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PLAN FOR IMPROVING OBSERVATIONS AROUND LAKE VICTORIA THAT SUPPORT NUMERICAL WEATHER PREDICTIONS, CLIMATE SERVICES AND ADAPTATION

Entebbe, Uganda
From 31 October to 2 November 2018

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PLAN FOR IMPROVING OBSERVATIONS AROUND LAKE VICTORIA THAT SUPPORT NUMERICAL WEATHER PREDICTIONS, CLIMATE SERVICES AND ADAPTATION

A plan for Burundi, Kenya, Rwanda, Tanzania and Uganda based on the joint GCOS, WIGOS, GCFS, and Copernicus workshop in support of the UNFCCC: Improving the value chain from observations to climate services to support climate policy, adaptation and mitigation in East Africa held in Entebbe, Uganda on 31 October to 2 November 2018.

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Draft 1.0	30 Nov 2018	First draft
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Draft 1.3	18 July 2019	Layout editing to comply with GCOS Reports

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1. EXECUTIVE SUMMARY

This plan is the outcome of a workshop Improving the value chain from observations to climate services to support climate policy, adaptation and mitigation in East Africa held in Entebbe, Uganda on 31 October to 2 November 2018.

In general, across the five countries in the region (Burundi, Kenya, Rwanda, Tanzania and Uganda) insufficient stations are reporting as needed by NWP and climate analysis (i.e. hourly) and will also not be sufficient to meet the proposed mandatory requirements of GBON. There are several reasons for this:

1. Many stations were reported to the workshop which are not reporting to WMO. Thus, the list of stations in OSCAR/Surface is incomplete. Stations, whose existence is not reported, and whose data is not exchanged, are practically useless.
2. Several countries reported lack of calibration capacity as an issue limiting operations and accuracy.
3. There were many stations that were either not operational or that are not operating as intended when they were installed. In general, there was a lack of planning and resources to ensure network sustainability.

All the countries agreed that there was a need for greater regional collaboration. Some collaboration is currently on-going on an ad-hoc bilateral basis but could be improved through some regional roundtable to exchange information and experiences, improve skills and cooperate on developments. There are some regional WMO centres and while they should be involved, this forum should be driven by the partnering countries themselves (see section 6.1.3).

In general, this can be summed up as three main, interrelated, issues:

1. Insufficient reporting to meet climate and weather needs
2. Lack of planning for sustainable operation
3. Need for a regional roundtable

As a result of the discussions between the participants, a plan was developed to improve the amount and timeliness of data submitted to international modelling centres. This plan includes:

- The development of costed national sustainability plans that cover:
  - consumables required,
  - maintenance planning,
  - the process to replace this equipment at 'end of life',
  - calibration requirements,
  - developing and costing a staff development plan,
  - holding a regional workshop to establish a regional roundtable to exchange best practices and develop regional cooperation.
- Developing plans to ensure timely reporting and transmission of data.
- Developing a long-term, data archive with easy and timely access to all users.
- When the actions above have been completed and implemented, develop and cost a plan to improve the national observing system to meet the GBON requirements. Unless issues such as annual costs, staff development and reliable transmission of data have been addressed, there is no point in adding additional stations.

2. INTRODUCTION

Fundamentally, numerical weather prediction (NWP) is a global enterprise. Predicting weather over timescales longer than a few days requires knowledge of the entire global weather. Global NWP centres take in observations from around the world and produce forecasts and predictions that are used by national and regional centres as boundary conditions to their own forecasts and predications. Weather forecasting, reanalysis and climate models are closely linked and require observations and information globally to support local policy making and decision making. Global data output from these NWP models and reanalyzes can be downscaled to local conditions and provide the boundary conditions for local models. The quality and accuracy of national forecasts and predictions depends on this supply of global information. Thus, data exchange is vital: national observations are sent to global modelling centres (NWP, reanalysis and climate modelling) and in return, detailed forecasts and predictions are provided.

Currently, the basic requirements for modern, global, NWP and reanalysis centres are not being met in many parts of the world. The situation is particularly acute in Africa where the percentage of stations reporting adequately is low and declining. In response to this, WMO, through its Integrated Global Observing System (WIGOS) framework, has proposed the Global Basic Observing Network (GBON) with the minimum reporting requirements for modern global NWP and reanalysis centres: a spatial separation of 500km and hourly reporting for surface stations and 12-hourly for upper air observations. This is the same as was proposed in the outcome of the GCOS regional workshop held in Fiji in 2017 for Pacific Islands states.

This plan is an outcome of the regional workshop *Improving the value chain from observations to climate services to support climate policy, adaptation and mitigation in East Africa* held in Entebbe, Uganda on 31 October to 2 November 2018. This was a Joint GCOS – Copernicus – WIGOS – Global Framework for Climate Services (GFCS) held in support of the United National Framework Convention on Climate Change (UNFCCC). The contribution of Copernicus was to provide training in the use of the Copernicus data store and so demonstrate how improving global datasets can support tailored climate services. The key messages from this workshop are given in Box 1.

At the workshop, representatives of the National Meteorological and Hydrological Services (NMHS) of Burundi, Kenya, Rwanda, Tanzania and Uganda, together with representatives of climate policy makers in those countries, met to discuss systematic observations in their countries and to identify ways to improve them. The workshop focussed on surface and upper air observations, especially those that support NWP and reanalysis, rather than trying to cover all Essential Climate Variables (ECV).

The plan described here aims to address issues around observations and reporting, sustainability and planning future network improvements.

