Plan for a Regional Upper Air Observing Network for the South Pacific

in Support of the GCOS and EGOS Implementation Plans

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1. Executive Summary

This document presents and justifies a Plan for a Regional Upper Air Observing Network for the South Pacific for the sustained international support of upper-air radiosonde observations in Pacific Island States. The main points are:

- All countries need the outputs from global numerical weather prediction (NWP), climate models and reanalyses to provide weather and climate services: e.g. early warning systems, planning and risk analysis.
- Sustained surface pressure and upper air wind observations made globally, meeting the minimum WMO requirements, are vital to maintain and improve the global numerical weather prediction (NWP) and climate models and reanalysis products.
- These observations are a global good: all nations will benefit from a global network of observations, while the local benefit of a single station may be limited.
- The current model of expecting all countries to sustainably provide the resources to maintain and operate monitoring stations does not work in countries with fewer resources, especially those with large oceanic territories: to provide the same level as spending as developed countries could consume an amount equal or greater than their entire GDP.
- A different funding model is needed where resources from those that can afford it are pooled to support other observations.
- It is proposed that across the Pacific region the requirement for an upper-air station every 500 km is relaxed to every 1000 km due to the lack of suitable land.

The Plan for a Regional Upper Air Observing Network for the South Pacific would cost 1.388 Million Euro a year for 10 years and includes:

1. 20 operational upper-air stations across the region across 13 countires reporting 2 times a day including repairs and replacement, where needed, and consumables and other running costs.
2. Upgrading one station to be a reference site, providing traceable high-quality data and becoming a centre of expertise for the regional network.
3. Establishment and operation of a regional network of operators with on-going training, and exchange will increase the sustainability of the network.

It is assumed that the National Metrological and Hydrological Services (NMHS) will provide the basic infrastructure (for example weatherproof building, mains power, water, communications and enclosure for balloon filling). It is also assumed that suitably trained staff will be available for the operations, management and maintenance of the station.

This plan is the main outcome of the Joint Global Climate Observing System (GCOS) and WMO Integrated Observing System (WIGOS) Workshop for the Pacific Small Island Developing States held in Fiji. This meeting was organised jointly by the Global Climate Observing System (GCOS), and the WMO Integrated Global Observing System (WIGOS) focusing on gaps in in the observing systems for weather and climate in Pacific island states. Upper air measurements were identified as the in-situ observations whose improvement would give most benefit to the models that underpin both numerical weather prediction and climate prediction and analysis - not just in the Pacific region, but also around the world. The conclusions of the workshop are contained in Annex A – Key messages from the Joint GCOS-WIGOS Workshop for Pacific SIDS.

The workshop concluded that

- Systematic upper air observations in the Pacific region, tend to have the highest measured impact, of all ground-based measurements, on the quality and accuracy of weather and climate analysis and prediction not only locally, but globally. The resulting products underpin weather and climate aspects of early warning systems as well as other climate-related services.

- Both the spatial density and observing frequency of the upper air network over the South Pacific region currently fall far short of GCOS and WMO requirements. Due to the unique geography of the region – vast swathes of ocean surface with relative little land mass distributed over some 20 small island states with modest populations and correspondingly modest GDPs – systematic observation is particularly challenging in this region.
- The upper air network over the South Pacific therefore needs sustained international support.

The workshop agreed that the participants should draft a plan for the sustainable establishment of a network of upper-air monitoring sites across the region that is suitable for long-term international support.

The UNFCCC has an important interest in systematic observations of the climate system as expressed in article 5 of the convention, together with national reporting requirements in article 4. The UNFCCC's Paris Agreement stresses the importance of systematic observations for adaptation and early warning systems together the need for developed counties to support those with fewer resources.

Box 1 GCOS and WIGOS

GCOS, established in 1992 and supported by WM0, aims to ensure that systematic observations are undertaken and that the results are made available to all users. It reviews the status of the climate system (GCOS 2015) and prepare Implementation plans (GCOS 2016) that are presented to the UNFCCC. These plans identify what needs to be monitored the Essential Climate Variables (ECV), and specific actions that should be undertaken to ensure the continuation and improvement of the global climate observing system.

WIGOS is an all-encompassing approach to the improvement and evolution of WMO and WMO co-sponsored observing systems in support of all WMO application areas, including their contributions to GCOS. It will foster the orderly evolution of the present WMO global observing systems, in particular the Global Observing System (GOS), the hydrological observing systems and the observing components of the Global Atmosphere Watch (GAW) and the Global Cryosphere Watch (GCW), into an integrated, comprehensive and coordinated system. It will satisfy, in a cost-effective and sustainable manner, the evolving observing requirements of WMO Members, while enhancing coordination of the WMO observing system with systems operated by international partners. Together with the WMO Information System (WIS), WIGOS will be the basis for the provision of accurate, reliable and timely weather, climate, water and related environmental observations and products by all Members and WMO Programmes, which will lead to improved service delivery.

Observational requirements clearly depend on the applications areas they are addressing. Therefore, requirements for global observations may not meet all the local needs. GCOS provides requirements for 54 Essential Climate Variables (ECV)[1]. However, not all these need to be observed by each state. Some are provided by satellite observations, while ocean observations are often performed by international consortia. The WMO Integrated Global Observing System (WIGOS) also maintains observational requirements in its OSCAR database[2] for a range of weather-related applications.

[1] GCOS (2016) The Global Observing System for Climate: Implementation Needs GCOS-200, pub. WMO, Geneva. http://gcos.wmo.int See annex A
[2] OSCAR: Observing Systems Capability Analysis and Review Tool. https://www.wmo-sat.info/oscar/

2. Global Climate Observations and Early Warning Systems

Meteorological observations are vital for both immediate needs such as weather forecasting and early warning systems, and longer-term needs such as supporting and planning adaptation to climate change and ensuring sustainable development. These twin needs were recognised by the UNFCCC. The Paris Agreement calls for *Strengthening scientific knowledge on climate, including research, systematic observation of the climate system and early warning systems, in a manner that informs climate services and supports decision-making* (Article 7, para 7). In 2016 (decision 19/CP.22), the UNFCCC emphasized "*the need to maintain, strengthen and build capacities for climate observations*…" while the need for support in the LDCs and small island developing States was also highlighted.

Weather and climate phenomena unfold on a variety of spatial and temporal scales, but common to them all is a general lack of respect for our shifting social, political and economic boundaries. In order to be successful, our efforts to observe, monitor, understand or predict them must therefore take this fundamentally transnational nature of weather and climate into account.

This has been at least intuitively understood for centuries, and as quantitative prediction methods gradually matured in the years after World War II, the World Meteorological Organization was established in 1950 with one of its primary goals being to coordinate and facilitate real-time international exchange of meteorological observations for weather prediction purposes. Since that time our collective, global weather prediction abilities have been able to develop and thrive, founded on the principle of free and open international exchange of weather observations through the Global Observing System and the Global Telecommunications System of the WMO World Weather Watch.

Over the last decade, the broadening mandate of WMO and the emergence of additional important application areas under the broader umbrella of weather, climate and water has led to the creation of the WMO Integrated Global Observing System (WIGOS) as a framework to include also observations related to hydrology, atmospheric composition and cryosphere monitoring.

After climate change had emerged as a growing political and economic concern through the 1980's and early 1990's, the Global Climate Observing System (GCOS) was established in 1992 by WMO, the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the United Nations Environment Programme (UNEP), and the International Council for Science[3] (ICSU). The primary role of GCOS is to advise on the observing needs for monitoring the so-called Essential Climate Variables (ECVs) and to periodically review how well the available observing systems meet those needs.

The two systems, GCOS and WIGOS, are closely linked via the fact that WIGOS is one of the primary implementation mechanisms for GCOS. Many of the observing systems used for ECV monitoring – especially those that provide atmospheric observations or measurements of other variables used for weather prediction purposes - are implemented or coordinated by national weather services of the WMO Members under the WIGOS umbrella, and the present document is therefore focused especially on those observations that are of common interest to WIGOS and GCOS.

For more than 20 years the WMO Commission for Basic System (CBS) has coordinated international efforts to collect, vet and record observational data requirements for numerical weather prediction and climate analysis via Workshops, dedicated studies and Expert Teams. As a result of this work, the observational requirements for most of the core variables used for weather prediction and climate analysis are now well understood and documented in WMO databases[4]. In many parts of the world, the local observing systems have in fact been designed to meet these requirements, whereas in other parts of the world this has not been achieved so far.

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[3] Now the International Science Council (ISC).

[4] WMO's Rolling Review of Requirements (RRR), see http://www.wmo.int/pages/prog/www/OSY/GOS-RRR.html and Observing Systems Capability Analysis and Review Tool (OSCAR), see https://www.wmo-sat.info/oscar/

To better understand both the importance of having a global observing system designed and developed to meet a certain standard and some of the limitations typically encountered when trying to implement it, it may be helpful to highlight and examine three basic characteristics of weather prediction and climate analysis:

The first is that all quantitative weather prediction and climate analysis ultimately hinges on output from global Numerical Weather Prediction (NWP) models, which are essentially detailed, hour by hour computer simulations of the actual global atmospheric behaviour. The fact that this must be done globally is dictated partly by the dynamics of the atmosphere itself, which of course has no horizontal boundaries, partly by the mathematics of the computer models used for analysis and prediction. So even though a given user of climate and weather data may only be interested in a very limited geographic area, e.g. in a particular country, the numerical modellers on whom he or she relies for advice do not have that same luxury: They must attempt to model and understand the global atmosphere in its entirety or face certain failure.

In order to stay close to reality, any global model will need to be continuously fed with global observational data, and the second defining characteristic of the problem is that the observational requirements are essentially identical everywhere, irrespective of geographic location. The reason for that is simply that any ignorance about the current weather upstream of the area of interest for a given prediction will at some point in the future render the prediction useless, and the only way to consistently improve the quality and the range of the prediction is therefore to ensure adequate coverage of observational data everywhere on the globe. Failing to do so means that the quality of prediction and monitoring products of even very well observed regions of the globe such as Europe, North America or East Asia will eventually be negatively impacted by the lack of observational data elsewhere, e.g. over Africa, the polar caps and the majority of the global oceans.

The third defining characteristic of the problem of weather prediction has to do with the specific purpose of local meteorological observations. The general concept of our ability to forecast weather being predicated on the availability of observational data applies in a global sense, but not in a local sense. An observation at a given location generally has only limited value for forecasting the weather at that location. Any local forecast instead relies primarily on observations at the locations from which the future weather is expected to come, and the longer the range of the forecast is intended to be, the further away from the region of interest for the forecast those locations are likely to be. This fact is fundamental to understanding the incentive to invest the very considerable human and financial resources necessary for making observations. As a general rule, countries – especially countries of small geographic extent - do not invest in observations with an expectation of reaping any major local benefit from them; the investment is made with the expectation to receive other and locally more beneficial observations from other countries in return. A very important implication of this is that in order for weather prediction to exist and thrive, it is not enough for all countries to agree to make routine observations, they must also all agree to share them amongst each other.

It is vital that these observations are exchanged internationally in order for them to be used in climate and weather modelling at global and regional scales, and for countries in the region to get the full benefit of these observations.

