>2025</Year><RecNum>1</RecNum><DisplayText>[1]</DisplayText><record><rec-number>1</rec-number><foreign-keys><key app="EN" db-id="5drtpt0wbe95whe50fb5rs0dvsrxsvdrz29t" timestamp="1761767552">1</key></foreign-keys><ref-type name="Generic">13</ref-type><contributors><authors><author>WMO</author></authors></contributors><titles><title>Guide to Instruments and Methods of Observation (WMO-No. 8)</title></titles><dates><year>2025</year></dates><urls><related-urls><url>https://library.wmo.int/idurl/4/41650 </url></related-urls></urls></record></Cite></EndNote>[1], which specify the realised uncertainty of individual measurements, accounting for instrument, calibration, environmental, and maintenance factors. A station in this Guidance Document’s operational Tier 1 will typically contain sensors aiming for WMO Measurement Quality Class A or B, but the "Tier" encompasses the entire system's purpose, design, and support model.

Table 10 Tier 1 systems characteristics and specifications.

Characteristic	**Tier 1 Specification**
Primary Purpose	Long-term climate monitoring and trend analysis; Contribution to GBON; Climate research and policy baseline
Key Applications	- Climate change detection - Global climate assessments (IPCC) - Sea-level rise reference monitoring - National climate policy development - Calibration reference for other stations
Measurement Accuracy	Highest technical specifications
Data Completeness	>98% data recovery; Gaps must be documented and justified
Redundancy	Multiple sensors for critical variables; Backup power and communications
Maintenance Schedule	Monthly visual checks; Quarterly detailed inspections; Annual full calibration
Calibration Requirements	Annual calibration against national/international standards; Traceable to BIPM
Spare Parts Strategy	Full redundancy at site; National inventory of all critical components
Technical Skill Requirements	Advanced training in metrology; Specialised calibration skills; Data quality expertise
Site Requirements	Long-term stable location (>20 years); Minimal environmental interference; Comprehensive site metadata; Secure from vandalism; Accessible for maintenance
Data Transmission	Real-time via redundant links (cellular + satellite); Complete daily datasets transmitted
Metadata Requirements	Full WIGOS metadata standard; Complete maintenance and calibration history

Characteristic	Tier 1 Specification
Lifecycle Expectation	10-12 years with mid-life refurbishment
Typical Sites	National climate reference stations; GBON stations; Primary tide gauges; Upper-air reference stations

TIER 2: OPERATIONAL FORECASTING STATIONS

Purpose: To provide real-time, reliable data for daily forecasting and warnings, including tropical cyclones, storm surges, floods, and high-impact weather events. Key characteristics and specification outlined in Table 12.

Table 11 Tier 2 systems characteristics and specifications.

Characteristic	Tier 2 Specification
Primary Purpose	Real-time severe weather warnings; Operational forecasting input; Aviation and maritime safety
Key Applications	- Tropical cyclone tracking - Flash flood warnings - Aviation weather services - Marine forecasts and warnings - Agricultural advisories
Measurement Accuracy	Meets WMO RBON RA IV requirements
Data Completeness	>95% data recovery; Critical during severe weather events
Redundancy	Backup power essential; Alternative communications pathway recommended
Maintenance Schedule	Monthly visual checks; Bi-annual detailed inspections
Calibration Requirements	Bi-annual verification; Annual calibration for critical sensors
Spare Parts Strategy	Essential spares at national level; Regional pooling for expensive items
Technical Skill Requirements	Standard meteorological technician training; Basic calibration skills; Fault diagnosis capability
Site Requirements	Representative of area; Secure from vandalism; Accessible for maintenance; Comprehensive site metadata
Data Transmission	Real-time via primary link; Daily synoptic transmissions; ≤15-minute latency for warnings
Metadata Requirements	Complete WIGOS operational metadata; Maintenance records
Lifecycle Expectation	8-10 years with regular maintenance
Typical Sites	Airport meteorological stations; Tsunami warning stations; Flood forecasting points; Cyclone monitoring locations

TIER 3: TARGETED APPLICATION STATIONS

Purpose: To address specific, local risks or sectoral needs with a practical, cost-effective solution where the highest accuracy specifications may be relaxed for non-critical parameters. Key characteristics and specifications outlined in Table 12.

Table 12 Tier 3 systems characteristics and specifications.

Characteristic	Tier 3 Specification
Primary Purpose	Specific local risk monitoring; Community-based applications; Sectoral decision support
Key Applications	- Community rainfall monitoring - Agricultural soil moisture - Small catchment flood alerts - Localised wind for renewable energy - Water resource management
Measurement Accuracy	Fit-for-purpose accuracy
Data Completeness	Gaps acceptable if documented
Redundancy	Minimal; Single power and communication systems
Maintenance Schedule	Quarterly visual checks; Annual inspections; Reactive maintenance approach
Calibration Requirements	Factory calibration with periodic verification (2-3 years); "As-failed" recalibration
Spare Parts Strategy	Minimal spares; Vendor-supported replacement; Regional pooling for common items
Technical Skill Requirements	Basic maintenance training; Community-based technicians acceptable
Site Requirements	Practical location for application; Community-managed sites acceptable
Data Transmission	Daily or weekly transmissions acceptable; Cellular or manual download
Metadata Requirements	Minimum metadata for interpretation; Site and sensor documentation
Lifecycle Expectation	5-7 years; Lower-cost replacement strategy
Typical Sites	Community rain gauges; School weather stations; Agricultural monitoring; Small river level gauges; Coastal erosion points

3.2 Mixed-Tier Stations & Tier Migration

Mixed-Tier Stations

A single site may include instruments from different tiers (e.g., Tier 1 climate sensors alongside Tier 3 application sensors). Each instrument stream should be **clearly documented** with its tier classification.

Tier Migration

Stations may change tiers over time due to:

- Changing national priorities
- Improved technical capacity
- Budget constraints
- Evolving risks

Migration plans should include:

- Assessment of current vs. desired tier specifications
- Budget implications for upgraded maintenance and calibration
- Training requirements for staff
- Timeline for transition with minimal data disruption

3.3 Pacific-Specific Design Requirements

All tiers must include Pacific-specific adaptations to ensure resilience in the region's challenging environments. Details outlined in Table 13.

Table 13 Pacific-specific design requirements for all tiers to ensure resilience in tropical and coastal environments.

Requirement	Specification
Cyclone Resistance	Structures and mounts designed to withstand Category 4+ cyclonic winds
Salt Spray Protection	Corrosion-resistant materials (marine-grade stainless steel, powder-coated aluminium)
UV Stability	UV-stable enclosures and sensor materials
Waterproofing	Minimum IP65 rating for all outdoor components; IP68 for coastal/marine installations
Solar Power Compatibility	Designed for off-grid solar operation with battery backup

3.4 Regional Minimum Standards

While the tiers have different performance levels, they all operate within a single, unified regional framework. This promotes interoperability by ensuring that data from a Tier 3 station is still shared in standard formats and can be understood and used alongside data from a Tier 1 station. It prevents technological fragmentation and supports the goal of a cohesive system for the Pacific.

All tiers must meet minimum regional standards for:

- Standardised data formats and transmission protocols (WIS 2.0)
- Complete WIGOS metadata required

- CliDE, or other NMHS preferred database, compatible systems to ensure secure and sovereign data collection
- WRP regional observation standards outlined in this Guidance Document

3.5 Facilitating Effective Procurement and Capacity Building

The tier specifications provide a clear basis for procurement. Partners and NMHSs can issue tenders with confidence that all bids will be evaluated against the same technical criteria.

Furthermore, training and capacity development can **be tailored to tier requirements**:

- **Tier 1 Technicians:** Advanced calibration, meteorology, data quality assurance
- **Tier 2 Technicians:** Routine maintenance, troubleshooting, basic calibration
- **Tier 3 Technicians/Community Observers:** Basic operation, visual checks, data collection

This allows for more targeted and efficient workforce development, ensuring that limited training resources are allocated where they are most needed.

4 Observing Network Variables

This section provides a prioritised list of variables essential to support PICTs' national mandates. These align with:

- WMO's GBON guidelines [7]
- Regional Basic Observing Network (RBON) guidelines for Regional Association (RA) V [17] which encompasses the South-West Pacific
- The Pacific Island Communications, Infrastructure (PICI) Panel's [18] focus areas
- Regional consultation outcomes from the WRP programme

The following tables categorise variables by domain, indicating their key applications and available technologies.

4.1 Variables

Table 14 List of key observation variables by category (Atmosphere, Marine, Freshwater & Hydrology, Land), with application areas and available technologies.