Box 1: Key messages from Workshop

1. Most of the value of sustained, systematic meteorological observations can only be realized at a national level if they are reported and exchanged internationally. International reporting of a basic network of surface and upper air observations leads to improvements in local weather prediction and national seasonal forecasts of temperature and precipitation. Global numerical weather prediction and reanalysis are used to provide the boundary conditions for local models and assessments.
2. While most of the five countries in the region (Uganda, Burundi, Kenya, Rwanda and Tanzania) have **operating** networks and sites and are meeting minimum WMO requirements, many of the stations are not fully **reporting** as needed by international centres for global numerical weather prediction and reanalysis (hourly for surface stations and every 12 hours for upper air observations Currently, in Africa, only about 10% of the surface and 20% of the radiosonde stations that are required to report meet this need.
3. The accuracy of climate services depends on the quality and quantity of the observations. Observations underpin all climate services, planning climate policy and adaptation.
4. Currently, WMO mandatory requirements, are not sufficient to support global NWP and consequently national climate services. However, the proposed WMO Global Basic Observation Network (GBON) will allow numerical weather prediction and reanalysis centres to meet the regional needs.
5. The workshop recognised the support of governments in the region for observations, but further and sustained support is needed for the required long-term sustainability of observation.
6. The workshop developed an outline for a regional plan to improve the value chain from observations to climate services in East Africa covering:
    - Planning to ensure the sustainability of systems and staff: recognizing the value of life cycle management of equipment and in-house staff training and mentoring;
    - Calibration and maintenance policies,
    - Meeting the observational needs of international centres for global numerical weather prediction and reanalysis centres,
    - Building on the benefits of the HIGHWAY project around Lake Victoria to enable fully functioning regional network of stations,
    - Support regional collaboration to build technical and operational capabilities.
7. Training by a representative of the Copernicus Climate Data Store increased the understanding of participants on how its global datasets can be used locally to produce nationally tailored climate services.
8. The workshop noted the opportunities to use the global datasets from global numerical weather prediction and reanalysis centres by national meteorological and hydrological services (NMHS) to support national climate services.
9. NMHS wish to improve the ways they communicate forecasts, such as the probabilities of extreme events, to the public and decision makers.
10. Regional climate service platforms could support communication and science-based decision making on adaptation.

3. GBON: MEETING REPORTING NEEDS

Global NWP is a foundational capability for all weather prediction and most climate monitoring activities. Generally, any lack of observations over one area of the globe will limit our ability to understand and predict weather and climate patterns everywhere else: weather prediction beyond the 5 to 7-day range essentially requires observations from the whole world. Global Numerical Weather Prediction depends on availability of a global coverage of observations.

Climate services and adaptation depend on data from reanalysis and climate models that are very closely linked to global NWP models: improvements to global NWP will be reflected in improvements to reanalysis and climate models. NHMS use the outputs from global NWP and reanalysis as boundary conditions and inputs to their short- and long-term models, predications and risk assessments.

Thus, improving the supply of national observations to global NWP centres is fundamental to improving national climate services and adaptation.

The pilot of the WIGOS Data Quality Monitoring System (WDQMS) shows continuing poor availability of surface-based observational data over many areas of the global domain (see Figure 1). This is echoed by reports on the performance of the GCOS Surface Network (GSN) and the GCOS Upper Air Network (GUAN) which show the worst, and declining, performance in Africa (see Figure 2 and Figure 3). This limits the ability of all NMHS and other national agencies to provide weather and climate services.

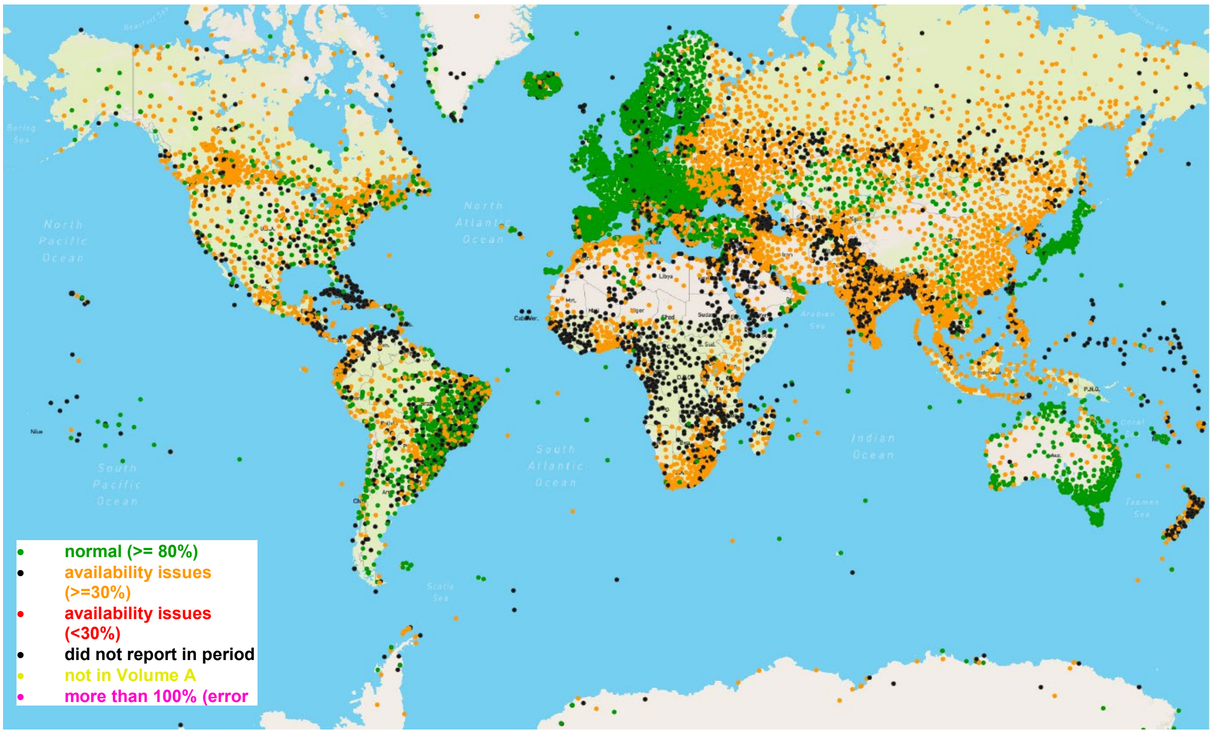

Figure 1. WIGOS monitoring pilot project - surface pressure (April 2019), numbers of reports v number expected. Stations that are reporting satisfactorily are indicated in green, purple indicates >100% which may imply a metadata issue, orange and red are not reporting as needed by Global NWP while black indicates silent stations. Africa is a region with very poor reporting.

