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Report of the 1st Meeting of the GCOS Surface Reference Network (GSRN) Task Team

Maynooth, Ireland
1-3 November 2017

GCOS-214

UNITED NATIONS
ENVIRONMENT PROGRAMME

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FOR SCIENCE

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1. OPENING OF THE MEETING

The meeting was opened with a welcome to all participants from Prof. Ray O’Neill, Vice-President of Research and Innovation of the University of Maynooth, Ireland. Caterina Tassone, GCOS Secretariat, introduced Tim Oakley, from GCOS Secretariat and Howard Diamond, Chairman of the Task Team. All other members of the task team introduced themselves. The list of participants can be found in Annex 11. The agenda (Annex 1) was adopted.

2. EXPECTATIONS FOR THE MEETING

Howard Diamond, in his role as chairperson of the Task Team, summarized the Terms of Reference (Annex 2) and what the expected outcomes of the meeting were. This meeting is the first meeting of a Task Team whose main objectives are to provide a concrete proposal on whether it is feasible to implement a global surface reference network and to assess this by identifying the major stakeholders, the benefits, the practicality of doing this, and probably most importantly the costs – both initial installation as well as long-term maintenance, operation, and monitoring. The primary purpose of this first meeting was to outline clear benefits for such a network and envision a strategy that will allow the group to undertake its tasks. This Task Team will produce a concept note that can be used to get clear feedback from the members on whether there is interest from their country in participating. This would avoid designing a perfect network to find that no one is interested in implementing it. The concept note will be used also to make a recommendation to the Atmospheric Observation Panel for Climate (AOPC), and will include a proposed list of steps to follow in the GSRN implementation.

3. BENEFITS AND EXPECTATIONS FOR A SURFACE REFERENCE NETWORK

Peter Thorne briefly introduced the paper developed by members of the community “Towards a global land surface climate fiducial reference measurements network” (Thorne et al, 2018) which includes the rationale of the existence of a surface reference network. The underpinning principles for a reference network are traceability, comparability, representativeness, long term operational viability, careful management of unavoidable change, full data and metadata retention sufficient to understand and as necessary reprocess observations (something that is nearly impossible for most past data), and open data provision.

Howard Diamond gave an overview of the U.S. Climate Reference Network (USCRN) which are unstaffed stations taking high-quality climate observations. Typically, at a USCRN station, air temperature, precipitation, soil temperature and moisture are measured, with a triple sensor redundancy configuration for all four of these ECVs. Measurements are transmitted hourly via the Geostationary Operational Environmental Satellite (GOES) and meet or exceed the GCOS monitoring principles. Ancillary measurements (e.g., solar radiation, surface radiation, 1.5m winds, and relative humidity) are also taken to assist in the quality control of the primary ECV measurements, but are performed without redundancy. USCRN has 114 stations in the conterminous U.S., 21 stations in Alaska, and 2 stations in Hawaii, and the program plans to install an additional 8 stations in Alaska by the end of 2022. The USCRN sites are not staffed, but are regularly serviced as well as serviced upon exception. Further details on the USCRN can be found in Diamond et al. (2013) and at <http://www.ncdc.noaa.gov/crn>.

In the discussion that followed the presentations, some of the benefits of having a GSRN were discussed, including the resulting improved confidence in detecting the global increase in temperature and the possibility of using modern GSRN data to have more confidence in the historical records. Observations from a GSRN will become a fundamental climate research resource. Rigorously time series from these sites will lead to the development of a better understanding of the climate related processes, including extreme events, and will also be useful for assessing mitigation effectiveness and burdens due to climate change impacts. Observations from a GSRN can be used to improve measurements made at other, non-reference site and co-located reference quality measurements will provide a valuable data set for the calibration and

validation of satellite. New technique and equipment can be tested at the reference site which will also provide good locations to base future field campaigns. Many of these benefits also apply to other uses such as numerical weather prediction and disaster and emergency response systems. The outcome of this discussion is summarized in Annex 4.

A discussion on which surface-based Essential Climate Variables would be monitored at each GSRN station followed. The options to be considered are whether several ECV should be monitored simultaneously, as specified in the paper Thorne et al. (2018) or whether is better to have a minimum set at each station, e.g. temperature and precipitation, and then only have a subset of the stations to monitor more ECV. However, it was noted that by having integrated ECV observations, the societal benefits will not only be limited to monitoring climate change but also for more broadly monitoring environmental changes.