Category	Variables	Key Application Areas	Available technologies (non-exhaustive)
Atmosphere (Near Surface)	Air Temperature (Instantaneous)	Real-time monitoring for forecasting, agriculture, health (heat stress), aviation, and climate monitoring	Integrated AWS sensors (Temperature probe/Digital thermometer) Manual Observers (alcohol thermometers or digital with display)
	Daily Maximum Air Temperature	Heatwave and health warnings, climate records, agricultural	Integrated AWS sensors (Temperature probe/Digital

Category	Variables	Key Application Areas	Available technologies (non-exhaustive)
		stress indices, fire weather indices	thermometer with max temperature logging capability) Manual Observers (alcohol thermometers or digital with display)
	Daily Minimum Air Temperature	Frost monitoring, agricultural impacts (crop damage), climate records, public health (cold stress)	Integrated AWS sensors (Temperature probe/Digital thermometer with min temperature logging capability) Manual Observers (alcohol thermometers or electronic handhelds used instead)
	Air relative humidity	Weather warnings, health, fire weather	Integrated AWS sensors (Humidity Probe/Digital hygrometer/Wet bulb temperature probe) Manual Observers (dry and wet bulb thermometer or digital with display) Radiosondes
	Temperature dew point	Forecasting, Aviation	Integrated AWS sensors (Dew point probe/Digital hygrometer/Wet bulb temperature probe) Manual Observers (dry and wet bulb thermometer or digital with display)
	Air pressure	Forecasting, storm surge modelling	Integrated AWS sensors (digital barometers) Standalone Barometers/Barographs
	Wind speed and direction	Cyclone monitoring, aviation, maritime safety	Integrated AWS sensors (Anemometer, cup counter, propeller, Ultrasonic anemometer) Radiosondes
	Wind gust		
	Accumulated precipitation	Hydrology, flood early warnings, agriculture	AWS (Tipping Bucket Rain Gauge TBRG) Manual Observers (manual rain gauge) Pluviograph
	Precipitation intensity		

Category	**Variables**	**Key Application Areas**	**Available technologies (non-exhaustive)**
			Standalone TBRG Radars
	Solar radiation & sunshine duration	Energy generation, agriculture productivity, modelling climate, public health assessment, urban planning	Sunshine recorders (e.g. Campbell-Stokes) Silicon photodiode sensors, All-sky cameras Integrated AWS radiation sensors Satellite remote sensing
Atmosphere (Upper Air)	Atmospheric Temperature (Profile)	Forecast modelling, aviation, cyclone prediction	Radiosondes Pilot balloons Aircraft observations (Doppler) Weather Radar Wind profiler radar GNSS-Radio Occultation (RO) Surface-based remote sensing stations such as Microwave Radiometers, Raman Lidar, DIAL
	Atmospheric Pressure (Profile)	Synoptic analysis, model assimilation	
	Relative humidity (Profile)	Cloud formation, storm development	
	Wind/wind shear	Jet streams, vertical wind shear analysis	
Marine	Sea surface temperature (SST)	Coral bleaching monitoring, ocean heat content tracking, cyclone forecasting, fisheries management	In situ thermistors (Drifting/Moored Wave Buoys, Argo Floats) Manual Measurements Satellite infrared sensors
	Coastal sea level (tide) including: • storm surge, • coastal sea level, • coastal inundation, and • sea surface anomaly	Coastal flood forecasting, infrastructure planning & zoning, tide predictions for navigation & fishing, sea level rise monitoring	Water (Tidal) Level Gauges (radar, bottom pressure) High-frequency (HF) near-shore water level sensors Satellite scatterometers
	Sea state including: • significant wave height, • dominant (or peak) wave period,	Marine safety and navigation, port operations, coastal erosion forecasting, wave energy potential	HF radars Pressure sensors Acoustic Doppler Current Profiler (ACP)

Category	Variables	Key Application Areas	Available technologies (non-exhaustive)
	• mean wave period, • dominant (or peak) wave direction and • mean direction		Wave Buoys Manual Observations
Freshwater & Hydrology	River Height / Discharge	Flood early warning systems, water resource allocation, dam and reservoir operations, hydrological modelling	Pressure or radar water level sensors Acoustic Doppler sensors Staff gauges (manual)
	Groundwater Levels	Drought monitoring, sustainable water extraction, climate change impact assessment, agricultural planning	Pressure transducers in boreholes Datalogger systems for continuous monitoring
	Water Quality	Drinking water safety, pollution control, public health monitoring, ecosystem health assessments	In situ multivariable sondes Handheld field meters Lab analysis kits
Land	Soil moisture	Agricultural productivity & drought monitoring, irrigation scheduling, landslide risk assessment, flash flood warning	Integrated AWS sensors (capacitance sensors) Remote sensing
	Ground (earth) temperature	Agricultural productivity & drought monitoring, soil & ecosystem health, climate change & carbon monitoring, environmental monitoring, landslide risk assessment	Integrated AWS sensors (thermistors) Data loggers with temperature probes Remote sensing
	Land Use / Cover	Deforestation tracking, urban expansion monitoring, disaster impact assessments, emissions reporting & carbon stock estimates, hydrological modelling	Satellite imagery (e.g., Sentinel-2, Landsat) Aerial surveys Field surveys

4.2 Variable Selection Guidance

When planning an observing network, consider:

1. **Service-Driven Selection**

- Which variables are needed for specific services (e.g., flood warnings → rainfall, river level)?
- Which user groups depend on which variables?

2. **Tier-Appropriate Instrumentation**

- Tier 1: Highest accuracy, redundancy, regular calibration
- Tier 2: Operational reliability, real-time transmission
- Tier 3: Fit-for-purpose, cost-effective, low maintenance

3. **Integration Potential**

- Can one sensor measure multiple variables (e.g., multi-parameter sonde)?
- How will data flow into national and regional systems?

4. **Sustainability**

- What are the long-term costs for calibration, maintenance, and replacement?
- Is there regional capacity to support this variable's measurement?

5 Infrastructure & Sensor Specifications

This section outlines the recommended specifications for observation infrastructure and sensors across marine, freshwater, land, and atmospheric domains for the Pacific.

All infrastructure investments should align with regional and WMO standards, where possible, ensure compatibility with national forecasting and early warning systems, and follow a whole-of-system approach that supports sustainability, capacity development, and data-sharing.

5.1 Pacific Requirements

All observing equipment and systems (all tiers) should meet the following minimum general requirements outlined in Table 15.

Table 15 General Pacific infrastructure and sensor requirements applicable to all tiers.

Requirement Category	Specification
Pacific-Resilient Design	Equipment must be corrosion-resistant, UV-stable, cyclone-resilient, and waterproof to at least IP65 standards. Coastal/marine deployments must withstand salt spray and high humidity.
Power Supply	Solar-powered with minimum 14 days battery backup. Must include surge protection, voltage regulation, and local replacement capacity.
Telemetry	Reliable and redundant communications (e.g., GPRS, 3G/4G, Inmarsat BGAN, Iridium, VSAT, Starlink) compatible with national ICT infrastructure. Must support data transmission to CliDE or equivalent NMHS databases.
Data Storage	On-device storage for ≥1 year of data. Support for open data formats (CSV, JSON, WMO BUFR/netCDF).
Calibration Readiness	Designed for regular calibration cycles with accessible ports/connectors. Support for field verification using portable standards.
Vendor Support	Minimum 3-year warranty. Access to spare parts, local/regional technical support, remote diagnostics. Vendor must have ≥3 years' experience operating in PICTs with ≥5 successful tropical/marine installations. Regional office or dedicated Pacific support team preferred.

5.2 Tier Sensor Specification by Variable

The Tier 1, 2, and 3 values in **Table 16** to **Table 20** are derived from and aligned with primarily with:

- WMO Guidance [1, 19] for atmosphere near surface and upper air
- National Environmental Monitoring Standards (NEMS) New Zealand [9-13] for freshwater and hydrology
- Technical specifications developed under the Intra-ACP CLIMSA Programme which were widely circulated and reviewed by regional experts from WMO, SPREP, BoM, Earth Sciences New Zealand, and Pacific NMHSs. Covers atmosphere near surface and land.
- Manufacturing specifications for equipment typically used in the systems [20-30].

Practical experience with instrument performance in Pacific environments (high humidity, salt spray, intense UV, tropical rainfall).

Where sensor specifications were not available from WMO guidance, defined in previous regional projects, or from other primary sources, regional expert opinion has been relied upon.

Important Note on Specifications and Uncertainty: The uncertainties specified in Tables 2-6 represent *sensor performance under ideal test conditions*. The *realised system uncertainty* will be higher due to environmental exposure, installation effects, maintenance schedules, and calibration drift. These specifications are designed as a procurement tool to select instruments capable of meeting the intended operational tier's purpose and data quality goals, as defined by the WMO Measurement Quality Classifications.