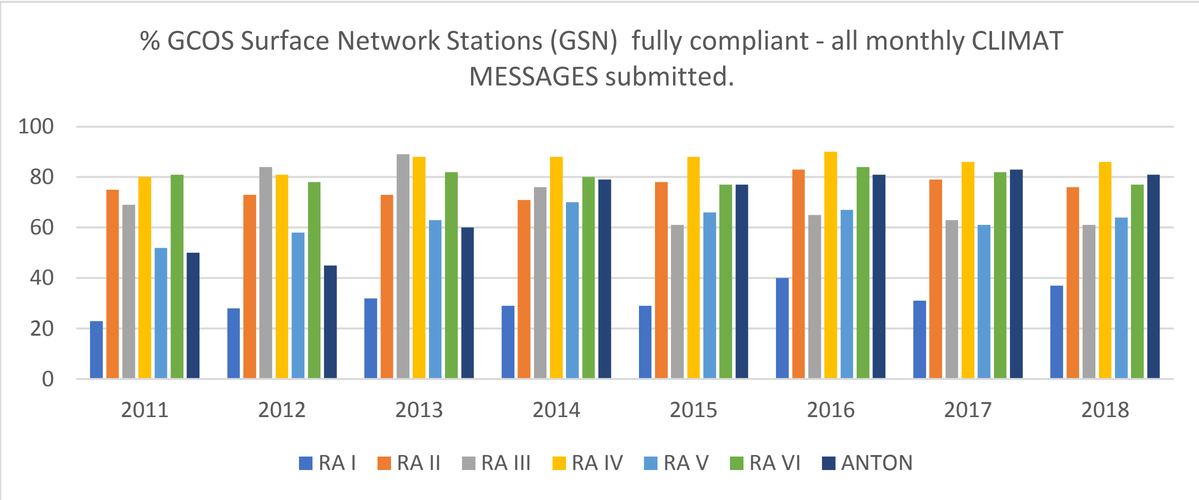

Figure 2. Percentage of GCOS Surface Network Stations fully compliant by WMO region. Region I is Africa.

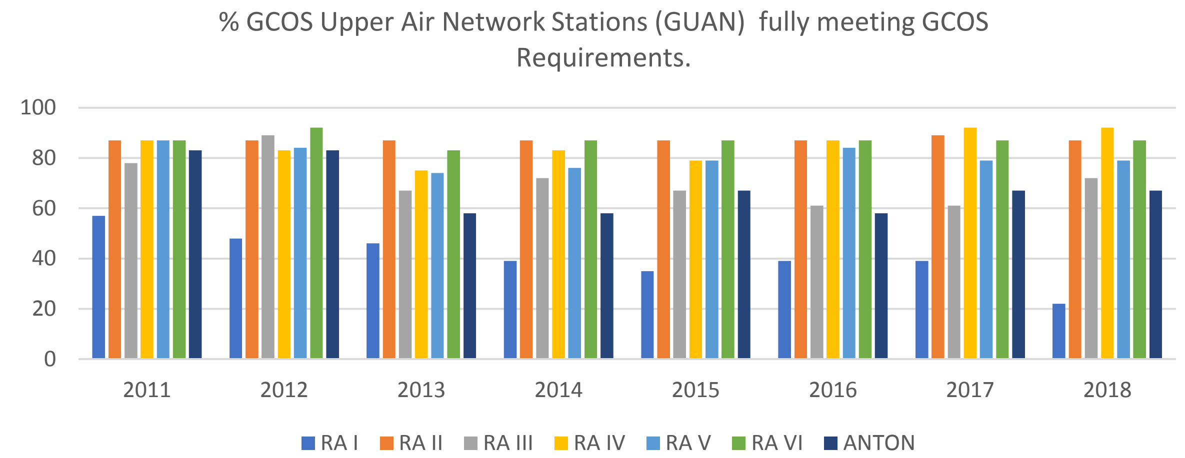

Figure 3. Percentage of GCOS Upper-Air Network Stations fully compliant by WMO region. Region I is Africa.

In order to ensure that observational requirements for Global NWP and climate reanalysis are met more effectively, WMO is proposing a new approach: a basic surface-based observing network that is essential to support these applications and is defined at the global level. This network is the Global Basic Observing Network, or GBON. These proposals were presented at the 18th World Meteorological Congress in 2019 where GBON was approved.

The GBON will be a subset of the surface-based component of WIGOS, which in combination with the space-based components and other surface-based observing systems of WIGOS, will contribute to meeting the requirements of Global NWP, including reanalysis in support of climate monitoring.

The specifications and requirements for GBON are given in Table 1. These follow the conclusions of the joint GCOS-WIGOS regional workshop held in Fiji in 2017 for Pacific Islands states. While this plan uses these requirements as a target, it is not sufficient to have and operate observing stations: the data must be exchanged internationally.

Table 1. Proposed specifications of GBON

Type of Station	Parameters measured	Required commitment by WMO Members
Surface – Land (manual or AWS)	Surface pressure; near-surface air temperature; humidity; wind; precipitation; snow.[4]	SHALL[1] implement - 500 km, hourly[3]; SHOULD[2] implement - 100 km, hourly
Surface - ocean (buoys, ships)	Surface pressure; sea surface temperature.	SHOULD implement - 500 km, hourly, or better
Upper air – land (radiosonde, profiler, aircraft)	Temperature; Humidity; wind profile.	SHALL implement radiosonde - 500 km, 12-hourly vertical resolution - 100 m or better top - 30 hPa or better SHOULD implement complementary observing systems radiosonde, aircraft, profiler up to density of 50 km, hourly radiosonde to 10 hPa, 1000 km, 24-hourly aircraft - ascent/descent, vertical res - 300 m or better; aircraft - flight level, horizontal res - 100 km or better
Upper air – ocean (radiosonde, aircraft)		SHOULD implement radiosonde, 500km, 12-hourly aircraft - flight level - 100 km or better

Notes:
[1] “SHALL” requirements are mandatory
[2] “SHOULD” requirements are optional – recommended but not required.
[3] recognizing that manual observations are taken less often, the requirement for hourly observations is waived for manual stations and is replaced by “as frequently as possible, up to hourly”
Additionally, for all GBON platforms listed above, Members SHALL disseminate what is observed (and available for dissemination) up to a resolution of 15 km horizontally and hourly temporally (the current goal requirements for Global NWP).
[4] observations of snow depth shall include observations of no snow; observing cycle for snow depth may be daily

These requirements are for maximum spacing of a station (surface and upper air) every 500 km – i.e. for an area of 250,000 km^2: Table 2 indicates the number of stations implied for each country. At the maximum spacing of 500 km a minimum of 7 stations would cover the 5 countries. Moving to 100 km would increase this to 182. These estimates are based solely on areas – a more detailed analysis considering local factors and additional regional needs may lead to a need for additional stations being identified. However, one conclusion is that Burundi and Rwanda, both small countries, may not need an upper air station if they can rely on data for nearby station in neighbouring countries and so they could then use their resources on other parts of the observing system. This would require that cooperation on data exchange between all countries in the region is established and ensured in the long-term to make this sustainable. Countries would need to agree the principles and modalities of this data exchange and be irreversibly committed for the future.