3. WMO and GCOS Quantitative Requirements

The most important gap across the region is in upper air observations. Most observations sites are not operational due to maintenance and running costs. Upper air (radiosonde) observations are very important for global numerical weather predictions, both regionally and globally, and therefore seasonal forecasts and climate models. The impact of these observations can reach planetary scale. For example, ECMWF has stated that better upper air observations in the south Pacific are critical for extended range forecasts over Europe. Isolated radiosonde observations in the Pacific are routinely shown to have the highest impact of all observations on skill of global NWP models.

Climate prediction and risk analysis, vital for planning adaptation to climate change, depend on outputs of reanalysis and climate models which are driven by the same global NWP models, that themselves, depend on the observational data across the globe. By making and freely exchanging the data, countries can benefit from the outputs of these models.

WMO provides requirements through its RRR[5] process and they are listed in the OSCAR database[6] (Table 1). The threshold horizontal resolution for the WMO requirements is 500km. In Europe and over North America the design separation is 200 to 250 km). However, even 500km is impractical over the oceans.

Radiosondes are critical for climate reanalysis produced by Global NWP systems. Langland et al. (2011) show that local uncertainties in analysis are substantially larger in areas with no conventional (non-satellite) upper air observations. Isolated radiosonde stations have a large impact and twice daily soundings more so than a single daily sounding. This has implications for trend analysis, process understanding, adaptation and potential inputs into the UNFCCC Global Stocktake under the 2015 Paris Agreement.

For global NWP we should focus on improving surface pressure and upper air wind observations. These parameters are amongst the fundamental variables for NWP (the others are temperature and humidity) and both provide driving requirements for surface-based observing systems, since – as opposed to temperature or humidity - neither is currently measured from space.

Satellite observations cannot replace radiosonde observations. Surface pressure can be derived in experimental mode from total CO_2 column measurements and satellite imagers provide horizontal wind components by feature tracking, but only for a single layer with no vertical resolution and limited height information: wind observations are particularly important in the tropics.

[5] RRR: Rolling Review of Requirements. See http://www.wmo.int/pages/prog/www/OSY/GOS-RRR.html
[6] OSCAR: Observing Systems Capability Analysis and Review Tool. https://www.wmo-sat.info/oscar/

Table 1 WIGOS requirements (from OSCAR and the WMO RRR)

		GOAL an ideal requirement above which further improvements are not necessary	**BREAKTHROUGH** an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view, when planning or designing	**THRESHOLD** the minimum requirement to be met to ensure that data are useful
Atmospheric temperature	Horizontal resolution	15 km (50 km High Stratosphere & Mesosphere)	100 km	500 km
	Uncertainty	0.5 K	3K	5 K
	Frequency	6 min	30 min	6 hour
Wind (horizontal)	Horizontal resolution	15 km (50 km High Stratosphere & Mesosphere)	100 km	500 km
	Uncertainty	1 ms^{-1}	3 ms^{-1}	5 ms^{-1} (8ms-1 High Troposphere)
	Frequency	6 min	30 min	6 hour
Wind (vertical)	Horizontal resolution	15 km	100 km	500 km
	Uncertainty	1 cm s^{-1}	5 cm s^{-1}	5cm s^{-1}
	Frequency	6 min	30 min	6 hour

The threshold requirement (given in WMO's OSCAR database) is 500 km, which means that in principle every grid cell of 500 km x 500 km = 250,000 km^2 should have a radiosonde station as a minimum. This may make sense for the continental landmasses: in Europe and over North America the design separation is 200 to 250 km. However, a 500 km resolution is unachievable in the Pacific.

A practical alternative would be to consider adopting a lower regional (Pacific) threshold resolution of 750 or 1000 km. Even 1000 km would be quite ambitious, given that the total surface area of the Pacific is about 165,000,000 km^2, which would require on 165 radiosonde stations.

The ECMWF Deputy Director of Forecasts noted in September 2017 regarding the potential value of rehabilitating the upper air network over Papua New Guinea:

> *"Radiosondes in PNG can help capture the amplitude and phase of the MJO, and the Kelvin waves, and help predict when Rossby wave trains may be triggered from that area, and then propagate across the Pacific to N. America, and where they influence the mid-latitude storms tracks and ultimately the weather in Europe"*

> *"Isolated radiosondes are individually much more valuable and bring much more benefit to forecast quality than observations in a dense network (benefit per station that is!)"*

Therefore, it is proposed to design a network around a regional WMO Requirement for Global NWP. This would be a foundational activity with a significant impact on almost all weather and climate products. This would provide for non-satellite observations surface pressure and upper air winds. A slightly lower threshold resolution requirement that recommended by WMO should be considered due to unique geography of the South Pacific. Such a redesigned network would be ambitious but not impossible.

4. Basic Observations are a Global Good

Meeting the WIGOS and GCOS observational requirements, and sharing the resultant data, implies that countries will be able to protect themselves from weather and climate change events. Forecasting events allows early warnings and preparations while understanding future risks of extreme events and how they will change with climate change allows planning and adaptation.

The conundrum hinted at in Chapter 2 – the fact that the heaviest users of weather and climate products are concentrated in relatively small, densely populated and generally affluent areas of the globe, while the requirements for observational data calls for a uniform density of coverage worldwide – constitutes the basic argument for the main thesis of this document:

A robust, global observing system providing a level of coverage everywhere that meets basic GCOS and WIGOS requirements is a global common good, and it should therefore be designed, deployed, managed and – most importantly - resourced accordingly.

In fact, the WMO Global Observing System of the World Weather Watch and its present-day generalization in WIGOS are both built on this notion, albeit in a limited form. The overall architecture of both systems is founded on two basic principles:

(i) The provision of an adequate number of observations over any national territory is solely the responsibility of the respective national government;

(ii) All WMO Members (i.e. national governments) are obliged to contribute their observations to the common global system (WIGOS) unrestrictedly and free of charge. In principle this then allows all Members to gain access to observations with the required global coverage, which then enables them to generate weather and climate products and provide services to their constituencies.

While this model has proven to be tremendously successful by a wide variety of metrics, it falls short in two important respects:

The first is that a very large part of the Earth's surface – especially in the open ocean and in the polar caps – falls outside any national territory, even when the geographically much more extensive concept of "Exclusive Economic Zones" is applied. The regulatory material under which the obligations of the WMO Members for the implementation of WIGOS are established does not stipulate who is responsible for the observing system in these areas, and the availability of coverage tends to be driven more by shifting national geopolitical agendas than by agreed requirements for observations.

The second is that human population – and thereby to some extent, human capacity, wealth and infrastructure – is highly unevenly distributed even across those parts of the globe that do fall within national territories or national EEZs. The current coverage provided by WIGOS is therefore highly variable, ranging from very good coverage for instance over Europe, South Asia and parts of South America, through adequate coverage for some areas in Central Asia and North America to very poor coverage over the polar caps, most of the global ocean, and large parts of sub-Saharan Africa.

This is well recognized by donor organizations and funding agencies, and numerous projects have been implemented over the last couple of decades attempting to strengthen the observing systems in the areas where they are weakest. Generally, the projects are built around the notion of providing capital investments to develop an adequate observing infrastructure, coupled with an assumption – or in some cases even a formal agreement – that once the project period is over, the recipient country will take on the responsibility for sustaining the network and its operation indefinitely.

This assumption has almost invariably proven to be wrong. In many cases, no additional observations have been flowing into the global networks based on even very substantial investment projects, while in others, relatively short-lived bursts of observational data have resulted. In no case known to us has observing system investment projects resulted in subsequent, long-term sustained observing networks operating under national funding.

The hypothesis underlying the present proposal is that this record of failure is not due to a lack of national willingness within individual national governments, but rather to an incomplete analysis and understanding of the underlying economics of meteorological observations. The following simple comparison between two countries that by many measures belong to opposite extremes of the scale may help illustrate why project-based approaches to the problem of a shortage of weather and climate observations are often doomed to fail.

Switzerland, a relatively small, but highly developed and wealthy European country, has a surface area of some 41,000 km^2 and a GDP of just over USD 520 billion. Switzerland is land-locked, and following the WMO convention is only responsible for providing observational data for its own area. Excluding its contribution to international organizations responsible for meteorological satellite programs, Switzerland spends about USD 22M per year on the acquisition of meteorological observations, which translates into a bit more than USD 500 annually per km^2 of surface area.

At the other end of the scale, Kiribati, an island country in the Pacific has a surface area of just 811 km^2 and an annual GDP of roughly USD 166 million. However, the EEZ of Kiribati extends over almost 3.5 million km^2, and this is arguably the area for which the country would be expected to provide observational data.

There are some obvious differences that need to be taken into account: Switzerland is a very densely populated country, and it has a very high level of economic activity, both of which tend to drive up demand for meteorological products and services. However, from a global perspective, the observational requirements for Switzerland and Kiribati are not all that different; the global models that drive most of the weather and climate applications see no particular difference between the observational requirements in one area versus another.

Switzerland is a mountainous country, and observing systems in mountainous regions are relatively expensive to install and maintain. In contrast to Switzerland, the EEZ of Kiribati is 99.98% covered by water. The large distance between the few spots of dry land where observing systems can be installed, and the associated difficulty of transportation and telecommunication, also makes it extraordinarily costly to operate an adequate observing system here.

Let’s therefore, for the sake of the argument, assume that the cost per surface area of running an adequate observing system for the Kiribati EEZ is roughly similar to what it costs Switzerland to run its observing system, namely USD 500/km^2 per year. The amount required for Kiribati would then be a rather staggering USD 1.75 billion annually, close to 1000% of the GDP of the country. Even scaling back the level of ambition by an order of magnitude or more, this would clearly be impossible both to fund and to justify purely based on a requirement to support local services in the area.

Using a different measure of comparison, Switzerland spends less than 0.004 % of its GDP on meteorological observations. Were a country like Kiribati to apply the same proportion of its national wealth to it contribution to a global observing system, that would amount to just over USD 25K, barely enough to operate a single surface station for an area roughly the size of Europe.

The point of these two comparisons is to demonstrate that it both unrealistic and unreasonable to expect economically small but geographically large countries to shoulder the burden of operating “their” part of even a minimally adequate global weather and climate observing system on their own, under terms that are similar to those applied to affluent and often small countries in the developed world. The current map of the distribution of the WIGOS assets and WIGOS data delivery – with both hardware and observations concentrated over areas of great average population density and wealth – provides ample illustration of this point for many areas of the globe. There is no valid no reason to expect that a continued reliance on project funding will lead to any substantial change in the overall picture.

Table 2 shows that all the countries in the region have relatively small populations, GDP and land areas but have large areas of ocean in their exclusive economic zones (EEZ). It should be noted that even taking into account the EEZs will not cover all areas of the ocean, while the requirement for observations for global NWP and climate analysis remains in essence the same irrespective of national borders and EEZs.

Table 2 Basic statistics for the Pacific Island States. with USA, and Japan added for comparison. Data form UN and World Bank.