Use WMO Measurement Quality Classifications (A, B, C, D) defined in WMO-No. 8 ADDIN EN.CITE <EndNote><Cite><Author>WMO</Author><Year>2025</Year><RecNum>1</RecNum><DisplayText>[1]</DisplayText><record><rec-number>1</rec-number><foreign-keys><key app="EN" db-id="5drtpt0wbe95whe50fb5rs0dvsrxsvdrz29t" timestamp="1761767552">1</key></foreign-keys><ref-type name="Generic">13</ref-

5.2.1 Atmosphere (Near Surface)

Table 16 Atmosphere (Near Surface) variable specification for each Tier (1-3). Tier 1 aligned with WMO No. 8 Annex 1.A and 1.G [1]. Tier 2 and 3 extrapolated from Tier 1 and informed by other sources, including expert judgement. Uncert. = Uncertainty; Res. = Resolution

Category	Variable	Tier 1	Tier 2	Tier 3	Comments
Atmosphere (Near Surface)	**Air temperature** (Instantaneous)	Uncert.: ±0.2 °C Res.: 0.1 °C Range: -40 to +60°C	Uncert.: ±0.6 °C Res.: 0.2 °C Range: -20 to +60°C	Uncert.: ±1.0 °C Res.: 0.5 °C Range: -20 to +60°C	Sensor to be installed outdoors in a thermometer screen with sensor at a height of 1.25 m minimum above ground level.
	Daily maximum / minimum air temperature	Uncert.: ±0.1 °C Res.: 0.1 °C	Uncert.: ±0.2 °C Res.: 0.1 °C	Uncert.: ±0.5 °C Res.: 0.1 °C	Daily max derived from continuous records or digital thermometers
	Air relative humidity	Uncert.: ±2% Res.: 1% Range: 0–100%	Uncert.: ±5% Res.: 2% Range: 0–100%	Uncert.: ±10% Res.: 5% Range: 0–100%	Sensors must be stable in high humidity and salt air. Co-located with temperature sensor in same shield.
	Air pressure	Uncert.: ±0.2 hPa Res.: 0.1 hPa Range: 500–1080 hPa	Uncert.: ±1.0 hPa Res.: 0.2 hPa Range: 500–1080 hPa	Uncert.: ±2.0 hPa Res.: 0.5 hPa Range: 500–1080 hPa	Station level and mean sea level to be reported.
	Wind speed	Uncert.: ±0.5 m/s for wind speed ≤5 m/s and ±10% for a wind speed >5 m/s Res.: 0.5 m/s or better Range: 0–75 m/s	Uncert.: ±1 m/s for wind speed ≤5 m/s and ±15% for a wind speed >5 m/s Res.: 0.5 m/s or better Range: 0–75 m/s	Uncert.: ±2.5 m/s for wind speed ≤5 m/s and ±20% for a wind speed >5 m/s Res.: 1.0 m/s or better Range: 0–60 m/s	Cup or ultrasonic anemometers. Standard exposure is at a height of 10 m above flat ground. Distance from obstructions-to-free-flow-of-air by a minimum of 10 (preferably 30) times the height of the obstruction.
	Wind gust	Uncert.: same as wind speed Res.: same as wind speed Range: 0.1–75 m/s Sampling interval: ≤3 secs	Uncert.: same as wind speed Res.: same as wind speed Range: 0.1–120 m/s Sampling interval: ≤3 secs	Uncert.: same as wind speed Res.: same as wind speed Range: 0.1–100 m/s Sampling interval: ≤5 secs	Gust is defined as a 3-second average.

Category	Variable	Tier 1	Tier 2	Tier 3	Comments
	Wind direction	Uncert.: ±5° Res.: 1° Range: 0–360°	Uncert.: ±10° Res.: 2° Range: 0–360°	Uncert.: ±15° Res.: 5° Range: 0–360°	As for wind speed regarding obstructions. Direction head to be set to True North not Magnetic North.
	Accumulated precipitation	Uncert.: ±1 mm or 2% Res.: 0.1 mm Range: 0-1000 mm/day	Uncert.: ±3 mm or 5% Res.: 0.5 mm Range: 0-1000 mm/day	Uncert.: ±5 mm or 10% Res.: 1 mm Range: 0-500 mm/day	The area of the collector shall be at least 300 cm^2. The typical gauge used in the region is 200 mm diameter (area 314 cm^2).
	Precipitation intensity	Uncert.: ±0.2 mm/h or 5% Res.: 0.1 mm/h Range: 0–500 mm/h	Uncert.: ±0.5 mm/h or 10% Res.: 0.3 mm/h Range: 0–300 mm/h	Uncert.: ±2 mm/h or 15% Res.: 1.0 mm/h Range: 0–300 mm/h	Must be suitable for heavy tropical downpours. Circular aperture on gauge should be minimum of 200 mm (AWS)

5.2.2 Atmosphere (Upper Air)

Table 17 Atmosphere (Upper Air) variable specification for each Tier (1-3). Tier 1 aligned with WMO No. 8 Annex 1.A and 1.G [1]. Tier 2 and 3 extrapolated from Tier 1 and informed by other sources, including expert judgement. Uncert. = Uncertainty; Res. = Resolution

Category	Variable	Tier 1	Tier 2	Tier 3	Comments
Atmosphere (Upper Air)	**Atmospheric temperature** (profile)	Uncert.: ±0.2°C Res.: Range:	Uncert.: ±0.5°C Res.: Range:	Uncert.: ±1.0°C Res.: Range:	
	Atmospheric pressure (profile)	Uncert.: ±0.2 hPa Range:	Uncert.: ±1.0 hPa Range:	Uncert.: ±2.0 hPa Range:	Balloon-borne or GNSS-derived
	Relative humidity (profile)	Uncert.: ±2% Range:	Uncert.: ±5% Range:	Uncert.: ±10% Range:	Sensors must perform well in upper tropical troposphere
	Wind/wind shear	Uncert.: ±0.5 m/s Direction:	Uncert.: ±1.0 m/s Direction:	Uncert.: ±3.5 m/s Direction: ±	From pilot balloon, radiosonde, or aircraft (AMDAR)

5.2.3 Marine

Table 18 Marine variable specification for each Tier (1-3). Class A aligned with WMO No. 8 Annex 1.A [1]. Tier 2 and 3 extrapolated from Tier 1 and informed by other sources, including expert judgement. Uncert. = Uncertainty; Res. = Resolution

Category	Variable	Tier 1	Tier 2	Tier 3	Comments
Marine	**Sea surface temperature** (SST)	Uncert.: ±0.2°C Res.: 0.1°C Range: -5 to +35°C	Uncert.: ±0.6°C Res.: 0.1°C Range: 0 to +35°C	Uncert.: ±1.0°C Res.: 0.1°C Range: 0 to +35°C	In situ thermistors on moorings or buoys
	Coastal sea level (tide, surge, SSA)	Uncert.: ±0.05 m Res.: 0.01 m Sampling: ≤1 min	Uncert.: ±0.1 m Res.: 0.01 m Sampling: ≤1 min	Uncert.: ±0.5 m Res.: 0.01 m Sampling: ≤5 min	Radar or pressure tide gauges with cyclone resilience
	Wave height (significant)	Uncert.: ±0.5 m for ≤5 m or 10% for >5 m Res.: 0.1 m Range: 0–50 m	Uncert.: ±1.0 m for ≤5 m or 15% for >5 m Res.: 0.1 m Range: 0–50 m	Uncert.: ±2.0 m for ≤5 m or 20% for >5 m Res.: 0.1 m Range: 0–50 m	
	Wave period (peak/mean)	Uncert.: ±0.5 s Res.: 1 s Range: 0-100 s	Uncert.: ±1 s Res.: 1 s Range: 0-100 s	Uncert.: ±2 s Res.: 1 s Range: 0-100 s	
	Wave direction (peak/mean)	Uncert.: ±10° Res.: 1° Range: 0–360°	Uncert.: ±15° Res.: 1° Range: 0–360°	Uncert.: ±20° Res.: 5° Range: 0–360°	Mooring-based wave buoys preferred

5.2.4 Freshwater & Hydrology

Table 19 Freshwater & Hydrology variable specification for each Tier (1-3). Tier 1 is aligned with National Environmental Monitoring Standards New Zealand (NEMS) QC600 standard [9-13]. Tier 2 and 3 are extrapolated from Tier 1 based on NEMS QC500 and QC400, as well as being informed by expert judgement. Uncert. = Uncertainty; Res. = Resolution, SpC = Specific Conductivity, DO = Dissolved Oxygen

Category	Variable	Tier 1	Tier 2	Tier 3	Comments
Freshwater & Hydrology	**Water level** (Rivers, Lakes)	Uncert.: The greater of ±3 mm or ±0.2% of effective water level. Res.: 1 mm Sampling interval: 5 min	Uncert.: The greater of ±3 mm or ±0.2% of effective water level. Res.: 3 – 5 mm Sampling interval: 5 min	Uncert.: The greater of ±3 mm or ±0.2% of effective water level. Res.: 3 – 5 mm Sampling interval: 5 min	Remote data retrieval; Secure mounting in flood-prone areas
	Groundwater level	Uncert.: The greater of ± 10 mm or ± 0.2% of effective water level Res.: 1 mm Sampling interval: 15 min.	Uncert.: The greater of ±15 mm or ±0.5% of effective water level Res.: 3-5 mm Sampling interval: 15 -30 min.	Uncert.: The greater of ±20 mm or ±0.2% of effective water level Res.: 3-5 mm Sampling interval: 15-30 min	Borehole installations with vandal-proof casings
	River discharge (Flow)	Uncert.: ±8% (discharge)	Uncert.: ±10% (discharge)	Uncert.: ±15% (discharge)	The in-situ measurement of water volume (flow) has a maximum permissible uncertainty of ±10% of reading over the entire range of expected flow rates to a confidence level of 95%.
	Water quality (river and lake)	pH: ±0.2 pH units SpC: ±1 μS/cm or ±0.5% DO: ±0.3 mg/L	pH: ± pH units SpC: ± μS/cm or ± % DO: ± mg/L	pH: ± pH units SpC: ± μS/cm or ± % DO: ± mg/L	Remote logging preferred; Field calibration kits required

5.2.5 Land

Table 20 Land variable specification for each Tier (1-3). Tier 1 aligned with previous tender documents in the region, as well as National Environmental Monitoring Standards New Zealand [9-13]. Tier 2 and 3 extrapolated from Tier 1 and informed by expert judgement. Uncert. = Uncertainty; Res. = Resolution, VWC = Volumetric Water Content

Category	Variable	Tier 1	Tier 2	Tier 3	Comments
Land	**Soil moisture**	Uncert.: ±3% VWC Res.: ±1.5%	Uncert.: ±5% VWC Res.: ±1.5%	Uncert.: ±10% VWC Res.: ±1.5%	Can have multiple depths for sensors.