Table 2. Minimum number of stations per country according to the proposed GBON requirements

	Area (km2)	Minimum number of stations (500 km separation)	Minimum number of stations (100 km separation)
Burundi	27,834	0	3
Kenya	582,644	2	58
Rwanda	26,338	0	3
Tanzania	945,087	4	95
Uganda	241,037	1	24
All	1,822,940	7	182

4. CURRENT SITUATION

These country summaries are derived from the reports presented and discussed at the GCOS regional workshop *Improving the value chain from observations to climate services to support climate policy, adaptation and mitigation in East Africa* held in Entebbe, Uganda on 31 October to 2 November 2018. The plots of stations are produced by the WIGOS Data Quality Monitoring System[1] in November 2018 and show those stations whose details have been entered into the OSCAR/Surface[2] system and how they are reporting to four international NWP centres (the European Centre for Medium-Range Weather Forecasts (ECMWF) UK, Deutsche Wetterdienst (DWD) Germany, Japan Meteorological Agency (JMA) Japan and National Centers for Environmental Prediction (NCEP) USA.

4.1 Burundi

While Burundi is not currently reporting internationally from any station, it has:

- 2 Synoptic stations operating for 24 hours (Bujumbura and Muyinga)
- 19 main climatological stations
- 125 rainfall sites
- 5 automatic weather stations (AWS)
- A "good" number of rainfall sites operated by PROSANUT; a project of the Ministry of Environment, Agriculture and Livestock.

Figure 4. In Burundi, only one, non-reporting, station (Muyinga) has been reported to WMO.

Burundi reported a number of issues:

- Insufficient human resources in meteorological and hydrological services
- Inadequate observational monitoring equipment
- Lack of upper-air observational network
- Inadequate telecommunication networks and systems for data exchange
- Inadequate data processing and forecasting systems
- Inadequate information dissemination facilities.
- Migration from Traditional Alphanumeric Codes (TAC) to Table Driven Code Forms (TDCF)
- Low capacity in human resources for data management.

[1] A system under development that monitors data received from individual stations by 4 international NWP centres.
[2] The WMO Observing System Capability and Analysis Review Tool (OSCAR) has three components: OSCAR/Surface, OSCAR/Space and OSCAR/Requirements. OSCAR Surface is WMO's official repository of WIGOS metadata for all surface-based observing stations and platforms see https://oscar.wmo.int/surface//index.html#/.
OSCAR/Requirements is the official repository of requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes.

The main climate related risks in Burundi are linked to floods, drought, hailstones, strong winds and landslides (exacerbated by precipitation).

4.2 Kenya

Kenya has an extensive set of observation sites and equipment measuring a wide range of climate variables. However, no station reports internationally to over 80 of observations. Stations include:

- 39 manned 24-hr Synoptic Stations
- 14 Agro-Met Stations
- 111 Automatic Weather Stations
- 19 Hydromet Automatic Weather Stations: 17 in the River Nzoia Basin & 2 in Tana River;
- Three River gauging stations also installed
- Five (5) Airport Weather Observing Systems (AWOS) are operational
- 2 Fixed Mooring Buoys in Lake Victoria at Utajo in Winam Gulf and Rusinga Island in the Open Lake (however neither is currently operational)
- Four tidal gauge stations at Lamu, Mailindi, Kilifi and Shimoni for multi-hazard detection, ocean waves, sea level rise, salinity, sea surface temperature and water quality, including tsunami related at the Coast
- 50 Drifting Buoys deployed by KMD in collaboration with Scripps Institute for Oceanography
- 1 Global Atmospheric Watch (GAW) Station at Mt Kenya
- 1 Ozone Profile measuring system in Nairobi
- 2 urban pollution stations at Chiromo and JKIA.

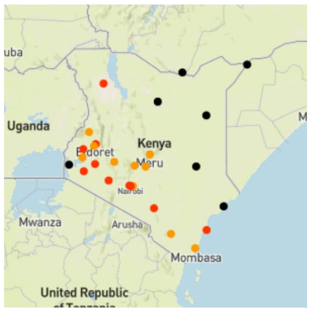

Figure 5. Stations in Kenya: black are non-reporting, red report less than 30% and orange more than 30%, none report satisfactorily.

Issues noted include:

- High cost of Meteorological equipment, plants and instruments required for improved information, products and services.
- Inadequate funding for procuring, maintenance and renovation of instruments / equipment
- Rapidly changing Technology means regular changes in observation systems
- A number of institutions engaging in making observations without involving the NMH
- Lack of motivation for the Voluntary Observers.

4.3 Rwanda

Only one station has been reported to WMO and that does not report satisfactorily. Rwanda reported that it had:

- 5 Surface synoptic stations (one non-operational) Hourly observations for 12 hours/day, Only one report every 24/24 hours
- 9 Agro-meteorological stations 9 (all operational) Hourly observations for 12 hours/day
- 79 (all operational) Climate stations, daily reporting
- 71 (all operational) Rainfall stations, daily reporting
- 56 Automatic Weather stations, 10 min observations
- 100 Automatic Rain Gauges, 10 min observations
- 1 Weather Radar, 6 min observations
- 1 Climate change observatory station.

Figure 6. Only one station has been reported to WMO and that does not report satisfactorily.

Rwanda does not have any upper air stations.

A significant challenge in Rwanda is the huge gaps in data collected from 1993 to 2010. Meteo Rwanda has consolidated new climate datasets by blending satellite data and ground station data to a resolution of 4 km^2.

Other issues include:

- Inefficient maintenance and calibration of stations
- No spare parts of AWS and Radar
- No storage and back up of radar data (very expensive)
- Thermometers are still using mercury
- Lack of upper air station
- Irregularity in observed data at stations managed by volunteers
- Most of automatic weather stations are installed after 2014 (short time range data available)
- GTS (few stations are reporting).