	Land Area	Area of EEZ	Population	GDP	GDP per km^2	Population Density including EEZ
	km^2	million km^2 including land area	thousands, UN Estimate for 2017	World Bank. 2016, million US$	US$ per km^2	km^2 per person
Cook Islands	240	1.80	17	311 [a]	0.00017	0.01
Federated States of Micronesia	702	3.00	106	322	0.00011	0.04
Fiji	18,274	1.30	906	4632	0.00360	0.70
Kiribati	811	3.44	116	166	0.00005	0.03
Marshall Islands	181	1.99	53	183	0.00009	0.03
Nauru	2	0.31	11	102	0.00033	0.04
Niue	26	0.39	2	10 [b]	0.00003	0.00
Palau	535	0.60	22	293	0.00048	0.04
Papua New Guinea	45,258	2.87	8,251	16929	0.00590	2.88
Samoa	283	0.13	196	786	0.00600	1.50
Solomon Islands	2,799	1.62	611	1202	0.00074	0.38
Tonga	72	0.66	108	395	0.00060	0.16
Tuvalu	3	0.75	11	34	0.00005	0.01
Vanuatu	12,300	0.68	276	774	0.00110	0.41
Total above	81,486	20	10,687	26,139	0.00130	0.55
USA	9,525,067	11.35	325,958	18,569,100	1.60	28.72
Japan	377,930	4.48	126,670	4,939,384	1.10	28.28

Notes: [a] data for 2014, [b] data for 2003

5. Gaps in Existing Observations

5.1. Existing Networks

WMO has defined two regional networks; the Regional Basic Synoptic Network (RBSN) and the Regional Basic Climatological Network (RBCN). These networks were designed to meet to the Regional needs for both surface and upper-air observations, whilst contributing to the Global needs as defined on the WMO Observations requirements. (see Section 3 and https://www.wmo-sat.info/oscar/observingrequirements). Whilst not intended, these two networks were almost exclusively for nominated stations from National Meteorological surface and radiosonde observations, and thus a new network is currently being introduced; the Regional Basic Observation Network (RBON) which incorporates all observational systems which contribute to the Regional and Global requirements.

Also in order to serve specifically the needs of global climate applications, two networks of observing stations have been established as GCOS Baseline Networks, mainly on the basis of existing GOS networks. These are; the GCOS Surface Network (GSN) (1023 stations as of April 2017); and the GCOS Upper-Air Network (GUAN) (177 stations as of April 2017). These networks form a minimum configuration required for global applications. Regional climatic needs can be much more extensive, and it is anticipated that such needs will be served by more dense networks on a regional basis, possibly with more extensive requirements for observing programmes and specifications. (see https://public.wmo.int/en/programmes/global-climate-observing-system/networks for more information)

5.2. Current gaps as reported at the GCOS/WIGOS workshop in Fiji (October 2017)

Annex B provides, country by country details of the observation stations as reported by those countries represented at the workshop, along with the current station metadata in WMO/OSCAR surface and an analysis at the time of reports being received at the WMO monitoring centres. It was quite evident that there were significant gaps, and challenges, in the observation networks in the region, and these were summarised as follows:

- The large distances between islands and the remoteness of monitoring sites poses special challenges. Access to some islands by ship may be infrequent and time consuming.
- Communications between monitoring sites and central offices can be difficult without internet, land lines or reliable electrical power.
- Costs of consumables can be prohibitive for small low-GDP countries, and are often at a premium price owing to the low quantities being ordered and cost of shipping.
- Training and capacity building are important widespread needs. This covers all aspects of meteorological service provision from observations, maintenance and repair, to reporting and using data. Assistance is needed to ensure that procurements deliver high-quality, cost-effective equipment.

5.3. Current gaps as reported through WMO/GCOS monitoring

Given the country reports and issues in section 6.2 above, it expected that the monitoring of data availability will show significant deficiencies in the region. Figure 1 below is a 6-hour snapshot of surface pressure observations (SYNOP reports) and it is very evident that many stations are not reporting (black dots), and those that are, are not reporting at the frequency expected. Figure 2 shows the number of CLIMAT reports available over a 12-month period and it can be seen that many of the RBCN stations are red, indicating no reports.

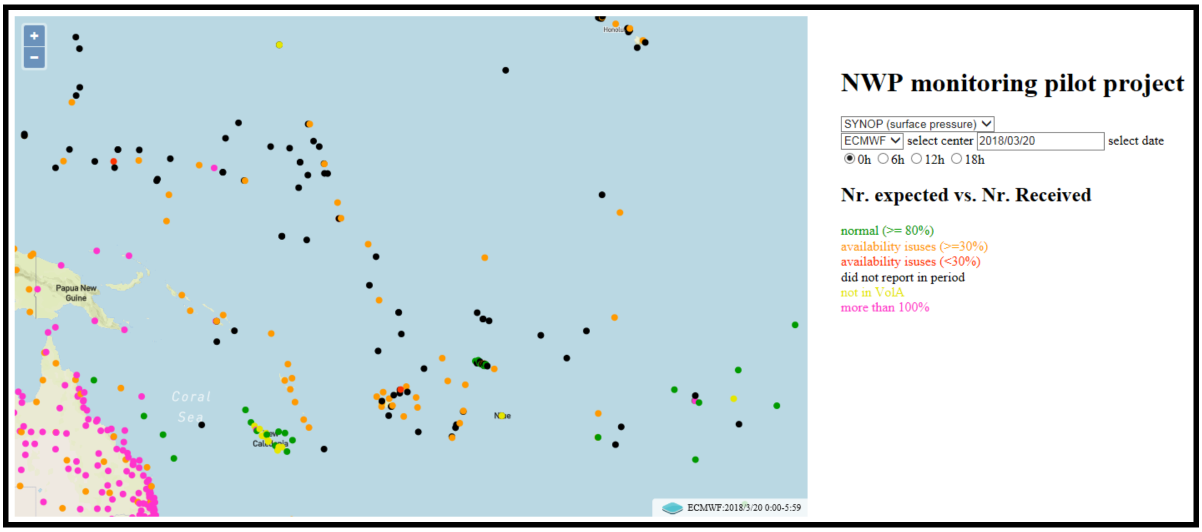

Figure 1 Surface pressure availability (ECMWF 20/03/2018 00utc)

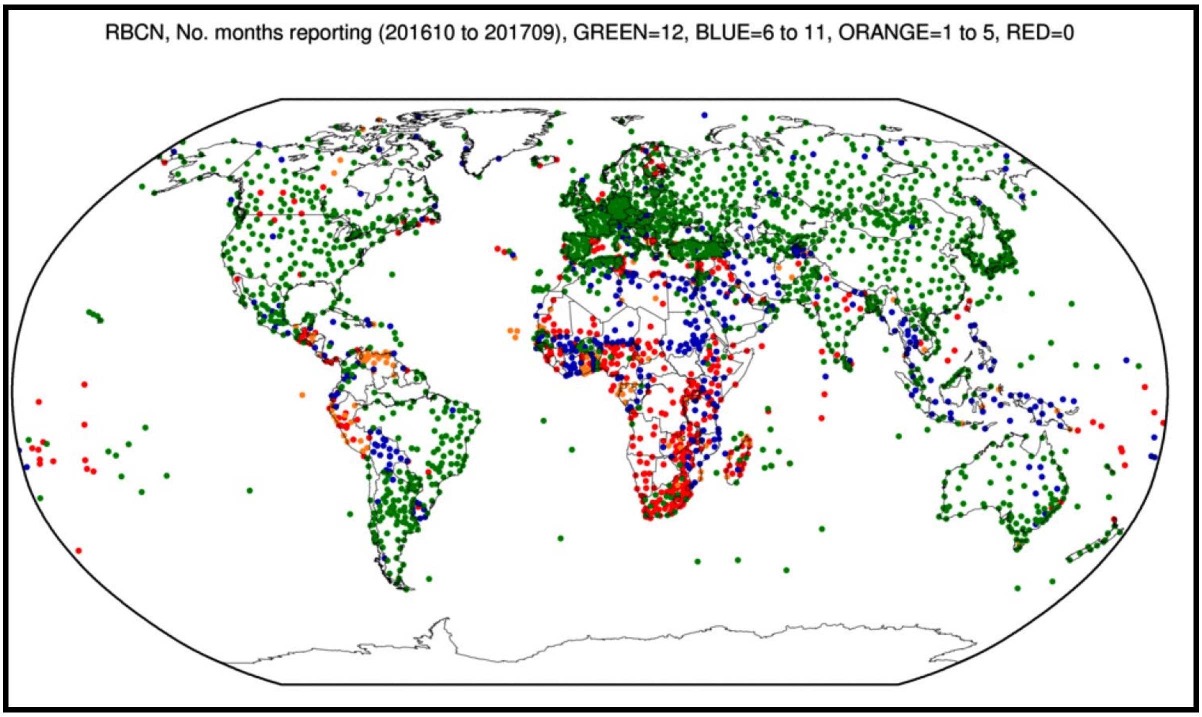

Figure 2 CLIMAT reports availability (NCEI – Oct 2016 to Sept 2017)

For the upper-air (radiosonde) observations the monitoring shows similar deficiencies and, given the importance of these observations as described above, the impact is more significant. Figure 3 shows the 2017 GUAN monitoring with all stations below the red-line not meeting the minimum requirements, and four of the stations from the target region providing zero observations (i.e. silent). Figure 4 shows all radiosonde stations in the target region, plus some neighbouring stations, with total soundings as received at the UK Met Office for 2017. Green dots show stations on average with more than 1 sounding per day, yellow with up to 1 sounding per day and red silent stations.