Category	Variable	Tier 1	Tier 2	Tier 3	Comments
					Consider inclination, topography, soil type, depth of water table, obstacles and application needs (e.g., agricultural practices).
	Ground (earth) temperature	Uncert.: ±0.3°C Res.: 0.1°C Range: 0 to +55°C	Uncert.: ±0.5°C Res.: 0.2°C Range: 0 to +55°C	Uncert.: ±1.0°C Res.: 0.5°C Range: 0 to +55°C	Standard soil depths (including some or all of 5, 10, 20, 50 and 100 cm).
	Land use / land cover	Res.: 1-3 m (satellite/drone)	Res.: 10 m (satellite)	Res.: 30 m (satellite)	Ground truthing via GPS & drones.

5.3 Site & Installation Guidelines

Table 21 Site selection and installation guidelines for all tiers.

Consideration	Specification
Exposure	Sensors positioned to avoid obstructions (wind, precipitation), representative of surrounding area.
Foundations	Secure, permanent mounting capable of withstanding cyclonic winds and flooding.
Cabling	UV-resistant, rodent-proof, with drip loops and surge protection.
Access	Safe, reliable access for maintenance and calibration.
Security	Fencing, signage, and where possible, remote monitoring to prevent vandalism/theft.
Environmental Impact	Minimal disturbance to local ecology; avoid culturally sensitive sites.

6 Procurement Tool Kit

Adopting a standardised procurement approach is essential to achieving regional interoperability, sustainability, and value for money. This section outlines a structured framework for procuring Earth observation systems in the Pacific, drawing on the principles of standardisation, whole-of-system thinking, and lifecycle management presented throughout this guidance.

A companion **Procurement Toolkit** has been developed alongside this Guidance Document, containing ready-to-use templates, evaluation matrices, and checklists. The toolkit is designed to:

1. Ensure consistent and transparent procurement aligned with regional and WMO standards.
2. Promote technical compatibility across the Pacific and with global systems (GBON, RBON, WIGOS, WIS 2.0).
3. Support informed decision-making through a structured evaluation process.
4. Enhance long-term sustainability by integrating whole-of-life considerations and “Supply & Support” contract models from the outset.
5. Strengthen capacity development by selecting systems that support local maintenance and operations.

6.1 Key Procurement Domains

The Procurement Tool Kit evaluates tenders across seven critical domains outlined in Table 22.

Table 22 Key procurement domains and considerations for evaluating tenders.

Domain	Key Considerations
1. System Design & Technical Suitability	Meets national use cases and regional standards; fit-for-purpose for Pacific conditions (cyclone-prone, high humidity, salt exposure, off-grid).
2. Power, Telemetry & Data Integration	Solar resilience, battery backup, redundant communications, compatibility with national/regional data systems (e.g., CliDE, WIS 2.0).
3. Installation & Localisation	Adherence to regional installation guidelines; involvement of local technical staff and NMHSs during installation.
4. Vendor Capability & Support	Regional track record, after-sales support, availability of spares, warranties, training provisions, documentation quality.
5. Lifecycle Costs & Maintenance	Total Cost of Ownership (TCO) evaluation covering purchase, installation, calibration, software, training, spare parts, and decommissioning.
6. Sustainability & Environmental Protection	Materials durability, corrosion resistance, cyclone-proofing, end-of-life management, environmental safeguards.
7. Data Sharing & Sovereignty	Supports national data ownership while capable of integration with regional/global platforms. Prefers open standards (BUFR, netCDF). Proprietary systems only if no open alternative exists, with guaranteed data export in open formats.

6.2 Evaluation Approach

The Procurement Toolkit uses **scoring matrices** to assess tenders objectively. Key features of the evaluation approach are outlined in Table 23.

Table 23 Example weighting scheme for procurement evaluation.

Element	**Description**
Weighted Criteria	Domains are weighted based on national priorities, technical complexity, and regional integration needs (e.g., Vendor Support may carry higher weight than aesthetics).
Multidisciplinary Review	Evaluation panels should include NMHS technical staff, ICT specialists, procurement officers, and service delivery representatives.
Regional Alignment	Where possible, align evaluation criteria with neighbouring NMHSs to enable pooled procurement and cross-national compatibility.
Whole-of-Life Focus	Scoring emphasises long-term sustainability, not just upfront cost. "Supply & Support" models are incentivised.

Example Weighting (Adjustable per NMHS):

- Technical Suitability: 25%
- Vendor Support & Track Record: 20%
- Lifecycle Cost & Sustainability: 20%
- Telemetry & Data Integration: 15%
- Installation & Training: 10%
- Environmental & Social: 10%

6.3 Pre-Procurement Considerations

Before releasing tenders, NMHSs, national stakeholders, or regional agencies should take the necessary steps and actions to ensure a successful procurement outlined in Table 24.

Table 24 Pre-procurement steps and responsibilities.

Step	**Action**
1. Needs Validation	Confirm site-specific requirements, siting conditions, installation challenges, and power/telemetry constraints.
2. Standards Alignment	Ensure alignment with WMO standards (WIGOS, GBON, RBON) and this Guidance Document's tiered specifications.
3. Stakeholder Engagement	Involve technical, procurement, and end-user representatives from relevant ministries/agencies.

Step	Action
4. Regional Peer Review	Where appropriate, engage with SPREP, WMO, or other regional partners for tender content review.
5. Budget Confirmation	Secure not only capital expenditure but also confirmed operational and maintenance funding for the system's lifecycle.
6. Capacity Readiness	Ensure staff training plans are in place and that national technical capacity matches system complexity.

6.4 "Supply & Support" Contracting Model

A strong recommendation is made to adopt **"Supply & Support" contracts** that extend beyond initial supply and installation to include long-term provisions. Minimum requirements are outlined in Table 25.

Table 25 Minimum requirements for "Supply & Support" contracts models.

Component	Minimum Requirements
Spare Parts	Guaranteed availability of critical spares for the system's lifecycle, with regional stocking options.
Consumables	Supply of batteries, desiccants, filters, etc., for at least 3–5 years.
Technical Support	On-call remote support, with defined response times (e.g., ≤24 hours for critical failures).
Calibration Services	Access to calibration (onsite, regional, or return-to-factory) at agreed intervals.
Training	Comprehensive initial training plus periodic refresher courses, with materials in appropriate languages.
Software Updates	Updates, security patches, and compatibility maintenance for the contract duration.

Key consideration: Minimum 3 to 5 years contract duration, align with expected calibration and major maintenance cycles.

6.5 Procurement Templates

The Procurement Toolkit includes pre-populated templates for major equipment types:

1. Automatic Weather Station (AWS) – GBON/RBON compliant
2. Climate Reference Station (Tier 1)
3. Upper-Air Sounding System
4. Marine Observation Buoy/Tide Gauge
5. Hydrological Monitoring Station
6. Telemetry & ICT Infrastructure Package

Each template includes:

- Technical specifications drawn from Section 5 of this guide
- Required documentation (manuals, calibration certificates, drawings)
- Training and support requirements
- Evaluation criteria and scoring guidance

6.6 Post-Procurement Actions

Table 26 post-procurement actions and responsibilities.

Phase	Key Activities
Contract Award	Notify all bidders, debrief unsuccessful vendors, sign contract with clear KPIs and reporting requirements.
Delivery & Inspection	Verify equipment against delivery notes, check for damage, validate calibration certificates.
Installation Oversight	NMHS staff should be present during installation; conduct joint commissioning tests.
Training & Handover	Ensure all planned training is delivered and documented; complete handover checklist.
Performance Monitoring	Track uptime, data quality, and support responsiveness against contract KPIs.
Contract Management	Schedule regular review meetings, maintain log of issues, plan for contract renewal/extensions.

6.7 Regional Pooled Procurement

Where feasible, NMHSs are encouraged to explore **pooled procurement** through regional mechanisms (e.g., SPREP, PIFS, WMO) to achieve:

- Economies of scale (bulk discounts)
- Standardisation across multiple countries
- Strengthened negotiating power with vendors
- Shared logistics and warehousing for spares
- Joint training and capacity building

SPREP/WRP can facilitate regional procurement coordination upon request.

7 Spare Parts, Maintenance & Lifecycle Management

Effective observation networks require robust maintenance systems, reliable access to spare parts, and careful lifecycle management to ensure data quality and long-term sustainability. In the Pacific, where logistics, remoteness, and harsh environments create added challenges, proactive and strategic planning is not just beneficial but critical to the sustainability of these vital assets.

This section outlines a tiered approach to spare parts, maintenance, calibration, and lifecycle management, aligned with WMO guidelines and regional best practices. See Appendix A for a list of WMO Regional Instrument Centres (RICs) and Regional Training Centres (RTCs), as well as other regional partners, that can assist.

7.1 Tiered Spare Parts Strategy

A tiered spare parts strategy is recommended to mitigate operational risks and minimise costly downtime (shown in Table 27).