In any case, once the fundamental quantity is measured, secondary measurements to quality control the fundamental one are needed. The question of the network density is intertwined with the choice of the parameters measured and what the timescales are, as lower correlated variables need higher network density. Even though the cost of a GSRN would be significantly less than that of a satellite mission, funding remains a real concern, and for the GSRN to be successful, it requires not only initial funding but also the budget to support the network through the years, as well as the lead centres(s) dedicated to the network.

4. REQUIREMENTS

The presentations during the afternoon of the first day of the meeting concentrated on understanding the requirements from the perspective of different communities. For the atmosphere, Phil Jones underlined that the GSRN needs to measure all the GCOS surface ECVs, i.e. water vapour, surface radiation and wind speed, in addition to air temperature, pressure and precipitation. GCOS has many other networks, among them the GCOS surface network (GSN). However, the GSRN will differ since it will provide metrological quality measurements. There is the question of whether observations at the reference quality level are also needed to improve reanalysis.

Nigel Tapper reported that the Terrestrial Observation Panel for Climate (TOPC) strongly supports the idea of the GSRN. TOPC terrestrial ECVs, are substantially based on satellite data, and are very complementary to the at-site atmospheric variables of air temperature, vapour pressure, etc. The terrestrial ECVs to be included in the GSRN were proposed to include soil moisture, snow, and land-surface temperature; and while soil temperature is not yet a formal ECV, it was deemed as being of equal importance to soil moisture. These ECVs are mostly satellite based and have the advantage of having a global coverage, ensuring that they can compare to any station location of the GSRN; additionally they have metrologically traceable metadata, there is substantial continuity of satellite capabilities over time, and usually standardized algorithms are used for post-processing of ECVs derived from satellite spectral measurements, with raw data usually archived.

A critical issue is the identification of station locations for the GSRN sites. Nigel Tapper reported key points of a discussion with Karl Monnik, covering some of the requirements from the Bureau of Meteorology of Australia. These include representation of different climate zones, including coastal and metropolitan locations, multiple measurements methods as well as multiple redundancies; representation of the range of standard measurement heights, infrared measurements of surface temperature, good documentation of procedures, computing and processing methods.

Following this presentation, there was an extensive discussion on whether urban and metropolitan stations should be included in the GSRN. Due to inhomogeneity considerations, urban stations are considered problematic and have been excluded from many long-term records. However, they are critically important because over 50% of the global population is concentrated in cities. A possible way forward would be to consider 'urban' as a climate region, and start defining standards for this particular category. While the urban subset of GSRN could not be used for calibration/validation, as this requires an unchanged environment, it could be useful at a national and regional level for studies on adaptation and mitigation. Clearly a concrete societal benefit could derive from such a subset of GSRN.

Andrew Harper summarized the requirements from a metrological perspective. Measurements have to be traceable, comparable (between sensors, stations, countries), and representative for a larger region. The guide for the GSRN should be a list of reference to other guides, such as for example the Commission for Instruments and Methods of Observation (CIMO) guide and the Guide to the Expression of Uncertainty in Measurement (GUM).

Peer Hechler presented the current WMO meteorological observing station category 'Reference Climatological Station (RCS)' as defined in the WMO Manual on the Global Observing System (WMO No. 544): "A climatological station the data of which are intended for the purpose of determining climatic trends. This requires long periods (of not less than 30 years) of homogeneous records, where human-induced environmental changes have been and/or are expected to remain at a minimum. Ideally, the records should be of sufficient length to make possible the identification of secular changes of climate." The Manual determines that each Member shall establish and maintain at least one reference climatological station. From the CCI perspective, the GSRN should be defined in a way that it can cover the above requirement for long-term homogeneous observations. Rather than introducing a new type of meteorological observing stations, it is desirable from a CCI perspective to merge the GSRN and RCS concepts into one concept of reference stations that meet GCOS and CCI requirements. In general reference stations should be part of WMO Integrated Global Observing System (WIGOS) and meet related standards. The definition of a reference network should (i) be seen in the context of a future tiered network approach, (ii) provide an inclusive and integrated approach, and (iii) consider existing reference climatological stations and Regional Basic Observing Network (RBON) stations (where appropriate and feasible). Further discussion of these points is in Thorne et al. (2018). Guidance needs to be developed on how to use data from reference stations to improve the quality of second and third tier network stations.

A more detailed summary on the topic of CCI perspective for a GSRN can be found in Annex 10.

A round table discussion followed this session. The main purpose of this discussion was to identify the most important requirements for a GSRN. The list of identified requirements is in Annex 5.

5. NETWORK DESIGN

On the second day, Tim Oakley, Peter Thorne and Howard Diamond presented design principles, governance and management respectively for the GSN, GRUAN and USCRN.