Region	WMO No	SITE Name	Country	Total	1	2	3	4	5	6	7	8	9	10	11	12	AVG	[2016]	[2015]	[2014]	[2013]
5	91285	Hilo	Hawaii	732	248	220	244	244	244	240	248	248	236	236	240	240	241	245	251	244	235
5	91765	Pago Pago	Samoa	727	224	180	232	224	220	232	244	232	236	228	228	216	225	220	223	227	220
5	91592	Noumea	New Caledonia	716	228	204	240	200	232	212	240	240	216	220	224	236	224	212	207	160	171
5	91376	Majuro	Marshall Is.	718	228	216	212	228	232	232	208	240	212	236	212	216	223	223	210	220	228
5	91680	Nadi	Fiji	700	204	196	208	220	244	228	232	232	240	220	232	188	220	207	224	213	121
5	94998	Macquarie Is.	Australia	715	232	212	208	220	212	192	220	236	224	244	216	224	220	190	190	196	183
5	91212	Guam	Mariana Is.	681	240	168	248	224	248	240	232	224	84	224	240	236	217	228	227	221	237
5	91334	Chuuk	FS of Micronesia	727	204	200	200	196	232	216	236	236	220	228	216	212	216	219	213	192	224
5	91408	Koror	Rep of Palau	728	216	184	204	224	244	228	212	236	204	212	216	204	215	224	230	222	239
5	91938	Tahiti-FAAA	Society Is.	727	204	196	208	204	224	228	232	240	216	220	188	220	215	199	206	174	174
5	93417	Paraparaumu	New Zealand	742	204	224	224	240	200	168	172	212	216	220	216	208	209	221	185	165	183
5	48698	Singapore/Changi	Singapore	717	168	172	208	192	228	220	208	216	220	156	168	172	194	166	165	135	153
5	98223	Laoag	Philippines	719	216	196	220	208	176	160	164	184	172	184	204	208	191	182	190	205	208
5	94610	Perth	Australia	721	204	204	188	200	196	200	152	176	176	168	176	208	187	187	190	182	207
5	96935	Surabaya/Juanda	Indonesia	714	136	136	176	192	196	204	224	212	204	176	96	132	174	147	195	199	167
5	94302	Learmonth	Australia	633	180	132	164	196	164	192	216	240	168	0	204	224	173	203	209	208	220
5	93844	Invercargill	New Zealand	747	160	196	188	124	156	132	204	192	164	196	160	188	172	165	151	139	156
5	94120	Darwin	Australia	724	120	84	108	128	196	184	224	224	208	192	168	172	167	190	190	189	196
5	94975	Hobart	Australia	705	188	148	176	132	132	120	96	52	124	148	148	176	137	125	134	132	69
5	94510	Charleville	Australia	363	116	116	160	80	128	120	124	124	112	104	108	112	117	109	118	120	124
5	94461	Giles	Australia	369	120	104	112	120	112	108	120	120	120	124	116	108	115	111	110	114	110
5	94294	Townsville	Australia	365	124	112	136	116	124	120	92	104	108	124	104	88	113	116	121	123	119
5	91925	Hiva-oa	Marquesas Is.	364	116	108	116	108	120	112	108	116	116	104	112	92	111	107	104	100	101
5	94995	Lord Howe Is.	Australia	357	104	104	112	88	112	104	96	116	120	116	116	120	109	117	107	103	101
5	94299	Willis Island	Australia	372	116	96	92	108	100	108	116	108	116	100	112	120	108	114	114	115	107
5	94996	Norfolk Is.	Australia	322	104	88	96	116	116	108	108	96	96	108	116	104	105	107	116	115	115
5	94659	Woomera	Australia	364	112	100	112	96	100	104	112	88	116	96	108	108	104	110	112	106	111
5	96315	Brunei	Brunei Dar.	545	156	120	128	144	112	120	128	136	132	64	12	0	104	130	63	26	15
5	94203	Broome	Australia	372	80	96	100	92	108	112	100	88	100	120	92	120	101	107	116	116	111
5	91958	Rapa	Austral Is.	365	108	112	116	112	104	72	80	80	92	124	56	116	98	100	76	81	89
5	93997	Raoul/Kermadec	New Zealand	343	116	104	108	108	116	84	108	60	48	28	72	92	87	90	53	39	76
5	91610	Tarawa	Kiribati	272	44	84	68	0	96	88	104	120	100	116	100	108	86	75	83	82	69
5	91643	Funafuti	Tuvalu	290	56	72	48	80	80	116	100	96	100	100	100	80	86	76	97	94	92
5	96996	Cocos Island	Cocos Is.	244	112	44	32	72	108	92	52	80	16	72	120	28	69	110	112	93	104
5	91517	Honiara	Solomon Is.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
5	91557	Bauerfield	Vanuatu	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	38	35	18
5	91843	Rarotonga	Cook Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	106	103	98
5	92035	Port Moresby	Papa New Guinea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4

Figure 3 GUAN Monitoring (NCEP – 2017)

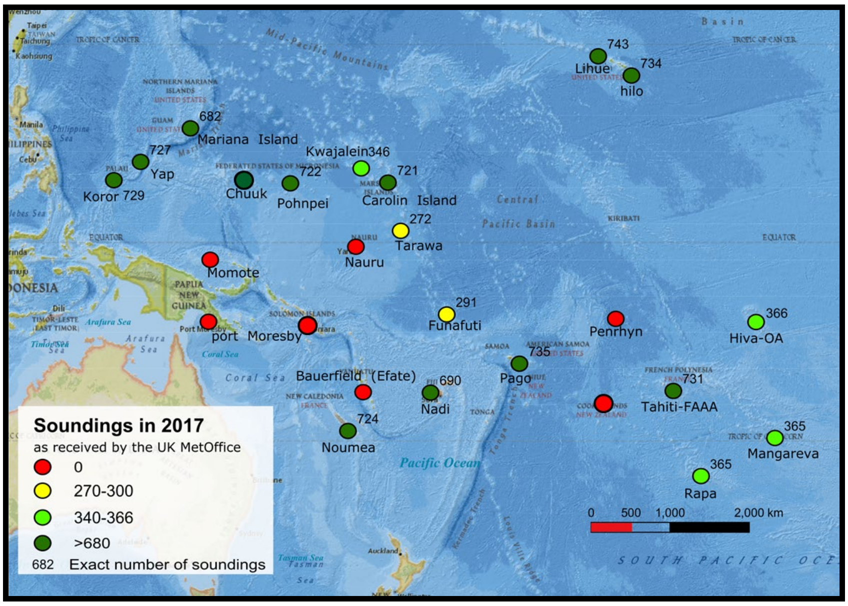

Figure 4 Radiosonde availability (UK Met Office – 2017)

In summary, reporting of both the surface (SYNOP) and radiosonde network shows significant deficiencies in 2017, and it is likely that is also true for other observational networks in the region. Given the issues identified by the country, and supported by the monitoring, there is an urgent need to address the gaps at a Regional scale, through the design, operations, capacity development and resourcing, in order to deliver a sustainable solution and direct benefit to both the countries and the Region.

6. The Pacific Meteorological Council's (PMC) Pacific islands Meteorology Strategy 2017–2026

The Pacific Meteorological Council (PMC) is a specialized subsidiary body of the Secretariat of the Pacific Regional Environment Programme (SPREP), established at the Fourteenth Regional Meteorological Services Directors meeting in Majuro, Republic of Marshall Island in August 2011 to facilitate and coordinate the scientific and technical programme and activities of the Regional Meteorological Services. The PMS produced the Pacific islands Meteorology Strategy 2017–2026 (PIMS 2017) with the vision of enabling National Meteorological and Hydrological Services of the Pacific island countries and territories provide relevant weather, climate, water and ocean services to their people to make informed decisions for their safety, socio-economic well-being, prosperity and sustainable livelihoods. This plan aims to:

- Guide national governments to support NMHSs through national efforts;
- Guide action to meet NMHS priorities through strengthened coordination;
- Guide NMHSs toward critical activities to build or strengthen capacity and planning and to P
- Guide donors and partners to focus on priority capacity building activities and transfer of technology identified by NMHSs and
- delivered either bilaterally or through regional approaches; and
- Guide the PMC and Pacific Meteorological Desk Partnership (PMDP) with respect to sustaining priority actions at the regional level.

The Plan for a Regional Upper Air Observing Network for the South Pacific (as outlined in this document) cuts across all the priorities in the PIMS. For example:

- Priority 1: Improved Weather Services (with improved public weather, aviation and marine services)
- Priority 2: Disaster RISK Reduction (strengthening the capacity of NHMS to implement to Multi-Hazard early Warning Systems and contribute to climate change activities).
- Priority 3: Improved Climate and Hydrological Services (Improved climate information and prediction services)
- Priority 4: Integrated Observing and Communication Systems (Integrating observing and communication systems with long-term maintenance)
- Priority 5: Coordinated Support for NMHS and PMC (Capacity development, Coordination of donors and technical agencies, and efficient and effective partnerships)

7. Plan for a Regional Upper Air Observing Network for the South Pacific

The plan has three main components:

- Establishing a network of 20 stations (with a minimum of one per country). This will be based on existing operational stations, upgrading existing stations that are not reporting 2 observations per day and by establishing some new stations.
- Supporting the existing station in Nadi, Fiji, to become a GCOS Reference Upper Air Network (GRUAN) station and then using this as a centre of expertise to support the other stations in the region by sharing this expertise.
- Establishing a network of trained personnel across the region to support each other, share expertise and experiences and support capacity development. This includes some support for communications, training and data sharing.

7.1. Upper Air Observations

This section proposes an optimum design for the regional network, to address, as far as possible, the requirements detailed in chapter 3 and the gaps identified in chapter 6.

In any network design key principles need to be identified to select optimum observation locations. The underpinning WIGOS network design principles are given in Annex C. This plan attempts to provide, as best as feasible, a horizontally well distributed network across the region, ideally with at least 1 radiosonde station per country and is based on locations which currently have operational evidence of upper air or surface observations. The following criteria were used to select stations and identify the work needed to implement this plan:

Criteria		Assumptions and Actions
1	Existing 'operational' radiosonde stations i.e. those providing at least 2 soundings per day	None
2	Stations providing around 1 sounding per day	increase their frequency to 2 soundings/day, assuming only additional consumables are required
3	Stations providing less than 1 sounding per day but demonstrating an operational capability (i.e. more than 100 soundings per year)	assumes that a technical assessment of the station is necessary to determine if the availability is solely due to supplies of consumables or also technical issues and 5-yearly servicing of hydrogen generator system (HGS)
4	Non-reporting stations with historical evidence, ideally with soundings reported in the last 5 years	an assessment of the local infrastructure would be required in addition to a technical assessment of the station. Assumes some the HGS will need to be replaced and all the others an immediate service repeated at 5-yearly intervals
5	New station locations will be proposed to fill the remaining gaps, identifying locations which currently have operational evidence of surface observations	These stations would require a feasibility assessment, and agreement from the National service, before being considered further. Costs include assessment and establishment of stations, consumables and 5-yearly HGS servicing

The availability statistics given in Figure 4 (UK Met Office 2017) has been used to apply the design criteria above[7]. The results are given in Table 3. The above proposed network would result in **20 radiosonde stations in the region**, and these are plotted in Figure 5.

The skills, motivation and knowledge of the NMHS staff is fundamental to enable this network to operate efficiently and effectively, to meet the user needs, to adhere to the design principle and to be sustainable. Therefore it is recommended that a radiosonde training workshop for the region is undertaken on a regular basis, at least every 4 years, so station managers can be updated on standards and practices, the benefits and requirements for the observations, technological improvements, quality management and system maintenance and exchange best practices and issues across the network. It is suggested that this training workshop takes place at the training facilities on Fiji.

Table 3 The availability statistics (UK Met Office 2017) used to apply the design criteria

Criteria	Number	Station	Number of soundings/ other observations	Support
1	91334	Chuuk, Federated States of Micronesia	728	US Weather Service
	91348	Pohnpei, Federated States of Micronesia	722	US Weather Service
	91376	Majuro, Marshal Islands	721	US Weather Service
	91413	Yap, Federated States of Micronesia	727	US Weather Service
	91480	Koror, Palau	729	US Weather Service
	91680	Nadi Airport, Fiji	735	Fiji Met Service
	91765	Pago, American Samoa	690	US Weather Service
2	91366	Kwajalein, Marshal Islands	346	US Weather Service
3	91610	Tarawa, Kiribati	272	NMS but supported by UK through SPREP
	91643	Funafuti, Tuvalu	291	
4	91520	Honiara, Solomon Islands	silent since 2013	
	91530	Nauru Airport, Nauru	silent since 2014	
	91557	Bauerfeld, Vanuatu	silent since 2016	
	91801	Penrhyn, Cook Islands	silent since unknown	
	91843	Rarotonga, Cook Islands	silent since 2016	
	92035	Port Moresby, Papua New Guinea	silent since 2013	
	92044	Momote, Papua New Guinea	silent since unknown	
5	91490	Christmas Island, Kiribati	3Hr'ly Synops	
	91701	Kanton Island, Kiribati	Synops at 12 and 18utc	
	91779	Lupepau'u International Airport, Tonga	3Hr'ly Synops and GSN station	

[7] This is consistent with the reports form the countries themselves made at the Joint GCOS-WIGOS Workshop for Pacific SIDS, 2017.