Table 27 Tiered spare parts strategy, maintenance frequency, calibration verification frequency, and lifecycle expectations aligned with WMO Guidelines [31, 32].

Tier	Key Spare Parts Strategy	Preventative Maintenance Frequency	Calibration Verification Frequency	Typical Lifecycle
1	**Full redundancy**. Critical to have 100% sufficient functional spares/components on shelf. National inventory of all critical components.	Intensive: Monthly visual checks, quarterly detailed inspections with field verification, annual full service.	Annual (or per manufacturer, whichever is stricter)	8-12 years with mid-life refurbishment
2	**Essential spares for high-failure items**. Regional pooling recommendations for expensive items. National stock of common spares.	Regular: Monthly to quarterly visual checks, bi-annual detailed inspections with field verification.	1-2 years (aligned with regional RIC schedules)	7-10 years with regular maintenance
3	**Minimal spares**. Focus on low-cost, replaceable sensors. Vendor-supported replacement. Regional pooling for common items.	As-needed / Reactive: Bi-annual checks, annual inspections with field verification.	2-3 years or "as failed"	5-8 years with lower-cost replacement strategy.

7.2 Spare Parts & Consumables Management

To ensure continuity of observations, each NMHS or relevant agency should maintain a three-level spare parts inventory outlined in Table 28.

Table 28 Three-level spare parts inventory structure (site, national, regional).

Level	Description	Examples
Site-Level Stock	Minimum critical spares kit at each operational site for immediate repairs.	Fuses, cables, basic tools, desiccant, batteries.
National Central Warehouse	Consolidated national stock for higher-value, common-failure, and aging-risk components.	Sensors, data loggers, telemetry modules, solar panels.
Regional Procurement Agreements	Collaborative agreements with suppliers and partner agencies for rapid procurement of long-lead-time or catastrophic-fail items.	Specialised sensors, calibration equipment, cyclone-proof mounts.

Through regional coordination:

Key consideration: As a guiding principle, for critical Tier 1 (Reference) systems, a **full replacement set of key components** should be held in stock as a minimum requirement to safeguard the continuity of high-priority climate records and forecasting data.

- Stock essential spares for high-frequency replacement items (e.g., sensors, batteries, cabling, seals).
- Develop regional spare part pools to improve cost-effectiveness and reduce procurement delays, coordinated through WRP and SPREP.
- Ensure spare parts are standardised across systems to minimise stock requirements and simplify logistics.

7.3 Maintenance Planning

Maintenance planning enables NMHSs to move from reactive repairs to scheduled, proactive maintenance. This is vital for data continuity, budgeting and resources. Maintenance planning requirements are outlined in Table 29.

Table 29 Maintenance planning requirements and components.

Component	Requirement
National Maintenance Schedules	Develop and document schedules aligned with WMO standards and tier specifications [31, 32].
Standard Operating Procedures (SOPs)	Include protocols for grounds maintenance (vegetation clearing), sensor cleaning, corrosion control, and cyclone preparedness.
Digital Maintenance Logs	Maintain asset history including calibration dates, parts replaced, faults, and performance trends. Use existing systems and tool to capture this information, e.g., CliDE metadata functionality.
Training	Train NMHS staff and local technicians in first-line maintenance, troubleshooting, and grounds maintenance, with support from RTCs and regional partners.

7.4 Field Verification & Calibration

7.4.1 Field Verification

Field verification is the process of evaluating and confirming the accuracy, reliability, and operational performance of measuring instruments at their operational site against pre-defined requirements. This is carried out under actual environmental conditions using reference or portable standards.

Frequency:

- Tier 1: Quarterly
- Tier 2: Bi-annually
- Tier 3: Annually or as needed

7.4.2 Calibration Infrastructure

Access to calibration services is non-negotiable for data credibility. NMHSs should leverage RICs, coordinate with regional partners, and where capacity exists, develop in-country calibration capability for routine verifications.

Key consideration: The high cost and customs complexities of moving equipment across the Pacific for calibration should be addressed through intergovernmental arrangements to facilitate temporary import/export.

7.5 Traceability and Quality Assurance

The value of our Earth observation systems is realised only when the data they produce is reliable.

Traceability and Quality Assurance form the essential bridge between a sensor in the field and the confident decisions made by forecasters, climate scientists, and disaster managers. This process guarantees that our data is accurate, comparable with global networks, and fit for its purpose.

Guiding principles adopted in this document include:

- Ensure regular field verification of network instruments following recommend frequency in this guidance.
- Ensure calibration of field verification equipment using national, regional, or mobile calibration services following recommended frequency in this guidance.
- Access calibration services through RICs [34] (see Appendix A), which supports instrument calibration for the Pacific region, or through mobile calibration campaigns coordinated with regional partners.
- Build in-country technician capacity with support from regional RTCs and/or partner-led training courses and workshops (see Appendix A).

Key consideration: WMO and the SOFF Secretariat have developed guidance on approaches for traceability assurance in GBON stations which is applicable to all network stations in the Region ADDIN EN.CITE

7.6 Lifecycle Management

Procuring a sensor is a single event; managing the data it produces is a multi-decade responsibility. Lifecycle management is the practice of stewarding an asset from installation to decommissioning. It ensures the continuity of vital climate records, prevents catastrophic data gaps from unexpected failures, and safeguards our investments by planning for renewal before obsolescence strikes. Phases of the lifecycle management and recommended actions are outlined in Table 30.

Table 30 Lifecycle management phases and associated actions.

Phase	Actions
Planning	Apply a Total Cost of Ownership (TCO) approach, accounting for procurement, operation, maintenance, calibration, and decommissioning.
Operation	Monitor performance, conduct regular maintenance, update software/firmware, and ensure cybersecurity.
Renewal	Plan for timely equipment upgrades to prevent obsolescence and ensure compatibility with evolving ICT/data standards. The importance of NMHS system compatibility is critical.
Decommissioning	Include a phase-out protocol with ≥12 months' notice to ensure data overlap with new systems. Ensure proper disposal of hazardous materials.

Key consideration: Technology evolves rapidly, especially in communications. Ensure compatibility with core regional systems like **CliDE** to avoid stranded data and duplicated infrastructure.

7.7 Key Recommendations

1. Adopt the tiered spare parts strategy outlined in Table 7.
2. Develop and fund national maintenance plans with clear SOPs and digital logs.
3. Leverage regional calibration networks and plan for logistics/customs facilitation.
4. Implement lifecycle planning from procurement through to decommissioning.
5. Build in-country technical capacity through training and mentorship programmes.

8 ICT, Data Management, and Telemetry Considerations

Observation systems are only as valuable as the data they deliver. Pacific NMHSs must ensure reliable, secure, and wherever possible, interoperable ICT and telemetry systems that can transmit, process, and share data nationally, regionally, and globally. These systems should follow a "whole-of-system" approach from sensor to end-user.

8.1 Telemetry Systems

8.1.1 Redundant Communications Strategy

A single communication link is a single point of failure. The standard for critical sites (Tier 1 and 2) must be redundant communications. A primary/secondary model is the Pacific standard.

Table 31 Telemetry redundancy strategy options and technologies.

Link Type	Technology Options	Use Case
Primary	Cellular networks (GSM/3G/4G/5G) with industrial-grade modems and external antennas.	Where coverage exists; low cost, high bandwidth.
Secondary	Satellite services: Iridium SBD, Inmarsat BGAN, Starlink, VSAT.	Sites beyond cellular reach or as failover. Include pre-paid 2-year data plan in contract.
Tertiary (Optional)	Manual download via USB/SD card, or local wireless (Wi-Fi).	For non-critical sites or backup during extended outages.

8.1.2 Design for Resilience

Table 32 Design specifications for resilient telemetry and power systems.

Consideration	Specification
Hardware Protection	Corrosion-resistant connectors and enclosures (IP68) for all outdoor telemetry hardware.
Data Storage	Data loggers must have sufficient on-board storage (minimum 1 year) to bridge extended telemetry outages.
Power Systems	Solar power systems must be sized to support both primary and secondary telemetry continuously, plus battery backup for ≥14 days.
Standardisation	Use the same make/model of loggers and telemetry units across the network where possible to simplify troubleshooting, spare parts, and training.

8.2 Data Management and Sovereignty

8.2.1 National Data Sovereignty

The default should be that raw and primary processed data are stored on infrastructure owned or controlled by the NMHS**,** whether on national servers or a designated, secure cloud platform.

Table 33 Data storage options and sovereignty considerations.

Storage Option	Considerations
National Servers	Full control, higher upfront cost, requires IT maintenance and potentially requires high support from partners.
Designated Cloud Platform	Scalable, off-site redundancy, ongoing subscription costs. Must have data sovereignty clauses.
Hybrid Model	Critical data on national servers, archived/less critical data in cloud.

Key consideration: All vendor contracts must explicitly state that the NMHS retains all rights to the data.

8.2.2 Robust Archiving and Metadata

Table 34 Archiving and metadata management requirements.

Component	Requirement
Long-Term Archive	Separate from operational databases, with clear data preservation and backup policies.
Metadata	Collect and manage complete metadata (WIGOS Metadata Standard) at installation and update with every maintenance action. Essential for data discovery, use, and credibility.
Version Control	Maintain version histories of datasets and processing algorithms.