4.4 Tanzania

Many stations have not been included in the WMO OSCAR Surface. Of those that have none achieve satisfactory data exchange.

- 27 synoptic stations, 19 making hourly observations 24/7 and 8 making hourly observation for 12hrs a day
- 13 agrometeorological stations observing twice a day
- 139 climatological stations observing once a day
- 48 automatic weather stations measuring at 10 minute intervals
- 2 weather radar, operating 24/7 during rainfall season, 3 days a week off season
- >1000 rainfall stations.

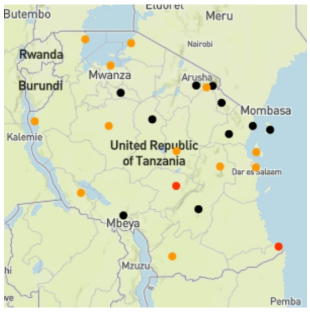

Figure 7. Stations in Tanzania: black are non-reporting, red report less than 30% and orange more than 30%, none report satisfactorily.

The main need is for more monitoring to fill gaps in coverage.

4.5 Uganda

None of the stations in Uganda that have been included in OSCAR Surface are exchanging data. Uganda has 11 synoptic stations (only one of which manages 24-hour operation) and one upper air station. Most of the synoptic stations have two weather observers instead of six observers required and thus only operate for 12 hours a day.

Other issues limiting manual operations are:

- The 30-minute observations are tedious.
- Manual instruments no longer in production
- Mercury based thermometers no longer in production.
- Automation of observations still in process.
- Calibration of weather instruments (there is no national capacity).

Figure 8. None of the stations in Uganda are reporting to international NWP centres.

5. KEY ISSUES AND CHALLENGES

The conclusions in this chapter are based on the discussions and agreed outcomes from the workshop Improving the value chain from observations to climate services to support climate policy, adaptation and mitigation in East Africa held in Entebbe, Uganda on 31 October to 2 November 2018.

Across the 5 countries in the region (Burundi, Kenya, Rwanda, Tanzania and Uganda) are several recurring issues:

- Stations are not reporting as needed by NWP (i.e. hourly). They may meet minimum WMO requirements, but this is not sufficient to support modern NWP and reanalysis. This will also not be sufficient to meet the proposed mandatory requirements of GBON.
- Many more stations were reported to the workshop which have not been reported to WMO. Thus, the list of stations in OSCAR/Surface is incomplete. The usefulness of stations, whose existence is not reported, and whose data is not exchanged is questionable.
- Several countries reported lack of calibration capacity as an issue limiting operations and accuracy.
- There were many stations that were either not operational or that are not operating as intended when they were installed. In general, there was a lack of planning and resources to ensure network sustainability.
- All the countries agreed that there was a need of greater regional collaboration. Some of this is currently on-going on an ad-hoc bilateral basis but could be improved through some regional roundtable to exchange information and experiences, improve skills and cooperate on developments. There are some regional WMO centres and they should be involved but this forum should be driven by the countries themselves.

In general, this can be summed up as three main, related, issues:

1. Insufficient reporting to meet climate and weather needs
2. Lack of planning for sustainable operation
3. Need for a regional roundtable

Several countries identified the need to extend their networks. This may be needed, especially to meet the upcoming GBON requirements. However, until the issues identified above are solved there seems unlikely that additional stations would improve the situation, especially in the long-term. The workshop also noted that there are other projects providing resources to add additional monitoring sites, thus there is no need to replicate this but there is a need to address some of the other issues identified.

5.1 Sustainable Networks

Observation systems, especially for climate, must be sustainable. Long-term, reliable observations are the bedrock of all weather and climate services, planning adaption to climate change and disaster and risk reduction planning and warning systems.

Sustainability includes more than just ensuring sufficient resources, although this is needed as well. It is about avoiding single points of failure: one issue with staff, consumables or maintenance should not disrupt the long-term observations. Sustainable networks include:

- **Planning for consumables into the future.** All monitoring equipment will need consumables and replacement parts, this is particularly true for radiosondes where consumables are a significant cost. To ensure long-term, continuous operation it is important to ensure that consumables and spares are available as needed. Planning should therefore, include future resources and ensure purchases can be made in far enough in advance to ensure there is no interruption in equipment operation.
- **Plans for maintenance and equipment replacement at end-of-life.** All equipment will need to be maintained at known intervals and allowance should be made for this in future network operational plans. Similarly, all equipment has a limited lifetime and replacements should be planned in advance to ensure continuous operation. Waiting until equipment fails will lead to significant gaps in the climate records. Sites and equipment should be regularly inspected, and any issues noted and addressed before they can impact site operations.

- **Staff retention and training plans.** Trained, competent staff are an important part of observation networks. Not only do new staff need to be trained, but all staff should be provided refresher training to ensure their skills keep up-to-date. There also needs to be some duplication of skills amongst the staff: interruptions in observations while a staff member leaves or is replaced are not acceptable. Therefore, plans need to be put into place to ensure adequate training, and to ensure that staff who change jobs can be replaced.
- **Calibration.** Accuracy, especially over long periods of time, is vital to detect climatic changes that are generally small in comparison with natural variability. In order to achieve this, systematic calibration is needed. A calibration facility could be shared between several countries, however the costs and feasibility of transporting equipment for calibration over long distances needs to be considered.
- **Affordable and reliable communication systems.** Data must be exchanged hourly. This requires a reliable and affordable communications system. Systems need to be put into place and maintained in order to do this.
- **Data retention policies, storage and long-term archiving facilities.** While data must be exchanged it is also important for each country to archive its own data. This should be done in a way that allows local organizations to develop services based upon the data. The development of a pool of users depending on the data develops a constituency supporting the maintenance of the network and also acts as a quality check by identifying and reporting any data inconsistencies.
- **Planned resources.** Operating a network requires resources. By identifying the components of sustainable networks and planning future activities as described above will allow the future resource requirements to be identified. If resources cannot support the size of network planned, then it is preferable to design a network that can be sustained within the available resources.