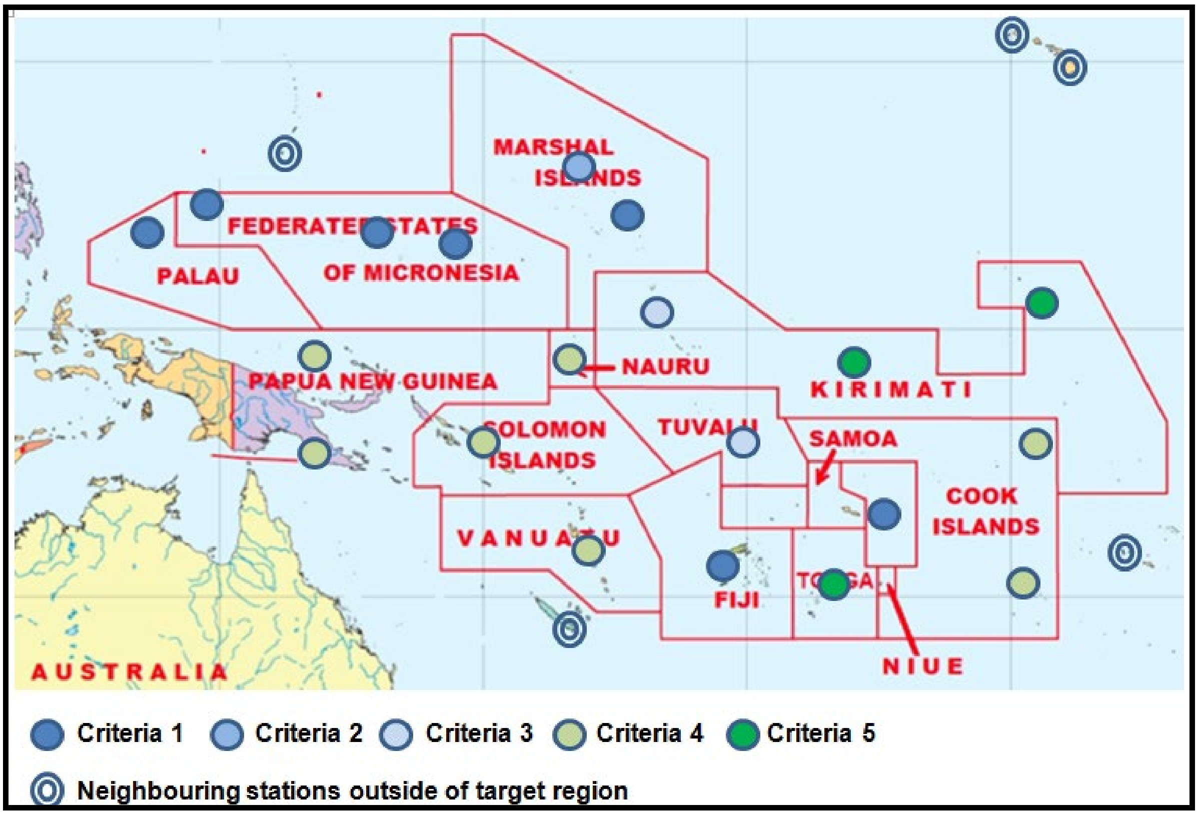

Figure 5 Proposed regional radiosonde network

7.1.1. Costs

The costs for upgrading the network to 20 stations reporting twice a day for 10 year is given in Table 5. The costs are based on the indicative costs given in Table 4 for specific items. The costs assume that there is basic infrastructure available (or to be provided by National Service); for example weatherproof building, mains power, water, communications and enclosure for balloon filling). It is also assumed that suitably trained staff will be available for the operations, management and maintenance of the station. The costs also include an allowance for the remote nature of some of the sites and the time an difficulty of visiting them.

Table 4 Indicative costs (based on recent similar contracts through WMO procurement).

Description	Cost
1 year supply of consumables (Radiosonde, Balloons etc) for 2 soundings per day) – 800 soundings. (Note if enough radiosonde units are ordered this price through a competitive tender would include the ground-system, installation and local staff training.)	90,000 Euro
Service, repair and local staff training for Hydrogen Generator system. (Basic level spares and parts)	35,000 Euro
Replacement or new Hydrogen Generator System (HGS)	100,000 Euro
Replacement or new HGS storage tanks (includes installation)	20,000 Euro

Table 5 Costs of implementing and running a regional upper air network for 10 years (thousand Euro)

	Criteria needs	Number of stations	Start-up costs				1st five year consumables	subsequent 10 years consumables and 5-yearly HGS servicing	Total
			Technical Assessment	New HGS	HGS Service	Total start-up costs			
1	None	7	*0*	*0*	*0*	0	0	0	**0**
2	50% of consumables each year	1	*0*	*0*	*0*	0	225	225	**450**
3	50% of consumables each year, HGS Service each 5 years	2	*0*	*0*	*70*	70	450	520	**1,040**
4	Assume 25 kEuro per site detailed technical assessment and hardware budget, and that 2 stations will require new HGS system, other 5 an immediate service of HGS, 100% of consumables and HGS service every 5 years	7	*175*	*200*	*175*	550	3,150	3,395	**7,095**
5	Detailed technical assessment and 50k hardware budget and new HGS system per location, 100% of consumables and 5 yearly HGS service	3	*150*	*300*	*0*	450	1,350	1,455	**3,255**
	Total equipment, consumables and installation								**11,840**

7.2. GCOS Reference Upper Air Station

The network design principles include the requirement to establish a tiered network[8] approach. Given the already sparse network in this region it would be expected that most, if not all, of these stations would be nominated to the baseline network, the GCOS Upper Air Network (GUAN), but also of value to the region would be the inclusion of a GCOS Reference Upper Air (GRUAN) station (See annex D for details of GRUAN). This would provide reference and traceable measurements, that can be linked to the wider Pacific region network and to GUAN to support the quality and long-term reliability and accuracy needed for climate observations. The GRUAN station would also provide scientific expertise to support the training workshops. A representative of the station would be expected to attend, once a year, the International Coordination Meeting to report, exchange experience and ideas and for additional capacity building.

There are additional benefits to hosting a GRUAN site. The organization running the site will have access to the service and structures provided by AOPC (Atmospheric Observation Panel for Climate), the WCRP (World Climate Research Programme), UNEP (United Nations Environment Programme), IOC (Intergovernmental Oceanographic Commission), ICSU (International Council for Science) and WMO (World Meteorological Organization). Measurements at the sites are anchored to a reference network that provides traceability to internationally recognized measurement standards and users are able to benefit from access to this additional data at no extra direct cost. Furthermore, specialists from various fields of expertise are actively involved in GRUAN, and their knowledge is shared within the network to the benefit of the participating sites. Finally,

[8] The idea that a sparse network of reference stations (e.g., GRUAN) from can be be used to benchmarked other stations. Reference stations should be calibrated to SI or community-accepted traceable standards with fully quantified uncertainties, have the highest level of robustness (e.g. duplicate or triplicate sensors of key variables such as temperature and precipitation), be well sited in locations least affected by urbanization and other non-climatic influences, have regular maintenance and replacement cycling of instruments, the highest standard of metadata collection including photo documentation, and continuous monitoring of system performance to resolve instrument and environmental issues as they arise. Stations such as the “baseline” networks of GCOS (e.g. GSN, GUAN) can form an intermediate data layer, with quality between that of Reference stations and the larger comprehensive network of all observing stations .

GRUAN has a data delivery service through NOAA's national centers for environmental information. The raw measurement data of measurements performed at GRUAN sites are processed at a centralized data processing facility, applying the best possible GRUAN-based corrections to the data, and are subsequently provided to a wide range of users.

It is proposed that the site at Nadi, Fiji, is supported to become a GRUAN station because it already has demonstrated is capability to maintain and report 2 soundings a day, because it is establishing a calibration facility for meteorological observations and because it is capable of hosting training and regional workshops. The minimum requirement is to undertake 1 reference sounding each week and a monthly sounding with a ozonesonde. The estimated costs are given in 1 million EURO over 10 years, including setting up the station, consumables training and travel (See Annex D).

7.3. Establishing regional expertise and capacity.

The skills and experience of operational staff and their managers together with the training provided are vital components of any observing network. Staff should be proficient in all aspects of the observing chain for which they are responsible, and, in particular, should know who to go to when there is a problem with the equipment, operational practices or with the observations themselves. This is an essential part of the quality assurance system: where capacity and knowledge are lacking (often due to a lack of training and documentation) the required quality of the observations cannot be ensured.

Thus regular training on the operational practices, equipment maintenance, quality management and general data awareness is essential. A good example of this is at the UK Met Office where all observational analysists and experts are required to complete an Initial Meteorology and Observing System course which is run every 2 years. There is also a Further Meteorology and Observing System course for those more experienced staff. Both these courses are continually updated and reviewed to ensure they are relevant and up to date. In this region, with many small countries, training will more effective and efficient if undertaken at a regional level. Suitable facilities are available in Fiji (the Fijian Meteorological Office) and Samoa (SPREP).

It is recommended that a radiosonde training workshop for the region is undertaken on a regular basis, at least every 4 years, so station managers can be updated on standards and practices, the benefits and requirements for the observations, technological improvements, quality management and system maintenance and exchange best practices and issues across the network. This could alternate with a more general workshop on broader issues surrounding the network and its data.

A addional role that needs ot be performed centrally for the region is to monitor network performance, report issues and to support solving problems. This could use the WIGOS Data Quality Management System to detect when stations are not reporting and raise this as an issue.

1 MEuro over 10 years should fund:

- a regional workshop held every two years
- additional training around the establishment of new sites or restoration of old site and
- monitoring network performance and detecting issues. Preparing reports on network performance for those funding and manging the overall plan and for meetings of the Pacific Meteorological Council
- travel for site operators, or experts from the GRUAN site in Fiji, to meet to address issues as they arise. One of the criteria for success will be site reporting twice-daily observations: clearly prompt action to address failures and issues will be needed.

7.4. Other General Improvements

The Fiji workshop identified several region-wide issues that also need to be addressed.

7.4.1. Telecommunications

The challenges of telecommunication, both for reporting data and assessing the status of the equipment, was highlighted in by many countries and is often a significant contributor to the poor availability of observations from the region. Given the unique nature of this region (with many remote and isolated islands) the standard practices for communications may not be available (i.e. fixed telephone line, Internet, mobile phone). Therefore bespoke solutions are required.

The use of 'short-burst' satellite communications has been proven, both in the region and for marine observations, to be very effective (both low-cost and technically appropriate). However, these systems and their data charges need to be designed and negotiated at a regional scale, in order to secure the lowest prices from industry and to ensure a sustainable solution. The 'Chatty Beetle' equipment is a good example of this approach.

7.4.2. Integration with measurements from aircraft, ships and buoys

Whilst it is the design above for a regional upper air network is designed according to the observation type, it is important to ensure that this network, and the associated observations, are complementary, and as far as possible, integrated, with other observing systems. If a network is truly to be efficient and cost effective, there should be no excessive duplication of observation data with other systems, except where redundancy and referencing, is a key component of the requirements (e.g. where duplication is needed for validation).