8.3 Integration and Interoperability

Data must flow seamlessly into the tools used by NMHSs for forecasting, warning, and service delivery.

8.3.1 Direct Integration Pathways

Design systems so that data flows automatically from the telemetry gateway into key operational systems, such as:

Table 35 Primary data integration pathways into national, regional, and global systems.

System Type	Examples
National Forecasting Platforms	Forecaster workstations, numerical weather prediction (NWP) models.

System Type	Examples
Data Management Systems	CliDE, WIS 2.0 nodes, national hydrological databases.
Early Warning Dissemination Systems	Common Alerting Protocol (CAP) platforms, SMS gateways, web portals.

8.3.2 Adhere to Already Adopted Standards

Table 36 Key standards for ensuring data interoperability.

Standard	Purpose	Requirement
WIS 2.0	Global data exchange framework	All Tier 1 and 2 stations must be WIS 2.0 compliant.
BUFR/netCDF	Data formatting	Use for operational and archival data exchange.
Open APIs	System interoperability	Prefer systems with open, documented APIs for integration.

8.4 Cybersecurity and Data Integrity

8.4.1 Secure Transmission and Access

Table 37 Cybersecurity measures for data transmission and access.

Measure	Implementation
Encryption	Use HTTPS, VPNs, or encrypted satellite links for data transmission from field to server.
Authentication	Implement strong access controls (API keys, tokens, multi-factor authentication) for all system access.
Network Segmentation	Isolate operational networks from public-facing systems where possible.

8.4.2 Ensure Data Integrity and Availability

Table 38 Best practices for ensuring data integrity and availability.

Practice	Description
Backup Regime	Daily incremental backups, weekly full backups, with regular tested recovery procedures.
Contingency Procedures	Fallback methods for critical data reception (e.g., manual satellite retrieval, redundant data paths).
Integrity Checks	Use checksums, hash validation, and automated data quality checks to detect corruption.

8.5 Data Sharing & Regional Collaboration

While NMHSs retain ownership, they should share data regionally and globally in line with the WMO Unified Data Policy, using standard formats and protocols.

Table 39 Mechanisms for regional and global data sharing.

Mechanism	Purpose
WIS 2.0	Primary channel for global and regional data exchange.
Regional Data Hubs	SPREP, SPC, or NMHS-led portals for Pacific-specific data sharing.
Bilateral Agreements	For tailored data exchanges with neighbouring countries or regional centres (RSMCs).

Key consideration: Turns national observations into a **global public good** and increases their value through wider use in regional forecasting, research, and climate services.

8.6 Capacity Development for ICT & Data Roles

Sustainable ICT and data management requires skilled personnel. Training should be integrated into the system lifecycle and tailored to specific roles (see also Section 9).

Table 40 ICT and data management roles and key competencies.

Role	Key Competencies
ICT & Telemetry Engineer	Telecommunications protocols, solar power management, network security, hardware/software integration.
Data Management & QC Officer	Use of CliDE and other data systems, WIGOS metadata standards, data quality control procedures.
Forecasting & Warning Specialist	Application of real-time data in models, user-centric product development.

8.7 Key Recommendations

1. Implement redundant telemetry for all Tier 1 and 2 stations.
2. Ensure data sovereignty through contractual agreements and national/controlled storage.
3. Adhere to WIS 2.0 and open standards for interoperability.
4. Apply cybersecurity best practices including encryption, authentication, and regular backups.
5. Share data regionally and globally to maximise value and support regional forecasting efforts.
6. Build ICT and data management capacity through targeted training and regional partnerships.

9 Capacity Development

A sustainable observation network is fundamentally dependent on a skilled, confident, and well-supported workforce. In the Pacific context, often characterised by small teams, remote locations, and high staff turnover, capacity development must be strategic, continuous, and institutionalised.

This section moves beyond one-off training events to provide a holistic framework for building human capability that aligns with the tiered observation system.

9.1 Training Integrated with the System Lifecycle

Capacity development is not a standalone activity. It must be integrated into every stage of the observation system lifecycle, from procurement to decommissioning, and tailored to the specific requirements of each tier.

Table 41 Training framework aligned with the system lifecycle stages.

System Lifecycle Stage	Capacity Development Focus	Example Activities
Procurement & Design	Ensuring systems are supportable; defining training requirements in contracts.	Vendor questionnaires on training; mandating "Supply & Support" models with training clauses.
Installation & Commissioning	Hands-on, learning-by-doing for technical staff.	NMHS technicians working alongside vendor engineers; creating site-specific installation records.
Operations & Maintenance	Building routine and advanced competency for day-to-day sustainability.	Scheduled maintenance workshops; calibration training.
Data Management & Use	Maximising the value of observations for services.	Forecaster training on new data streams; data QC workshops; creating user-friendly products.
Refresh & Decommissioning	Managing technology change and preserving data heritage.	Training on new systems; data migration procedures; environmental disposal standards.

9.2 Role-Based Training Pathways & WMO Competency Alignment

Training must be targeted. The following framework defines core roles within the observation network and maps them to the required competencies and primary tier focus.

Table 42 Role-based training pathways aligned with WMO competencies and tiered systems.

Role	Primary Tier Focus	Core Responsibilities	Key Training & Competency Requirements
Observation Technician	All Tiers	Routine maintenance, visual checks, basic sensor replacement, groundskeeping, simple troubleshooting.	Vendor-specific equipment training; Safety procedures for remote / coastal sites

Role	Primary Tier Focus	Core Responsibilities	Key Training & Competency Requirements
Observation Systems Specialist	Tier 1, Tier 2	Advanced diagnostics, calibration, network performance analysis, managing technician teams, complex repairs.	Meteorology and traceability principles; Data quality control procedures
Data Management & QC Officer	All Tiers	Data ingestion, archival, quality control, metadata management, application of QC flags, user support.	Use of CliDE and other data systems; Understanding of WIGOS metadata standards
Forecasting & Warning Specialist	Tier 2	Interpreting real-time observations for forecasts and warnings; providing feedback on data quality and gaps.	Application of tiered data in models; User-centric product development
ICT & Telemetry Engineer	All Tiers	Managing telemetry networks, data flow architecture, cybersecurity, hardware/software integration.	Telecommunications protocols (WIS 2.0); Solar power system management
Observation Network Manager	All Tiers	Strategic planning, lifecycle budgeting, vendor management, overall network performance and reporting.	Procurement and contract management; Performance monitoring and evaluation

9.3 Leveraging and Strengthening the Regional Training Ecosystem

The Pacific benefits from a network of Regional Training Centres (RTCs) and technical partners. NMHSs should actively plan to utilise and contribute to this ecosystem.

- Align national training needs with other regional partners.
- Invest in developing in-country and regional trainers to ensure sustainability and local relevance of training.
- Participate in and contribute to regional forums, workshops, and online communities of practice for technicians, data managers, and forecasters.

9.4 Mentorship & Succession Planning

To mitigate the impact of staff turnover and preserve critical institutional knowledge:

Table 43 Mentorship and succession planning strategies.

Strategy	Implementation
Structured Mentorship	Pair junior staff with experienced mentors within the NMHS or from a regional partner agency.

Strategy	Implementation
Succession Planning	For roles essential to Tier 1 and critical Tier 2 operations, identify and actively develop at least one successor through planned experience and training.
Knowledge Repositories	Systematically document SOPs, site-specific knowledge, troubleshooting guides, and configuration details in a central, accessible digital repository.

9.5 Mandating Training in Procurement

Training must be a non-negotiable component of all equipment and system procurement. All procurement contracts, especially under "Supply & Support" models, must include:

Table 44 Mandatory training and documentation requirements in procurement contracts.

Requirement	Details
Initial Training	Comprehensive hands-on training during installation / commissioning for all relevant staff.
Documentation	Clear, durable documentation (hard and soft copy) in appropriate languages.
Refresher Options	Availability of refresher or advanced training sessions during the contract period.
Remote Support	Access to remote technical assistance and troubleshooting guidance.

Key consideration: A vendor's proven ability and commitment to training Pacific Island staff should be a **heavily weighted criterion** in procurement evaluations.

9.6 Monitoring the Impact of Capacity Development

Investment in people must be measured by its results. NMHSs should track:

Table 45 Metrics for monitoring the impact of capacity development.

Metric	Method
Training Participation	Number of staff trained, days of training, certifications achieved.
Performance Improvement	Station uptime, data quality scores, meantime-to-repair, reduction in repeat faults.
Service Impact	User feedback on forecasts/warnings; evidence of improved data use in decision-making.
Institutional Strength	Staff retention rates, progression into senior roles, contribution to regional training.

9.7 Cross-Training & Regional Collaboration

Table 46 Cross-training and regional collaboration initiatives.

Initiative	Description
Cross-Training	Train observation staff in basic telemetry troubleshooting and ICT staff in meteorological data fundamentals to build a more resilient, multi-skilled team.
Regional Partnerships	Actively participate in and contribute to regional training offered by RTCs and partner organisations.
Knowledge Sharing	Encourage sharing of tools, scripts, configuration templates, and SOPs between Pacific NMHSs to avoid "reinventing the wheel."
Train-the-Trainer Programmes	Develop in-country trainers to ensure sustainability and local relevance of training.

9.8 Funding & Resourcing Capacity Development

Capacity development must be budgeted for explicitly within both project and operational funding.