Ideally these components of a sustainable network should be considered and planned before new equipment is purchased and installed. Purchasing equipment without firm plans to address these issues is unlikely to lead to sustained improvements in the observing system. Planning should aim to have interoperable systems where observations are integrated into the operational data-flows and using standard data formats for reporting

6. THE PLAN: INCREASING DATA EXCHANGE

This plan focuses on ways to improve the collection and exchange of data through improving the sustainability of the networks. As noted above there are several projects in place that have, or will soon, upgrade equipment and monitoring sites. This plan focusses on ensuring the networks are sustainable and that resultant data is exchanged. Once these issues are addressed then attention can turn to upgrading the monitoring networks to meet the needs of modern global NWP and reanalysis as described in the proposed GBON network.

6.1 Improving Sustainability

As already discussed above, sustainability of an observing system, or systems, is not just a single item but is achieved through a range of activities and processes, addressing the end-to-end chain of the complete system. The points below will not ensure sustainability but can either improve the current methods of working at the national and/or regional level or can be used as a basis to develop new methods of working.

This is considerable overlap between ensuring sustainability and implementation of a Quality management system. The Commission for Instrumentation and Methods of Observation (CIMO) has prepared guidance on quality management in its *Guide to Meteorological Instruments and Methods of Observation* (2014 Edition updated in 2017), Part IV. *Quality Assurance and Management of Observing Systems*. This covers quality management in general, sampling meteorological variables, data reduction, testing, calibration and intercomparison, and training of instrument specialists. This guidance should be followed to ensure the highest quality data is produced. This section highlights the most important actions that need to be taken that will also ensure the sustainability of the observing networks.

6.1.1. Equipment

Consumables

Different observing systems have different levels of dependency on consumables. Some have no need; some only for regular maintenance and calibration; some just for part of the observing process (i.e. distilled water for wet-bulb measurements) and finally those that are completely reliant on consumables (i.e. radiosonde). It is important to understand and document the reliance on consumables for each observing system, but more importantly for those systems that are completely reliant on consumables, how readily these can be accessed. Some consumables are readily available in-country and in an emergency can be sourced within hours from local suppliers, but others are specialized equipment available from select international manufactures and often requiring significant timescales to acquire.

Each observing system should be documented with the consumables required for operations, the level of consumables which are held locally, the sources where new stock can be procured and the timescales necessary to acquire new stock. The level of stock should be actively managed as a component of monitoring the observing system, especially for those systems that are reliant on the consumables, and alerts should be generated to order new stock well before the levels get critical.

For consumables that are both critical and expensive, and thus often have long lead-times for procurement, monitoring and possible procuring, at a regional level could be more efficient and effective, both in terms of resources and ensuring the continuous availability of the observations. This does require a high degree of regional collaboration, both for management and resources, but there are good examples within RA-VI, where the network of European National Meteorological Services (EUMETNET) has supported selected observations at the regional level.

ACTION 1 – For each observing system document the consumables required, the current stock level, where the consumables can be purchased and the current process in place to restock.

Maintenance plan

Similar to consumables, the maintenance requirements for the different observing systems vary considerably but understanding, and implementing, the mandatory and recommended practices is another key component of ensuring sustainability. As part of the procurement process the manufacturers should be required to document, and if necessary, provide training, on the equipment maintenance, both regular (i.e. daily, weekly, annual) and more long-term (i.e. 5-year service). Even after procurement the manufacturer remains an important source of information, and can assist in identifying maintenance needs, plus provide additional training. Another source of relevant information is the CIMO Guide to Meteorological Instruments and Methods of Observation (WMO-No. 8 2018 Edition - CIMO Guide) which for many observing systems provides expert advice and best practices on maintenance and operating procedures.
Waiting until equipment fails will lead to significant gaps in the climate records. Sites and equipment should be regularly inspected, and any issues noted and addressed before they can impact site operations.

ACTION 2 – For each observing system document the current maintenance plan and compare how this relates to the manufacturers/CIMO guide advice.

End-of-life replacement

A specific part of the maintenance process is to know, or at least estimate, when an observing system will become redundant or more likely no longer cost-effective to continue operations. Again, this varies significantly across the different types of equipment, and generally, for an individual type of equipment, the more expensive the original investment the longer the expected lifetime. There is also a tendency for expensive systems to continue to be operated for as long as possible, as incurring higher running costs and accepting the risk of a catastrophic failure, is a significantly lower cost than procuring a completely new system. This strategy can work for a period of time, as long as the risks are understood, enhanced monitoring of the system is implemented, and resources are identified to procure new equipment in the long-term, assuming that there is a continuing requirement.

End-of-life equipment replacement is also an opportunity to consider if equipment should simply be replaced with similar equipment or upgraded equipment installed (e.g. replacing manual observations with an AWS). Understanding the full costs of equipment including the capital costs, operating costs (e.g. electricity, communications, site fees), consumables, maintenance and staffing will assist this choice.

ACTION 3 – For each observing system estimate the 'end of life', noting that different components of the system might have different timescales. Plan and implement a process to replace this equipment at 'end of life'.

Calibration facility

Whilst strictly the calibration of equipment is not a factor of sustainability, it is often connected to the maintenance plan and can be an early indication of faults with the equipment or sensors reaching end of life. For many observing systems the sensor/equipment calibration is a fundamental part of the quality chain, ensuring that measurements delivery to the expected requirement and thus is relevant to all users of the data. Calibration requirements vary significantly across the different system, with some requiring no calibration once operational (i.e. radiosondes), others long-term referencing to a standard (i.e. surface pressure) and finally those requiring continuous calibrations (i.e. reference observations). Once again, the best source of knowledge of the calibration requirements, are the manufacturers of the equipment and the expert advice within the CIMO guide.

Calibration is an area where regional cooperation may be efficient and cost-effective, by sharing the calibration resources across several countries (see 6.1.3).

ACTION 4 – For each observing system document the calibration requirements. Produce, fund and implement a plan to meet these calibration needs. Consider regional solutions.

6.1.2. Staff

Providing observation operators, technicians and managers, with the appropriate skills and knowledge, is not only a fundamental component of the observing system but is also key to the sustainability. Quite often it is the case that training is provided to operators and technicians at the time of equipment installation but this only focuses on the equipment, and little attention is given to the measurements themselves or the benefits of the data. Skills and knowledge are passed between staff on a 'need to know' basis, with much of this being as 'on-the-job' training. From the information gathered from the NMHS representatives at the workshop there was little evidence of a structured observing system training programme, and several examples of single points of expertise within the service. There are different forms of training which can be used to develop a structured training programme, some of which are listed below.