Designing integrated networks has been described extensively within WIGOS and the Expert Team on Observational System Design and Evolution (ET-OSDE) and these guidance documents should be reference as a matter of course when designing and implementing integrated networks.

7.4.3. Upgrading Other Networks

There are other monitoring networks in the region that need improvement. The workshop discussed precipitation where range of issues need to be addressed such as drought, flooding and salt-water intrusion. Observations are not made on all islands or, if they are, are often not representative. While planning for these will need to be performed on a country basis some general points can be made:

a. ***Equipment should match local personnel skills.*** The local infrastructure and staff capability need to be suited to the observing equipment in use. Without this in place neither the quality assurance nor the sustainability of the system is viable. There are many examples of significant investment in new equipment which have either not been operational for more than an year, or even not at all, due to a lack of sufficient local infrastructure and/or staff capability. A local technical assessment of the infrastructure and staff capability should be a mandatory requirement, and at the design phase, of any network improvement project.

b. ***Rehabilitation of existing stations.*** A similar approach to the design process to rehabilitate, and enhance, the radiosonde network in the region should be adopted for any other observing networks in the region, and this should be supported by following the WIGOS Network Design Principles. As part of the network design, priority should be given to existing stations, especially those with long climate records, but local infrastructure and capability need to be careful accessed to ensure a sustainable solution which is both efficient and effective.

c. ***Data Exchange***. Significant improvements to weather predictions and warnings can be made by improving the availability of surface observations by simply ensuring the international exchange of hourly data. This is a very low cost option with substantial benefits.

d. ***Installation of new stations as needed.*** Ideally any new stations should be complementary to the complete network, and a priority should be given to existing stations. However, new stations might be required to replace old stations where the location is no longer viable, or to fill gaps in the network in order to meet the spatial requirements. When considering a new station, particular attention must first be given to the local infrastructure and capability, to ensure that it is sufficient to accommodate and operate the equipment, and more importantly for the communications to report the data and maintain the system.

Table 6 Indicative costs of other potential improvements (kEuro)

	Cost (kEuro)		Notes
Surface observing equipment (automated/semi-automated), Cost dependant on type and range of observations, and the required quality, Local work-service are not included	10 – 100	(per station)	Need country-specific studies but likely need several per country
Communication – Chatty Beetle	30	(10 systems)	
Regional training on observations	200	(25 people) – per 2-week course	Hold every 2 years?
Improved Data Sharing (training and equipment)	0-10		

7.5.Total costs

The total costs of this Plan for a Regional Upper Air Observing Network for the South Pacific are presented in Table 7. This covers all the costs of equipment, consumables, capacity building and regional workshops: project management would be extra and depend on the mechanism chosen for funding. Each NMHS is expected to provide personnel and site infrastructure at their own expense. This does not include improvements to other monitoring sites. This could be achieved with additional funds but would need additional country-by-country assessment to match proposed observational improvements to their individual circumstances and needs.

Table 7 Total 10-costs of implementing the Regional Basic Observing Network for the South Pacific

Item	Cost (kEURO)
Total equipment, consumables and installation to run 20 stations for 10 years,	11,840
Upgrading one site to be a GRUAN station	1,000
Establishing regional expertise and capacity	1,000
Communication – e.g. Chatty Beetle	30
Improved Data Sharing (training and equipment)	10
Total Cost	**13,880**

8. Sustainability

As shown above, the current financing model (asking the WMO Members to fund this out of their NMHS own budgets) will not be adequate for a redesigned Regional Upper Air Observing Network for the South Pacific: As noted in the previous section all upper air observations in the region, apart for Fiji, are funded by countries outside the region (e.g. USA and UK) and it is unreasonable to expect the Pacific Island States to have the funds available to sustain this new network. Therefore it is essential that plans are in place for the long-term support of these stations before the plan is implemented.

Ensuring sustainability requires ***Global Support*** matched by a ***National Commitment***. Sustainability requires ***local technical skills***, ***efficient procurement*** and ***appropriate equipment***.

8.1.1. Global Support

This network will bring global benefits and as such international support should reflect this. This could take the for of financial guarantees from other donor countries or international organisations or a specific fund (e.g. the GCOS Cooperation Mechanism, or a new fund could be established). Whatever for the finance takes, it must be able to fund consumables, maintenance and repairs for at least a decade, together with training, travel and other capacity building. Providing technical support would also be a cost-effective way of supporting this network.

8.1.2. National Commitment

The Plan for a Regional Upper Air Observing Network for the South Pacific assumes that the individual NMHS will provide suitable technical staff, sites and infrastructure such as a weatherproof building, mains power, water, communications and enclosure for balloon filling. It also is based on countries sending data in a timely manner to support both NWP and climate studies. This can be a significant task for some small counties and their performance could be continually reviewed as a requirement for further funding.

8.1.3. Local Technical Skills

Maintaining the equipment and technical competence of the operators essential to maintain the long-term operation of these sites. Several actions are proposed:

- Technical training in making the observations is needed, and this should be repeated at intervals to ensure consistency of the operation of the network.
- Regional upper air workshops (perhaps every 4 years) to discuss the operation of the network and exchange experiences.
- Regular servicing of equipment is needed, and, for the HGS, this includes training it its use.
- Reporting to the Pacific Meteorological Council (PMC) on network performance
- Adding one of the stations to the GRUAN network could be used to provide checks on the other parts of the regional network, training and information exchange to support the other observing stations. Building up a local centre of excellence will support the quality of the regional network.
- A regional centre for training, based at one of the sites (perhaps the GRUAN site) should become a centre for developing and ensuring the necessary skills are available to run, maintain and improve the regional network.

8.1.4. Efficient Procurement

As shown above, for the radiosonde network, the cost of consumables constitutes a significant proportion of the ongoing running costs. This can also be true for other complex systems requiring regular maintenance and calibration. Both a clear and accurate system specification and a robust procurement process is very important to ensure that consumables are fit for purpose and at the best price. In many cases a regular competitive procurement process is the only way to get the best price from industry. This process might be more efficient and effective if conducted at a regional/sub-regional scale as this might allow for the quantity of the units to be level to attract the higher discounts. But for this to work careful consideration of the national procurement laws (liability and quality assurance) need to be considered.

8.1.5. Appropriate equipment

The equipment should match the resources and skills available. The total running cost of a site includes consumables, repairs and maintenance, calibration and validation, data transmission and storage, personal and their training and site infrastructure (buildings, fences etc.). A clear view of these running costs and how they will be sustainably financed is needed before equipment is purchased. In some cases it may be more appropriate to buy cheaper, easy-to-maintain equipment than more advanced but expensive technology.

8.1.6. On-going, real time monitoring of network performance and support to resolve issues

The plan includes funding for on-going, real time monitoring of network performance and also for the capability to resolve issues as they arise on a regional basis. This will ensure that stations do not become silent for extended periods. A significant part of this plan is to provide support for the region over a decade to ensure the long-term operation of the network. This monitoring of network performance will also provide a link to those funding the plan providing regular feedback on the network performance and supporting further investments.

8.1.7. Long-term funding after 10 years

The justification for this investment is that it will sustain a long-term observational activity. While the costs presented here are for 10 years it is intended that the network will continue indefinitely. Thus an important activity, towards the end of the 10 years, will be to secure further funding. It should be noted that the funds requires are modest – less thasn 1.4 million Euro per year covering over 10 countries.

9. Management

This Plan for a Regional Upper Air Observing Network for the South Pacific covers the establishment of a network of 20 sites and the consumables, servicing and capacity building costs over 10 years. The NMHS are expected to supply sites and personnel. As this plan is based on the use of donor funds clear reporting and accountability will be necessary. While the detailed project management and implementation will depend on the precise nature of the funds made available the following points should be followed.:

- Project Tasks will include:
    - Agreement with existing funders on how the stations they support will be integrated into the regional network, particularly where there may be additional funding from the project.
    - Procurement
        - ⇒ Agreement on how to arrange and manage centralised procurement to get the best process for large order volumes Centralised procurement for the entire network rather than individually by site should reduce costs
        - ⇒ Clear, open and transparent tendering, specification and procurement with the requirement to meet WMO observational requirements
        - ⇒ Regional specification of equipment and parts
    - Management of the technical assessments needed to return sites to full operation, re-establish sites or to establish new sites.
    - Coordination with each NMHS on site infrastructure, especially for new sites
    - Management of repair/replacement and service of HGS
    - Establishment of GRUAN station
    - Capacity building
    - Regional Workshops
    - Reporting
        - ⇒ Statistics on the number of reports received by four NWP centres (European Centre for Medium-Range Weather Forecasts (ECMWF), National Centers for Environmental Prediction (NCEP), Deutscher Wetterdienst (DWD) and the Japan Meteorological Agency (JMA) should be used with a target of 2 report per day.
        - ⇒ The Regional Basic Observing Network for the South Pacific should be part of the regional systems and so reports to the Pacific Meteorological Council will be needed to demonstrate this.
        - ⇒ Centralised training is an important part of ensuing sustainability and so evidence of this including the numbers and capacities of trained staff will be important.
        - ⇒ Reporting by each NMHS of the resources they have allocated to the network including personnel and infrastructure.
    - On-going funding
        - ⇒ After the initial establishment of the network further funding for consumables, servicing and capacity building should be conditional on network performance (with due allowance for exceptional circumstances).

If a fund such as the GCOS Cooperation mechanism were to be used, then:

- Donors would have a seat on the Management Board with oversight of the funds and ability to direct project spending
- The project would use of WMO procurement expertise
- Technical expertise and experience in establishing and supporting similar networks in remote regions GCOS and WIGOS would be available.

Finally, before the end of the 10-year period, funding for further periods needs to be secured. This can be supported by successful implementation and documented improvements in data reporting.

Annex A – Key messages from the Joint GCOS-WIGOS Workshop for Pacific SIDS

- Systematic observation of the Earth's climate is a global common good that supports the implementation of the Paris Agreement, in the context of sustainable development and efforts to eradicate poverty.
- Many meteorological observations, made at high spatial and temporal density, support local forecasting and warning applications. These observations are a national responsibility contributing to national and regional needs with some additional global value.
- However, systematic upper air observations, made routinely by radiosondes under the WMO World Weather Watch (WWW) Programme, including the GCOS Upper Air Network (GUAN), support numerical weather prediction (NWP) leading to global benefits. These observations are used primarily for forecasting and climate applications at the international level, including climate reanalyses which form the basis of much of our understanding of climate and climate change; and
- Systematic upper air observations in the Pacific region, tend to have the highest measured impact, of all ground-based measurements, on the quality and accuracy of weather and climate analysis and prediction not only locally, but globally. The resulting products underpin weather and climate aspects of early warning systems as well as other climate-related services.
- Both the spatial density and observing frequency of the upper air network over the South Pacific region currently fall short of GCOS and WMO requirements. Due to the unique geography of the region – vast swathes of ocean surface with relative little land mass distributed over some 20 small island states with modest-size populations and correspondingly modest GDPs – systematic observation is particularly challenging in this region.
- The upper air network over the South Pacific therefore needs sustained international support.
- The workshop developed an outline for a Pacific region observing network plan in support of the GCOS Implementation Plan and the Implementation Plan for the Evolution of Global Observing Systems (EGOS IP) to:
    - Strengthen regional and national meteorological networks to support adaptation actions and avert loss and damage;
    - Identify capacity building needs to ensure the sustainability of the networks;
    - Be used to support requests for finance from the operating entities of the financial mechanism under the Convention, the GCOS Cooperation Mechanism and other relevant funding sources.
- Support of the observing network in the region should be based on transparent processes and a commitment to free and open data sharing in accordance with WMO Resolutions 40 and 60 and the GCOS Monitoring Principles. The network should be designed to be, efficient, sustainable, it should meet agreed international standards as well as national requirements. Ensuring sustainability is of paramount importance, and the network plan must therefore also include the necessary elements of capacity development.
- The draft plan will be developed by GCOS and WMO in collaboration with Secretariat of the Pacific Regional Environmental Programme (SPREP), the Pacific Islands Communication and Infrastructure Panel (PICI), and Pacific Meteorological Council, and submitted to COP 24.