Network design for GSN: Every GSN station is based on an already existing station as a subset of the national network. The design of the GSN is discussed in Peterson et al. (1997). Members approved or suggested alternatives to the selection. This has continued and members still suggest changes when stations stop reporting. The GSN is a global network and stations are selected to ensure global coverage, as there is no point in having too many in one country and none somewhere else. The GSN is intended to comprise the best possible set of land stations with a spacing of 2.5 to 5 degrees of latitude/longitude. Criteria for selection are the commitment by NMHSs with regard to continuity, the geographical representativeness of observations, the length and quality of historical time series and the available parameters.

Network design for GRUAN: The GCOS Reference Upper-Air Network (GRUAN) needed a different model than GSN, as reference upper air measurements are very expensive. GRUAN started by defining a minimum set of requirements for upper-air measurements, and stations that met these requirements were invited to join the network. Requirements can be found in [GCOS-112](#). GRUAN stations are certified as meeting the requirements stipulated in the GRUAN Guide ([GCOS-171](#)). GRUAN started small but has an ultimate goal of including around 40 global stations. As at the end of 2017, GRUAN comprised 24 sites, 9 of which have been formally certified by both the GRUAN Lead Centre and governing Working Group. The GRUAN network, like all high quality networks, struggles to get sites in the global south areas of South America and Africa. This is also likely to be an issue for GSRN.

Network design for USCRN: USCRN was developed based on new stations, aiming at a grid of stations roughly spaced at 265 km, located where minimal land use changes over a long-term period were expected, at least 100 m from any artificial heat source, with triplicate sensors and providing consistent and constant monitoring, annual maintenance for each station, excellent up-to-date documentation and good and easy data access. Free and open data access is fundamental as this type of measurement is expensive and therefore it is important that the data are extensively used. Robust engineering makes it possible for the system to operate in a wide range of environments with a minimum requirement of 98% data receipt and availability; although typically, USCRN realizes a data receipt and availability rate in the 99.5% range. Some of the sites are co-located with ecological sites and provide many additional ECV observations. Surface pressure is not included in the observed quantities, but it would be important to have it measured at least at a subset of the stations. This would allow study of the prevalence of a low pressure in a climatological sense. In the USCRN, 40 stations have been identified where pressure and 10 m wind could be measured as a supplement to hurricane landfall monitoring should the funding for that be available.

The three networks discussed how they all strive to follow the basic GCOS monitoring principles. They are built on three different approaches to network design, with the GSN built on existing stations, the USCRN on new ones and the GRUAN specifying first requirements and then asking countries to participate to the network with stations meeting those requirements.

Following these presentations, possible design principles for the GSRN were discussed in three break out groups, and the outcome was then summarized in one list (Annex 6).

6. NETWORK GOVERNANCE AND MANAGEMENT

Network governance and management of related networks.

Management of GSN. GSN governance is with the NMHS who has committed to adhere to the GSN requirements as specified in the guidance material and technical regulations of WMO. When requirements of a GSN stations are not met, the meteorological organisation owning the station is made aware of that and asked to rectify the situation. In practice, GSN generates one CLIMAT message on a monthly basis (in addition to any other messages they may transmit at higher frequencies for NRT applications). It is expected that a 'Daily' CLIMAT message, consisting of monthly transmission of daily summaries, will be finalised in the near future. The Deutsche Wetterdienst (DWD) monitors precipitation, the Japan Meteorological Agency (JMA) monitors temperature and NOAA's National Center for Environmental Information (NCEI) hosts the archive. CBS Regional Lead Centers diagnose problems in the GSN using the monitoring reports to look at their part of the network and where problems are detected they work with the national focal points and the GCOS Network Manager to resolve the issue ([GCOS-203](#)). The lead centres play also other roles such as liaising with nominated National Focal Points for GCOS to improve data and metadata availability and quality, and assisting AOPC in the revisions of GSN. The challenges with this type of management are the lack of real-time monitoring, reliance on a number of centres who do this work as an added task, and a complex communication chain.

Management of GRUAN. The GRUAN reports to AOPC and AOPC, supported by the GCOS Secretariat, and guided by the GCOS Steering Committee, provides direction and oversight of GRUAN. Guidance on operational requirements comes from CIMO, from the Commission for Basic Systems (CBS), from the Commission for Atmospheric Sciences (CAS) and from CCI, both through AOPC or directly, while guidance on research requirements comes from the World Climate Research Programme (WCRP) through AOPC. A dedicated Lead Centres monitors day-to-day engineering, operations, and maintenance. Data streams have central processing, data collection tools are used and data and metadata are processed at the Lead Centre and then sent to the NOAA's National Centers for Environmental Information (NCEI) for archiving. Communication is done through regular teleconference and one annual meeting.