- Ensuring and maintaining skills over time
  - Training for new staff
  - In-house training and support for existing staff
  - Training provided by experts during installation or a workshop
  - Refresher courses
  - Exchanges between sites, within country and within region (see section 6.1.3)
  - Mentoring

ACTION 5 – For each observing system document the skilled staff and the gaps and develop and cost a staff development plan.

6.1.3. Regional Cooperation[3]

Regional cooperation can have many mutual benefits. Sharing resources allows more cost-effective solutions. Options include:

- A regional roundtable for exchange. This should, as a minimum, be annual regional meeting where countries share experiences and best practices. Preferably there should also be regional seminars to provide training on specific aspects of the observing systems. The aim would be to improve the operational understanding and performance of the staff operating the networks across the region. The annual workshop could cover:
  - exchange of experiences and expertise
  - discussions of problems
  - agree bilateral support on specific areas
  - additional training opportunities
- Calibration and Maintenance of equipment. A centre providing calibration facilities for several countries would allow countries to share the costs and develop high quality, traceable, standards for all the contributing countries who may find it difficult to find the resources to do this alone.
- Procurement of equipment and consumables. Shared, planned, procurement should cut costs by placing higher volume orders with equipment suppliers. WMO is able to provide suitable contracts and equipment specifications.

Under the WIGOS the concept of Regional WIGOS Centres (RWC) was developed and approved by the 17th World Meteorological Congress (June 2015). Two mandatory functions for the RWC are support for management of WIGOS metadata and for the WIGOS Data Quality Monitoring System (WDQMS). These functions are critical for monitoring the availability and quality of observations data and metadata in the region/sub-regions covered by a RWC. The activities of these centres will also include identifying any issues with observations data and metadata as well as assisting Members of the region to solve those issues in order to improve the performance of their observing systems in a sustainable manner.

[3] Not discussed at the meeting was the role of WMO's Regional Climate Center ICPAC, which, given their mandatory functions, should contribute in implementing the actions related to regional and international data exchange and data archiving (Actions 6,7 and 8). The mandatory functions of the RCC include developing regional quality-controlled climate data sets and providing climate database and archiving services at the request of NMHSs. Therefore ICPAC should be engaged in implementing actions 6,7 and 8 potentially in the context of the GFCS Africa, Caribbean and Pacific (ACP) project, in which funds for observing system assessments and climate data components are available.

In Africa (WMO Regional Association I) Kenya and Tanzania have agreed and are preparing to jointly establish a RWC for the East Africa that will cover the Lake Victoria region.

An operating RWC in East Africa will significantly contribute to improving the quality, quantity and the timeliness of regional observations data and metadata, exchanged internationally. It will be a major factor in improving the sustainability of the observing systems in the region, by systematically implementing WMO standards. The RWCs are expected to progressively take on some of the optional functions under their responsibility, e.g. liaising with the existing regional/sub-regional centres (e.g. Regional Instrument Centres, Regional Climate Centres, Regional Training Centres, Regional Telecommunication Hubs) and contributing to the implementation of the WIGOS related projects in the region.

Thus, the regional cooperation can be strengthened and institutionalized by closely cooperating with the RWC.

ACTION 6 Agree to hold a regional workshop to establish a regional roundtable to exchange best practices and develop regional cooperation. Work together with the RWC for East Africa being established by Kenya and Tanzania

6.1.4. Data Archiving and Access

While data must be exchanged (section 6.1.5) it is also important for each country to archive its own data. This national archive should be able to support the development of climate services both by the NMHS and by other local organizations. The development of a pool of users who depending on, and regularly use, the data develops a constituency that supports the maintenance and development of the network. Feedback from users can also acts as a quality check by identifying and reporting any data inconsistencies.

The NMHS need to develop appropriate data retention policies. Open data polices encourage the widest use of the data and develop support for the observing system.

The development of a long-term storage facility will require consideration of the speed, security and safety of the data. Access through internet links is needed which will require adequate security. Backups of the data will be needed, with storage at separate locations. "Cloud"-based solutions are possible, but the financial considerations should be carefully considered.

In addition, this archive should be combined with data recovery activities to rescue old observations from paper or obsolete technology to establish the long-term time series climate analysis needs. Advice and support for the entire process is available through WMO. There are existing programmes that can provide advice and support to do this[4].

ACTION 7 - Develop and cost plan to ensure timely reporting and transmission of data.

6.1.5. International Reporting

Reporting of observed data is essential to ensure its full value is obtained. Reporting data to international modelling centres via the WMO systems is essential to ensure accurate weather and climate models of the countries. These global models can be used directly, are downscaled or are used to provide the boundary conditions for local forecasts.

[4] World Climate Programme: https://public.wmo.int/en/programmes/world-climate-programme; Guide to Climatological Practices: http://www.wmo.int/pages/prog/wcp/ccl/guide/guide_climat_practices.php; Climate Data Management System: Specifications: https://library.wmo.int/doc_num.php?explnum_id=7867; Guidelines on Best Practices for Climate Data Rescue: https://public.wmo.int/en/resources/library/guidelines-best-practices-climate-data-rescue.

Reporting and transmitting observed data is technically straightforward, however the systems that receive, use and archive the data need to be designed to cope with the data flows, use the data locally and transmit the data onwards in the correct formats.

To ensure routine reporting of observed data according to WMO regulations and the requirements of GBON, reliable communications systems are needed and staff well trained.

With the internet and mobile communications now widely available, data can be easily and cheaply reported by many of the observing sites. Where direct internet connections or landlines are not available, mobile phones can be used to transmit data to central locations where it can undergo QA/QC and onwards transmission to the international modelling centres. Automated stations should be able to do this without operator intervention. In some areas without mobile phone coverage, internet or land lines then communicating data in a timely manner will be more complex and costly, and may need expert advice, especially to find a long-term, sustainable solution.

Staff training should include:

- The need for timely reporting and transmission of data
- How to report the data, WMO codes etc.
- Appropriate QA/QC
- How to deal with problems and issues that arise

The costs for this will include mobile communications and central staff to coordinate and check data and ensure its onwards transmission. The cost of central equipment to collect store and transmit the data onwards.

ACTION 8 Develop and fund a long-term, central facility to receive, transmit internationally and archive data with easy and timely access to all users. Evaluate and address data rescue needs.