Annex B – Summary of Observing capabilities reported by countries and analysis of OSCAR metadata and operational exchange of data.

Summary Table followed by more detailed information for each country represented at the meeting.

	Presentation	OSCAR	SYNOPS (OGIMET) (8^{th} – 9^{th} October)	CLIMAT	Radiosonde
Fiji	32 AWS 10 TB3 Rainfall stations 41 Rainfall stations (manual) 34 Manual synoptic/climate 4 Lightning stations 1 Wind Profiler, 1 Tidal, 3 Weather Radar Hydrological Network 12 Stations for International Exchange	50 Stations → 22 GOS Stations → 22 WHOS Stations → 4 GCOS/GSN Stations → 1 GCOS/GUAN Station (91680)	16 stations (metadata) 8 stations (3 Hourly or better) 5 stations (zero obs) No hourly reports	5 Stations providing monthly reports	2 per day (62 August) Timeliness good (<60mins) Max Height 93% > 30hPa (Jan – Aug 2017) TEMP and BUFR
Cook Islands	7 AWS (Project to replace above with 10 new systems) 1 Upper-Air (No consumables)	13 Stations → 13 GOS Stations → 4 GCOS/GSN Stations → 1 GCOS/GUAN Station (91843)	8 stations (metadata) 91831 (Hourly) 91843 (3 Hourly) 91844 (2 Hourly) 5 stations (zero obs)	GSN stations not reporting CLIMAT	Silent since Jan 2017 (No Consumables)
Federated States of Micronesia	3 Weather Service Offices 2 SAWRS 21 COOP Stations 3 Upper-Air Stations	27 Stations → 27 GOS Stations → 3 GCOS/GSN Stations → 1 GCOS/GUAN Station (91334)	14 stations (metadata) 4 (6 Hourly) 9 (1 to 3 obs) 1 stations – zero obs No hourly/3hr'ly reports	3 Stations providing monthly reports	2 per day (62 August) Timeliness good (<70mins) Max Height 89% > 30hPa (Jan – Aug 2017) TEMP and BUFR
Kiribati	9 Stations	16 Stations → 14 GOS Stations → 3 GCOS/GSN Stations → 1 GCOS/GUAN Station (91610)	8 stations (metadata) 2 stations (3 Hourly) 4 stations (1 – 3 obs) 2 stations (zero obs) No hourly reports	GSN stations not reporting CLIMAT	1 per day (30 August) Timeliness good (<70mins) Max Height 84% > 30hPa (Jan – Aug 2017) TEMP No BUFR

	Presentation	OSCAR	SYNOPS (OGIMET) (8^{th} – 9^{th} October)	CLIMAT	Radiosonde
Marshall Islands	7 Stations 22 drought monitoring stations 2 Radiosonde stations	19 Stations → 19 GOS Stations → 2 GCOS/GSN Stations → 1 GCOS/GUAN Station (91376)	8 stations (metadata) 1 (6 Hourly) 4 (1 – 3 obs) 3 stations (zero obs) No hourly reports	2 Stations providing monthly reports	2 per day (62 August) Timeliness good (<60mins) Max Height 95% > 30hPa (Jan – Aug 2017) TEMP and BUFR
Nauru	Zero active stations	4 Stations → 4 GOS Stations → 0 GCOS Stations			
Niue	1 Station	3 Stations → 3 GOS Stations → 1 GCOS/GSN Stations	1 stations (metadata) 91824 (3 obs) No hourly reports	1 Stations providing monthly reports but not every month	
Palau	1 NWS Station 6 Coop Stations	3 Stations → 3 GOS Stations → 1 GCOS/GSN Stations → 1 GCOS/GUAN Station (91408)	1 station (metadata) 1 (6 hr'ly or better) No hourly reports	1 Stations providing monthly reports	2 per day (62 August) Timeliness good (<80mins) Max Height 90% > 30hPa (Jan – Aug 2017) TEMP and BUFR
Papua New Guinea	14 Manual Stations (3 closed) 22 Climate Stations 200 Rainfall Stations 6 AWS 2 Tide Gauges	43 Stations → 43 GOS Stations → 3 GCOS/GSN Stations → 1 GCOS/GUAN Station (92035)	9 stations (metadata) 1 station (3 Hourly) 7 stations (1 – 3 obs) 1 stations (zero obs) No hourly reports	6-8 Stations providing monthly reports	Silent since Feb 2013 (No Consumables) (Hydrogen generator issues)
Samoa	2 Manual Stations 13 Sites (AWS) Wind Profiler and RASS Tide Gauge	17 Stations → 17 GOS Stations → No GCOS Stations	10 stations (metadata) 8 stations (Hourly) 2 stations (3 Hourly) No hourly reports	No CLIMAT but none are GSN. Apia is a RBCN	
Solomon Islands	6 Synoptic Stations 1 Upper-Air Station (stopped)	9 Stations → 9 GOS Stations	7 stations (metadata) 4 stations (3 Hourly)	No CLIMAT reports	Silent since Oct 2011 (No Consumables)

	Presentation	OSCAR	SYNOPS (OGIMET) (8th – 9th October)	CLIMAT	Radiosonde
	8 AWS 12 Auto-Rainguage 4 Lightning stations 5 Hydrometric Stations 3 Agro Met Stations	→ 2 GCOS/GSN Stations → 1 GCOS/GUAN Station (91517)	3 stations (4-5 obs) No hourly reports		All equipment is now questionable
Tonga	8 Stations (7 Manual, 1 AWS) Seismic Network	9 Stations → 9 GOS Stations → 2 GCOS/GSN Stations	5 stations (metadata) 3 stations (3 Hourly) 2 stations (6 Hourly) No hourly reports	No CLIMAT reports	
Tuvalu	4 Manual 5 Rainfall (non operational) 1 Upper Air 1 Tide Guage 1 Lightning Detector 1 GPS positioning system 1 Seismic Station	5 Stations → 5 GOS Stations → 2 GCOS/GSN Stations → 1 GCOS/GUAN Station (91643)	4 stations (metadata) 1 station (3 hr'ly) 3 stations (6 hr'ly) No hourly reports	No CLIMAT reports	1 per day (30 August) Timeliness good (<80mins) Max Height 90% > 30hPa (Jan – Aug 2017) TEMP No BUFR
Vanuatu	8 Synoptic Stations 1 Upper-Air Station (Not working) 75 Rainfall Stations 4 Tidal Guages	13 Stations → 7 GOS Stations → 6 AWS with no affiliation → 2 GCOS/GSN Stations → 1 GCOS/GUAN Station (91557)	7 stations (metadata) 2 stations (3 hr'ly) 5 stations (2-4 obs) No hourly reports	No CLIMAT reports	Silent since Apr 2016 (No Consumables) Issues with Hydrogen Generator

Fiji

The Fiji Meteorological Service (FMS) is now under the Ministry of Disaster Management and Meteorological Service. It operates all the year around providing daily weather forecasting and warnings to Fiji, Cook Islands, Kiribati, Nauru, Niue, Tokelau, Tonga and Tuvalu. It is recognised as a WMO Regional Specialized Meteorological Centre. In Fiji there are networks of meteorological, rainfall and hydrological stations and weather radar. The site at Nadi Airport launches radiosondes twice daily. 12 stations report data internationally to the WMO WIS/GTS.

While Fiji has its own training needs, it also serves as a focal point for capacity building for the surrounding island states.

Transport to and from the smaller outlying islands adds to the difficulties of maintaining the observation system while deploying a reliable communications system is a priority.

Cook Islands

The Cook Islands have an upper air station that launches radiosondes once a day. This was supported by the UK until the end of 2016. The precipitation measurements are not representative, as rainfall on different sides of the island is markedly different. They have experience with a voluntary observing system using cheap rainfall gauges situated at schools.

Federated States of Micronesia

The Federated States of Micronesia Weather Services Offices (WSO) are built, operated and funded by the US while the Federated States of Micronesia hires and employs the WSO staff.

There are three Weather Service Offices (METAR/SPECI) on Pohnpei, Chuuk and Yap, and two SAWRS Stations (METAR/SPECI that operate for 2hrs pre/post US Airlines flights) at Pohnpei and Kosrae Airports. There are also 27 COOP Stations. There are upper air soundings from all three WSOs, twice daily at 00Z and 12Z.

Installation and maintenance can be a problem due to remoteness of islands with both communication problems and travel issues.

Kiribati

Of the nine meteorological stations 3 are silent and only 2 provide continuous hourly observations. Issues include the lack of resources for the maintenance and operation of equipment. Communications is also an issue and the use of existing internet links is being investigated.

Kiribati is looking for assistance with international tendering and donors to support the Kiribati joint implementation plan for climate change and disaster risk reduction which includes both the reactivation of existing meteorological stations and the establishment on new stations.

The upper-air station is supported by funds from the UK, managed through SPREP.

Marshall Islands

Majuro National Weather Services first started in 1950. It operates under the US National Oceanic and Atmospheric Administration (NOAA) and it’s contracted by the Marshall Islands government to provide weather products and services to the RMI citizens. Its staff are employed by NOAA. NOAA has assigned the WFO Guam and Honolulu to provide services and warnings for the North Pacific island states including the Marshall Islands.

The observations include surface stations, weather radar and an upper air station that operates twice daily.

There is a need for more observation sites in the outer islands to improve drought forecasting and monitoring. There also needs to be a sustainable and robust communication system for observation transmittal and for Early Warnings. Installation of Chatty Beetles[9] in 5 to 8 other atolls is underway.

Nauru

Currently there are no meteorological stations in Nauru. There are some limited observations made at the airport. Plans are being implemented to establish a meteorological office and to provide some equipment. Two officers are being trained in Nadi, Fiji.

Niue

Hanan Airport is Niue's only meteorological station. It is operated only in the event of active tropical cyclone in the area. Daily weather forecasts are provided by RMSC Nadi but Niue produces its own three-day weather forecast. There are also rainfall and seismic observations.

Palau

Due to cooperation between the NOAA National Weather Service and The Government of the Republic of Palau, the Palau Weather Service is 100% funded by the US Government and on the basis of a reimbursable funding. It employs a total of 13 staff.

There is a weather station at Koroor (which will move closer to the airport) and two COOP Stations measuring temperature and precipitation as well as three stations observing surf conditions.

Additional rain gauges are needed, and access to NOAA data should be improved.