Table 47 Funding and resourcing sources for capacity development.

Source	Potential Use
Project Budgets	Include training and capacity-building line items in all observation system procurement and upgrade projects.
National Budgets	Advocate for dedicated training funds within NMHS operational budgets.
Donor Funding	Seek aligned donor support for regional training initiatives, scholarships, and train-the-trainer programmes.
In-Kind Support	Leverage partner agency support for mentorship, remote training, and materials development.

9.9 Key Recommendations

1. Adopt role-based training pathways aligned with WMO competencies and tiered system requirements.
2. Integrate training into all procurement contracts, mandating vendor-provided training and documentation.
3. Leverage the regional training ecosystem through RTCs, USP, SPC, and technical partners.
4. Implement mentorship and succession planning to retain institutional knowledge.
5. Monitor and evaluate training impact on both technical performance and service delivery.
6. Budget for capacity development as a core component of sustainable observation networks.

10 Governance, Implementation & Regional Coordination

The successful adoption and sustainability of this guidance require clear roles and accountability across regional and national levels.

10.1 Roles and Responsibilities

Table 48 Roles and responsibilities of key actors in the implementation of this guidance.

Actor	Primary Role	Key Responsibilities
WRP Programme (through SPREP)	Regional oversight & adoption	Endorse and promote the guidance; coordinate regional compliance; facilitate pooled procurement; provide technical review of investments.
Pacific NMHSs	National implementation	Adopt standards in national planning; apply tiered specifications in procurement; ensure ongoing maintenance and data quality; report on performance.
Development Partners & Donors	Alignment & funding	Ensure investments align with this guidance; support WRP-coordinated procurement; avoid fragmented or incompatible systems.
Regional Technical Partners	Technical support & capacity building	Provide calibration, training, and maintenance support in line with tiered specifications; participate in regional review panels.

Key consideration: WRP support for NMHS operations will be prioritised for those adopting and complying with this guidance. Non-compliance may limit access to WRP technical and financial assistance.

10.2 Compliance Monitoring & Assurance

To ensure consistent application of standards, the following mechanisms will be used:

- WRP staff and SPREP officers will review major procurement plans (>USD 20,000) to ensure alignment with guidance before tenders are issued.
- Where requested, SPREP can conduct pooled or delegated procurement on behalf of NMHSs, ensuring full compliance with regional standards.
- NMHSs will complete a brief annual report against guidance KPIs (e.g., % of stations by tier, data availability, maintenance logs).
- Every 2 years, WRP/SPREP will coordinate light-touch audits of a sample of NMHSs to review compliance and identify support needs.

10.3 Phased Implementation Timeline

Implementation should be phased to allow for capacity building, system alignment, and sustainable investment:

Table 49 Phased implementation timeline for adopting the guidance.

Phase	Timeline	Key Activities
Phase 1: Awareness & Adoption	Years 1–2	Launch guidance; conduct regional workshops; integrate into WRP partner agreements; NMHSs map existing stations to tiers.
Phase 2: Procurement Alignment	Years 2–4	Apply tiered specs to all new procurements; establish regional review panels; begin pooled procurement pilots; update national maintenance plans.

Phase	Timeline	Key Activities
Phase 3: Full Compliance & Sustainability	Years 4–6	All new investments fully compliant; regional spare parts pool operational; NMHSs report annually on performance; guidance updated based on lessons learned.
Phase 4: Regional Integration & Scaling	Years 6–10	Full interoperability achieved; data sharing seamless; regional calibration and training hubs fully functional; guidance embedded in Pacific meteorological strategy.

10.4 Governance Structure for Regional Coordination

A practical governance structure is recommended to oversee implementation (see Figure 3).

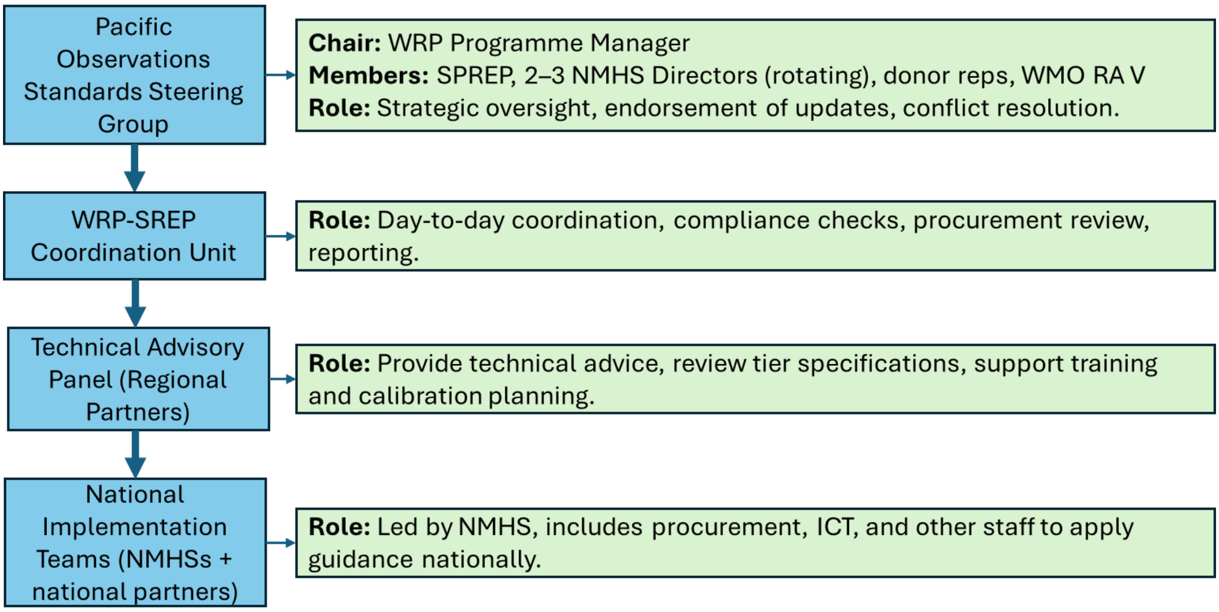

Figure 3 Governance and coordination structure for the implementation of this guidance across the Pacific region, showing roles of WRP, NMHSs, development partners, and regional technical bodies.

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Disclaimer

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12 Glossary of terms and acronyms

12.1 Terms and Definitions

Term	Definition	Source(s)
Air Temperature	The temperature of the air, typically measured in a shelter 1.25–2 m above ground level. **Maximum, minimum,** and **mean** temperatures are the highest, lowest, and average values over a specified period (e.g., 24 hours).	[1]
Relative Humidity	The ratio, in percent, of the observed vapour pressure to the saturation vapour pressure with respect to water at the same temperature and pressure.	[1]
Air Pressure	The force exerted by the atmosphere per unit area. Also called **atmospheric pressure**. Expressed in hectopascals (hPa).	[1]
Wind Speed and Direction	**Wind Speed:** The rate of motion of air. **Wind Direction:** The direction from which the wind blows, expressed in degrees from true north.	[1]
Wind Gust	The maximum value of the wind speed averaged over a short time interval, typically 3 seconds.	[1]
Accumulated Precipitation (total amount of precipitation)	The total amount of precipitation collected over a specified period. Expressed as the depth of water in millimetres (mm).	[1]
Precipitation Intensity	The rate of fall of precipitation, expressed in millimetres per hour (mm/h).	[1]
Atmospheric Temperature (Profile)	The temperature of the air at various levels in the atmosphere, measured by radiosondes, aircraft, or other profiling systems.	[1]
Atmospheric Pressure (Profile)	The atmospheric pressure at various levels above the surface.	[1]
Relative Humidity (Profile)	The relative humidity at various levels in the atmosphere.	[1]
Wind/Wind Shear (Profile)	**Wind:** Speed and direction at altitude. **Wind Shear:** The variation in wind speed and/or direction over a short distance, primarily vertical.	[1]; [35]
Dew Point Temperature	Temperature to which a volume of air must be cooled at constant pressure and constant moisture in order to reach saturation; any further cooling causes condensation.	[35]
Sea Surface Temperature (SST)	The temperature of the water layer from 1 mm to 20 m below the sea-air interface. An Essential Climate Variable (ECV).	[36]
Coastal Sea Level	The height of the sea surface relative to a fixed benchmark on land.	[36]