6.1.6. Resources

Clearly, a sustainable observing system will need on-going, secure and reliable sources of funding. As a first step each NMHS should estimate for each observing system they run the annual operating costs. This will include:

- Staff costs
- Site costs (rent, electricity etc.)
- Consumables
- Maintenance costs
- Staff development costs including training, mentoring, travel to regional meetings and exchanges
- Annualized Replacement costs of equipment as they reach their end-of-life (the expected replacement cost allowing for inflation, over the lifetime of the equipment).

These costs can be compared with the available resources to determine the extent of the observing system that can be sustained. More detailed planning can take account of periodic costs when they occur (such as a 5-year maintenance of a hydrogen generator) rather than annualizing all the costs. Such information should also support attempts to find additional sources of funding.

Table 3. Example of calculation of network cost, Improved estimates could be made by estimating costs for each year into the future rather than estimating an average annual cost.

Observing system		e.g. Upper Air	...
Number of sites		a	
Cost per site	Consumables	b	
	Maintenance	c	
	Calibration	d	
	Staff Costs	e	
	Site Costs	f	
	Communications	g	
	Replacement	h	
	Expected Lifetime	i	
	Total annual cost per site	j = b+c+d+e+f+g+(h/i)	
Staff development		k	
Central data reception		l	
Data Archive		m	
Total annual cost for total observing system		k = (j*a)+k+l+m	

Note:
This is an example – the details will vary from region to region depending of local factors.

ACTION 9 Estimate average annual costs of observing system and annual funding available.

6.2 Planning to meet GBON requirements

When the existing observing sites can be operated sustainably, with adequate funds to cover all the annual costs, then plans should be developed to ensure the national observations can meet the GBON requirements outlined in chapter 3. Given the large-scale resolution of the upper air observations, it may be possible to locate sites that cover more than one country. Thus, regional cooperation in developing these plans would achieve economies and should be encouraged.
The plan will

- Be based on existing operational sites.
- Consider the restoration or improvement of existing sites
- Identify new sites to fill gaps in the existing coverage
- Consider total cost of ownership: capital costs: e.g. consumables, maintenance, and the implications for staffing etc.

Support for developing such a plan may be available from WMO.
Resources should be identified for such a plan and will need to cover the initial capital costs and first year of operation, subsequent annual costs, and the replacement of equipment at its end-of-life.

Table 2, above, indicates that the minimum, mandatory, number of upper air stations to meet the GBON requirements is 7: while at the recommended spacing it is 182. Clearly this is a significant difference in the resources needed and the focus should be on achieving the mandatory requirements. Additional stations could be added for specific needs, but the long-term resources needed to maintain the operation of these stations operations over decades need to be assured.

In addition to GBON there may be local needs to be addressed such as higher-resolution precipitation observations in areas subject to floods or landslides. In planning to meet these needs, the same consideration of the sustainability of the observations should be followed and planning should assume operation for decades.

The national plans should be linked to the national implementation of WIGOS, which includes developing National WIGOS Implementation Plans (N-WIP) and a National Observing Strategy.

ACTION 10 Develop and cost plan to improve the national observing system to meet the GBON requirements

6.3 Summary of National Actions

This document has outlined a number of steps that need to be undertaken nationally in order to establish a sustainable observing system. These will produce a detailed plan and costing that could be used as the basis requests for additional funds.

The results of actions 1-9 should be combined to provide a costed sustainability plan. This plan will need to be compared to the available resources and the NMHS may need to mobilize additional resources to implement the plan. Unless all the issues in sections 6.1.1 to 6.1.6 are addressed then the network is unlikely to have a long-term future and spending additional funds on new observing site is likely to be wasted. Only observations that are made routinely, are exchanged in a timely manner and sustained into the future will support the climate services that the NMHS increasingly are asked to support.

Improving sustainability starts by a review of the existing monitoring and determining the annual cost of operating this network in a sustainable way. These steps are:

ACTION 1 – For each observing system document the consumables required, the current stock level, where the consumables can be purchased and the current process in place to restock.

ACTION 2 – For each observing system document the current maintenance plan and compare how this relates to the manufacturers/CIMO guide advice.

ACTION 3 – For each observing system estimate the 'end of life', noting that different components of the system might have different timescales. Plan and implement a process to replace this equipment at 'end of life'.

ACTION 4 – For each observing system estimate the 'end of life', noting that different components of the system might have different timescales. Plan and implement a process to replace this equipment at 'end of life'.

ACTION 5 – For each observing system document the skilled staff and the gaps and develop and cost a staff development plan.

ACTION 6 – Agree to hold a regional workshop to establish a regional roundtable to exchange best practices and develop regional cooperation. Work together with the RWC for East Africa being established by Kenya and Tanzania

ACTION 7 – Develop and cost plan to ensure timely reporting and transmission of data.

ACTION 8 - Develop and fund a long-term, central facility to receive, transmit internationally and archive data with easy and timely access to all users. Evaluate and address data rescue needs.

ACTION 9 – Estimate annual costs of observing system and annual funding available

When Actions 1-9 have been completed, and the required funding has been guaranteed, then the observing system can be extended to meet the GBON requirements. Unless issues such as annual costs, staff development and reliable transmission of data have been addressed there is no point in adding additional stations.

ACTION 10 – Develop and cost plan to improve the national observing system to meet the GBON requirements

7. SUMMARY

The workshop identified three main, interrelated, issues:

1. Insufficient reporting to meet climate and weather needs
2. Lack of planning for sustainable operation
3. Need for a regional roundtable

Sustainable operation of an observing network means that the network will continue operating and delivering data for many years to come. Climate data needs long-time series, over decades, to identify and measure changes. Planning for a sustainable network should cover:

- Consumables required,
- Maintenance planning,
- The process to replace this equipment at 'end-of-life',
- Calibration requirements,
- Developing and costing a staff development plan,
- Holding a regional workshop to establish a regional roundtable to exchange best practices and develop regional cooperation.
- Developing plans to ensure timely reporting and transmission of data.
- Developing a long-term, data archive with easy and timely access to all users.

Only when the sustainable operations are assured should consideration be given to extending the network. In extending the network the aim should be to achieve the mandatory minimum of the GBON network for observations that will be exchanged internationally as this will improve the accuracy of the outputs from global monitoring centres that are used nationally. In addition, there may be local needs to be addressed such as higher-resolution precipitation observations. The planning for new observations should always ensure they can be maintained over decades.

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