Papua New Guinea

Currently Papua New Guinea Weather Service has:

- 14 manual observation stations (3 recently closed)
- 22 climate stations & less than 200 rainfall stations
- 6 AWS & 20 rainfall data loggers
- 2 tide gauges (1 not operational)
- Hydrology network is under Ministry of Environment

However, it is unclear how well these operate and there is a lack of stations in the Highlands region. The two upper air stations ceased operation in early 2015 due to lack of funds for consumables.

Currently the National Weather Service needs to be restructured and to receive an adequate budget to restore the silent stations and train staff. There needs to be an effective communication strategy to allow the transmission of information from the data loggers and AWS and to link to airport observations. Data records from manual stations need to be rescued and digitized. The capacity of the staff needs to be enhanced.

Samoa

Samoa has 7 automatic weather stations in addition to those at the airport. It has a weather forecasting capability using satellite data and effective communications for data transmission. It operates a multi-hazzard early warning system with a smart phone app to distribute warnings.

It does not undertake upper air soundings but relies on those made in American Samoa which is nearby.

[9] a portable Iridium satellite terminal that permits text-based alerts and messaging in remote locations, where communication options are limited.

Solomon Islands

Currently the Solomon Islands has

- Six (6) Surface Synoptic Observation Stations,
- One (1) Upper Air Stations (not operational)
- Eight (8) Automatic Weather Stations -1 mSTAR, 1 iSTAR, 4 SWoCK, 2 NDMO,
- Twelve (12) Automatic Rain Gauges – 4 yet to be installed,
- Three (3) Agro-Meteorology Stations – Funded/Installed by CWB (Taiwan) but the data form these is not currently available
- Himawari High Resolution Satellite R/Stations. – Installed by JMA funded by JICA

Issues include lack of expertise and resources. This has led to a lack of upper air observations due to the lack of consumables and maintenance, lack of maintenance and calibration to ensure data quality. Poor international procurement of meteorological instruments contributes to these issues.

There are also problems with timely data transmission. Finally, the use of Mercury substance with Meteorological instruments needs to be phased out.

Tonga

Since 2005 Tonga has been producing its own weather forecasts, previously these were done by Fiji. Tonga has 8 meteorological stations. It does not perform any upper air observations. Limits on resources mean that equipment is not inspected regularly and few spares are held.

Tuvalu

The Tuvalu Metrological Office has:

- 4 manned synoptic stations including the capital – on operational
- 5 rainfall stations – non-operational
- 1 upper air program (Release time 2300UTC)
- 1 tide gauge with tsunami warning system
- Lightning detector

The upper air station is supported by funds from the UK, managed through SPREP.
The increasing population results in an increase in both the vulnerability and exposure of people to natural hazards such as sea-level rise, increased variability of weather, climate, storm surges and coastal inundation.

There are severe problems with communications to the outlying islands where there is limited internet access, no mobile coverage, no television and no HF radios. There are
power and cabling issues for land phones lines and there is one radio station service (AM radio) with a limited transmission. The electricity supply is insufficient. Solutions could include Chatty Beetles and HF radios.

Vanuatu

In Vanuatu there are:

- 8 Synoptic sites
- 3 are GCOS Stations (91551,91555,91568)
- 75 Rainfall sites
- 4 tidal Gauge
- 6 volcano monitoring station
- 3 broadband station

In addition, one upper air station, which has not been operational since September 2016 due to lack of funds.

There is limited expertise in maintenance and calibration of instruments (both manual and AWS) and upper air stations. Capacity development to help improve the quality of the stations is needed.

Communications is an issue with a need for improved back-up communications tools (such as HF radios)

Annex C – Network Design Principles (WIGOS Expert Team on Observation Systems Design and Evaluation).

Observing System Network Design (OSND) Principles

1. SERVING MANY APPLICATION AREAS
Observing networks should be designed to meet the observational needs of many application areas within WMO and WMO co-sponsored programmes.

2. MEETING USER REQUIREMENTS
Observing networks should be designed to address stated user requirements, in terms of geophysical variables to be observed and the space-time resolution, accuracy, timeliness and measurement stability needed.

3. MEETING NATIONAL, REGIONAL AND GLOBAL REQUIREMENTS
Observing networks designed to meet national needs should also take into account the needs of the WMO community for applications for which requirements are regional or global.

4. MAKING OBSERVATIONAL DATA AVAILABLE
Observational data from national observing networks should be made available to other WMO Members, at space-time resolutions and with a timeliness needed to meet the needs of regional and global applications.

5. PROVIDING INFORMATION SO THAT THE OBSERVATIONS CAN BE UNDERSTOOD
Observing networks should be designed and operated in such a way that the details and history of instruments, their environments and operating conditions, their data processing procedures and other factors pertinent to the interpretation of the observational data (i.e. metadata) are documented and treated with the same care as the data themselves.

6. DESIGNING COST-EFFECTIVE NETWORKS
Observing networks should be designed to make the most cost-effective use of available resources.

7. DESIGNING APPROPRIATELY SPACED NETWORKS
Where high-level user requirements imply a need for spatial and temporal homogeneity of observations, network design should also take account of other important user requirements, such as the representativeness and usefulness of the observations.

8. DESIGNING RELIABLE, STABLE AND SUSTAINABLE NETWORKS
Observing networks should be designed to be reliable, stable and sustainable.

9. DESIGNING THROUGH A TIERED APPROACH
Observing network design should use a tiered structure, through which information from reference observations of high quality can be transferred to and used to improve the quality and utility of other observations.

10. ACHIEVING HOMOGENEITY AND CONSISTENCY IN OBSERVATIONAL DATA
Observing networks should be designed to deliver observational data of the level of homogeneity and consistency by intended applications.

11. ACHIEVING SUSTAINABLE NETWORKS
Improvements in sustained availability of observations should be promoted through the design and funding of networks that are sustainable in the long term including, where appropriate, through the transition of research systems to operational status.

12. MANAGING CHANGE
The design of new observing networks and changes to existing networks should ensure adequate consistency and quality of observations across the transition from the old system to the new.

Annex D - Global Climate Observing System (GCOS) Reference Upper-Air Network (GRUAN)

The Global Climate Observing System (GCOS) Reference Upper-Air Network (GRUAN) is an international reference observing network designated to provide long-term high-quality, accurate climate data records between the surface and the stratosphere. GRUAN measurements are used to constrain data from more spatially comprehensive observing systems (including satellites and current radiosonde networks), to determine upper-air trends and to fully characterize the properties of the atmospheric column, thus providing data for atmospheric process studies and for climate monitoring. More specifically, the high-quality measurements provided by GRUAN will allow:

- Characterisation of changes in essential climate variables, in particular, temperature, humidity, and wind
- Understanding the climatology and variability of humidity, particularly in the region around the tropopause since this is where changes have their largest effect on climate sensitivity
- Understanding changes in the hydrological cycle
- Understanding and monitoring tropopause characteristics
- Understanding the vertical profile of temperature trends
- Bringing closure to the Earth's radiation budget and balance
- Understanding climate processes and improving climate models

GRUAN sites are routinely performing high-quality observations of upper-air ECVs using radiosondes, frost-point hygrometers, ozonesondes, GPS delay, lidars, microwave radiometers, Fourier Transform Spectrometers, and other relevant instrumentation. The GRUAN network is providing new information on humidity in the upper troposphere (UT) and lower stratosphere (LS). Water Vapour measurements in the UT/LS are particular important as water vapour is a key indicator of convection and radiative forcing. There is recent evidence that the Brewer Dobson circulation is changing in the Tropics due to climate change, which alters the balance of water vapour in the UT/LS markedly and has a strong feedback on climate change. Accurate in-situ measurements of water vapour in the UT/LS are sparse, and trends and variability in this region are not well established. A long-term sustainable strategy for accurate global measurements of water vapour in the UT/LS is required and GRUAN's contribution is going to be very valuable.

GRUAN measurements also include upper level winds, which are extremely valuable in the tropics, where data from aircrafts programs don't reach above 200mb altitude. Accurate measurements of winds are needed for prediction of the Monsoon, of the Madden Julian Oscillation (MJO) and for studies of the Quasi-Biennial Oscillation (QBO). The MJO is the dominant mode of intraseasonal variability in tropical regions. The importance of the MJO in the tropical climate is highlighted by its impact on the Indian and Australian summer monsoon, its influence on tropical cyclones monsoons and its effect on rainfall in general over Asia, Australia and America. Signals of the MJO are discernible in a number of meteorological variables such as the upper-and low-level zonal wind and sea-level pressure. However, a lack of in-situ observations in the region of the tropical oceans has impeded the progress of the study of the MJO.

Out of the initially planned 30-40 GRUAN sites, 22 are now operative, 8 of which have undergone a rigorous certification process. There is a clear need to increase the number of sites in the Tropics, South America and Africa. In its new IP GCOS specifically calls for the continuation of the implementation of the GCOS Reference Upper-Air Network, giving priority to implementation of sites in the Tropics (Action 15).

There are additional benefits to hosting a GRUAN site. The organization running the site will have access to the service and structures provided by AOPC (Atmospheric Observation Panel for Climate), the WCRP (World Climate Research Programme), UNEP (United Nations Environment Programme), IOC (Intergovernmental Oceanographic Commission), ICSU (International Council for Science) and WMO (World Meteorological Organization). Measurements at the sites are anchored to a reference network that provides traceability to internationally recognized measurement standards and users are able to benefit from access to this additional data at no extra direct cost. Furthermore, specialists from various fields of expertise are actively involved in GRUAN, and their knowledge is shared within the network to the benefit of the participating sites. Finally, GRUAN has a data delivery service through NOAA's national centers for environmental information. The raw measurement data of measurements performed at GRUAN sites are processed at a centralized data processing facility, applying the best possible GRUAN-based corrections to the data, and are subsequently provided to a wide range of users.

In order to join GRUAN, a minimum set of requirements has to be met. As a minimum a GRUAN site should offer a continuous long-term radiosounding program (at least one sounding/day) regularly reaching at least 10 hPa. Proper change management (documenting and reporting changes in instrumentation and/or procedures) is essential. In addition a monthly sounding providing a profile of water vapour in the stratosphere is highly desirable.

In terms of daily operations being a GRUAN site brings only very limited additional work: an additional ground check in a standard humidity chamber should be performed after the standard manufacturer-prescribed operational procedure to prepare the radiosonde. After completion of the sounding, the measurement data and the accompanying metadata should be submitted to the GRUAN Lead Centre using a software tool provided by the Lead Centre.

Table 8 Annual cost of launches for a typical GRUAN Station

Item	Cost (EURO)
Costs for minimum one per week launches to 10hPa	
Radiosonde	150
Balloon + gas	150
Total annual cost	15,600
Costs for monthly humidity and ozonesonde launches	
Radiosonde	150
Balloon + gas	180
Cryogenic Frost point Hygrometer (CFH)	3,000
Cryogen for the CFH	100
Ozonesonde	750
Total annual cost of monthly launches	50,160
Annual Cost of launches	65,760

Table 8 gives the typical minimum cost of launches for a GRUAN station. For the daily launch, no training is necessary. The preparation and operation of the CFH will require special training (additional 3000$). The lead scientist from the GRUAN site is expected to attend the annual GRUAN-ICM meeting.

Assuming that the station does more launches than the minimum, and including travel costs for the lead scientist and the roel of a centre of expertise for the region a sum of 1 million Euro should cover 10 years operation.