Term	Definition	Source(s)
	Includes components from **tides** (astronomical), **storm surge** (meteorological), and long-term **anomalies**.	
Sea State	A description of the ocean surface with respect to wind waves and swell. Characterised by **significant wave height** (Hs), **wave period**, and **wave direction**.	[35]
River Height / Discharge	**River Height (Stage):** The elevation of the water surface at a gauging station. **Discharge:** The volume of water flowing through a cross-section per unit of time (m^3/s).	[37]; [35]; [36]
Groundwater Levels	The depth of the water table, or the hydraulic head, in an aquifer, measured relative to a datum (often mean sea level).	[35]; [36]
Water Quality	The physical, chemical, and biological characteristics of water, determining its fitness for various uses and ecosystem health.	[38]
Soil Moisture	The average water content in the soil, which can be expressed in volumetric, gravimetric, or relative units. An Essential Climate Variable (ECV). Expressed as Volumetric Water Content (VWC).	[36]
Soil Temperature	The temperature of the soil at a specified depth. The standard depths for soil temperature measurements are 5, 10, 20, 50, and 100 cm below the surface.	[1]; [36]
Land Use / Land Cover	**Land Cover:** The observed (bio)-physical cover of the earth's surface for regional and global climate applications. **Land Use:** The arrangements, activities, and inputs people undertake in a certain land cover type.	[36]
Water Level	The elevation of the water surface of a river (or a lake, reservoir) regarding a reference (the ellipsoid).	[36]
Effective Water Level	(Operational term) The difference between the measured water level and the anticipated minimum water level over the station's lifecycle. Used for defining required uncertainty.	Derived from [9]; [36]
Interoperability	The ability of diverse systems and organisations to work together (inter-operate). In meteorology, this enables seamless data exchange.	[6]
Total Cost of Ownership (TCO)	A financial estimate to determine the direct and indirect costs of a product or system over its entire lifecycle.	[16]
Observation Network	A coordinated set of observing stations and facilities designed to monitor the state of the environment.	Derived from [1]
Telemetry	The automated process of measuring and transmitting data from remote sources.	Derived from [1]

Term	Definition	Source(s)
Calibration	Operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.	[1]
Maintenance Planning	The scheduled and systematic activities required to ensure an observing system continues to perform within its specified requirements.	Derived from [1]

12.2 Acronyms and Abbreviations

Acronym	Full Form	Notes / Context
ACP	African, Caribbean and Pacific	Group of countries engaged in the EU-funded Intra-ACP programmes (e.g., CLIMSA).
AWS	Automatic Weather Station	Unattended meteorological station measuring key weather variables automatically.
BoM	Bureau of Meteorology (Australia)	Key regional partner supporting Pacific NMHSs.
BUFR	Binary Universal Form for the Representation of meteorological data	WMO standard for transmitting observational data in binary format.
CLIMSA	Intra-ACP Climate Services and Related Applications Programme	EU-funded programme strengthening climate services in ACP regions.
COSPPac	Climate and Oceans Support Program in the Pacific	Australian and New Zealand Government-funded programme enhancing Pacific climate services.
CSV	Comma-Separated Values	Simple text file format used for data exchange and storage.
DIAL	Differential Absorption Lidar	Remote sensing instrument for atmospheric gas concentration measurements.
DO	Dissolved Oxygen	Key variable for freshwater and marine environmental monitoring.
DRR	Disaster Risk Reduction	Framework for reducing exposure and vulnerability to natural hazards.
EW4ALL	Early Warnings for All	Global UN initiative to ensure all people are protected by early warning systems by 2027.
GBON	Global Basic Observing Network	WMO initiative ensuring sustained, high-quality global meteorological observations.

Acronym	Full Form	Notes / Context
GNSS	Global Navigation Satellite System	Used for atmospheric profiling, timing, and positioning of observation stations.
GPRS	General Packet Radio Service	Mobile data communication used by some remote telemetry systems.
HF	High Frequency	Radio band used for long-distance communication from remote observation sites.
ICT	Information and Communication Technology	Encompasses digital systems for data management, processing, and sharing.
JSON	JavaScript Object Notation	Lightweight data format used in web applications and APIs.
M&E	Monitoring and Evaluation	Used for tracking performance and impact of projects and systems.
NEMS	National Environmental Monitoring Standards (New Zealand)	Reference standards for environmental monitoring methods and QA/QC.
NMHS	National Meteorological and Hydrological Service	National authority responsible for weather, climate, and hydrology observations.
O&M	Operations and Maintenance	Activities ensuring continuous and reliable performance of observation systems.
PAGASA	Philippine Atmospheric, Geophysical, and Astronomical Services Administration	Able to provide regional support and training through RIC and RTC.
PICI	Pacific Island Communications, Infrastructure Panel	Regional mechanism supporting communications standards and infrastructure.
PICTs	Pacific Island Countries and Territories	Refers collectively to the nations and territories of the Pacific region.
PIFS	Pacific Islands Forum Secretariat	Regional intergovernmental organisation coordinating political and policy cooperation.
QC	Quality Control	Procedures ensuring Uncertainty and reliability of observational data.
RA V	WMO Regional Association V (South-West Pacific)	WMO regional grouping for the Pacific and parts of Southeast Asia.
RBON	Regional Basic Observing Network	WMO regional network supporting GBON implementation and regional data exchange.
RIC	Regional Instrument Centre	WMO-designated facility supporting calibration, maintenance, and training.
RO	Radio Occultation	Satellite-based technique for atmospheric profiling using GNSS signals.

Acronym	Full Form	Notes / Context
RSMC	Regional Specialized Meteorological Centre	WMO-designated centres providing regional forecasting and analysis (e.g., RSMC Nadi).
RTC	Regional Training Centre	WMO-accredited institution providing technical training for NMHSs.
SOFF	Systematic Observations Financing Facility	Global financing mechanism supporting GBON implementation in developing countries.
SPC	Pacific Community	Regional scientific and technical organisation supporting development across PICTs.
SPREP	Secretariat of the Pacific Regional Environment Programme	Regional intergovernmental organisation focused on environmental protection and climate resilience.
SSA	Sea Surface Anomaly	Deviation of sea surface variables (e.g., temperature or height) from the mean.
SST	Sea Surface Temperature	Key climate indicator monitored regionally and globally.
TCO	Total Cost of Ownership	Full lifecycle cost including procurement, maintenance, training, and disposal.

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Appendix A Regional Support for Calibration, Training, and Capacity Development in the Pacific

Part A: WMO Regional Instrument Centres (RICs) and Regional Training Centres (RTCs)

Centre	Location	Type	Core Functions	Relevance for Pacific NMHSs
RIC Manila	Philippines (Philippine Atmospheric, Geophysical, and Astronomical Services Administration)	RIC	To assist WMO Members in calibrating their NMHS measurement reference standards (or field verification equipment in case a NMHS does not have measurement reference standards) and related monitoring instruments. To make a positive contribution regarding quality of observations. Advise Members on enquiries regarding instrument performance, maintenance and the availability of relevant guidance materials. To lead, actively participate in, or assist, in the organization of workshops and training events on calibration and maintenance of instruments.	Able to provide calibration and regional support for Pacific NMHS. Able to calibrate: • Temperature • Relative humidity • Atmospheric pressure • Wind • Precipitation
RIC Melbourne	Australia (Bureau of Meteorology)	RIC	As above.	Able to provide calibration and regional support for Pacific NMHSs until RIC Nadi is operational Able to calibrate: • Temperature • Relative humidity • Atmospheric pressure

Centre	Location	Type	Core Functions	Relevance for Pacific NMHSs
				• Precipitation
RIC Tsukuba	Japan (Japan Meteorological Agency)	RIC	As above.	Able to provide calibration and regional support for Pacific NMHSs; potential partner for specialised calibration needs. Able to calibrate: • Temperature • Relative humidity • Atmospheric pressure • Wind
RIC Nadi (planned 2027)	Fiji (SPREP/WMO partnership)	RIC	As above.	Proposed to calibrate: • Temperature • Relative humidity • Atmospheric pressure
RTC Nadi (planned 2027)	Fiji (in collaboration with USP/SPREP)	RTC	Training of Pacific NMHS staff in instrument maintenance, data management, ICT, and forecasting	Will be the dedicated Pacific training hub, building sustainable regional workforce capacity
RTC Melbourne	Australia (Bureau of Meteorology)	RTC	Training on forecasting, climate services, instrument management, and ICT systems	Current main training provider for Pacific NMHSs; will complement RTC Nadi from 2027
RTC Tsukuba	Japan (Japan Meteorological Agency)	RTC	Advanced training in meteorology, instrument use, and observation techniques	Specialised training opportunities for Pacific NMHS staff

Part B: Regional Partners Supporting Training, Calibration, and Service Delivery

Organisation	Location	Role	Core Functions
SPREP (Secretariat of the Pacific Regional Environment Programme)	Apia, Samoa	Regional Organisation	Training, technical support for climate services
USP (University of the South Pacific)	Suva, Fiji	Academic Partner	Provides formal education and vocational training in meteorology, ICT, and climate science; role in RTC Nadi
Earth Sciences New Zealand	Wellington & Christchurch, New Zealand	Technical Partner	Hydrology, marine, and climate services; training, maintenance, and calibration support
New Zealand Meteorological Services	Wellington, New Zealand	Technical Partner	Radar training, calibration and support; Technical training and support aviation, upper-air; forecasting training and support.
BoM (Australian Bureau of Meteorology)	Melbourne, Australia	Technical Partner	Technical training, radar and ICT expertise, bilateral NMHS support (beyond RIC/RTC functions)
JMA (Japan Meteorological Agency)	Tokyo/Tsukuba, Japan	Technical Partner	Advanced training, satellite data provision, calibration standards; support through JICA and WMO programmes
SPC (Pacific Community)	Noumea, New Caledonia & Suva, Fiji	Regional Organisation	Water resources, GIS, ICT, geoscience capacity development, hydrology training
WMO (World Meteorological Organization) Regional Offices	Singapore & Apia, Samoa	Regional Organisation	Coordinating regional meteorological activities, strengthening capacity development, and facilitating implementation of WMO programmes. Link between countries and WMO headquarters to improve service delivery, data exchange, and regional cooperation.

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Weather Ready Pacific