Management of USCRN. For the USCRN a lead centre plays a similar role to the GRUAN Lead Centre, monitors day-to-day engineering, operations, and maintenance, manages day-to-day data management

and documentation, as well as relations with site hosts, leading a Science Program to utilize the data and have input into operations. Regular monthly teleconferences and semi-annual in-person meetings are conducted to ensure that communication is ongoing and that issues that arise are resolved in as effective and efficient manner as possible. The key to a Lead Centre is a focused Program Manager whose only job is to oversee the installation, operation, maintenance, and monitoring of the network. This need is coupled with the need for a dedicated engineering, programming, and science staff that are dedicated 100% to the network.

Discussion following the presentations focused on network management options for the GSRN. The main question is to whom a GSRN would report to and where the budget would come from, but also what the parameters would be to indicate a successful implementation and management of the network. For the GSRN, one of the key outputs is the scientific production in terms of research papers and contributions to conferences, which means accounting also for other groups doing research and producing papers using the data. In GRUAN there is a Task Team who encourages research with GRUAN data. It was also noted that for a GSRN, CIMO should have an important role. However, the network is not going to be recognized until is adopted by technical regulations. In order to gain recognition, the GSRN has to be part of the WIGOS manual. In terms of management, it is clear that the GSRN needs one or more lead centres.

Main points identified as important for the governance and management of the GSRN are listed in Annex 7.

7. INTERACTIONS OF THE GSRN WITH THE METROLOGY COMMUNITY

Andrea Merlone presented on the interactions of the GSRN with the metrology community. He brought to the attention of the team the importance of tightly working together as benefits of this cooperation are being seen on both sites. The presentation reported on previous activities within the European MeteoMet project, having delivered results of interest for the WMO CIMO expert teams, mainly in terms of quantified measurement uncertainty components, studies on measurement and calibration best practice, and support in establishing traceability in the field. The interaction of the climate and meteorological community with members of the BIPM and the EURAMET was also illustrated, together with the roadmaps of the BIPM¹ CCT² and EURAMET Task Group Environment. The strategy document of CCT now clearly mentions metrology support to the creation of the GCOS Surface Reference Network.

8. WORKPLAN

Before AOPC 2018 (6-9 March 2018):

1. GCOS Secretariat will do first draft of initial meeting report, which will be circulated.

Report to also include:

- a) Tiered network (connections to other networks) and benefits to be part of this; e.g., GCOS-182 and GI Paper – Victor
- b) Benefits section – take bullets create good text – Howard (lead), Nigel, and Caterina

General - throughout the existence of the Task Team:

2. Rework of GCOS 112 into a GSRN doc: outline – Peter (lead) and Rachid
3. Measurements requirements: what, how; frequency – Andrew (lead), Andrea, and Jiankai
4. Terminology – Phil (lead), Andrea, and Peer
5. Identify climate zones – the most critical, sensitive ones (e.g., Galapagos Islands); perhaps a better approach than using WMO RAs; Dual Approach of existing stations and climate regions – Nigel (lead), Phil, and Victor

¹ Bureau International des Poids et Mesures – International office of weights and measures

² Consultative Committee for Thermometry

6. Satellite requirements (e.g., Cal/Val) – CEOS WG on Climate – Peter and Caterina to find someone – lead TBD

Schedule (Until March 2018)

- Initial Meeting Report out by end of November along with better defined work plan
- Report then circulated; comments back by 15 January
- Final draft of Item no. 1 due by end of January
- Items 2-6 – leads to begin coordination and decide a plan forward (November-December 2017)
- Teleconference – leads of items 2-6 report on their status (mid-February)
- Presentation of Initial Meeting Report at AOPC – 6-9 March 2018 (Howard)

After March 2018:

- Possible benefits to be included in a document for EC (June 2018)
- Resourcing? – Linkages to adaptation and mitigation activities - bring in people to the TT experienced with such applications for funding
 - Green Fund
 - Foundations/NGOs
 - EU
- Draft of rework of GCOS 112 for GSRN: AOPC 2019
- Final deliverable of Task Team – Rework of GCOS 112 for GSRN: AOPC 2020
- Potential Implementation Plan (depends on the existence of a Lead Centre): AOPC 2020
- Canvassing of potential Lead Centre candidates and site candidates (ongoing)
- Considerations of building into WMO technical regulatory documentation and framework (TBD)

Outreach activities:

- Workshop
- Publication (EOS)
- CIMO Commission Meeting in October 2018
- Keep events in mind as they are presented – e.g., EGU, AGU, EMS, etc.
- Side events where people already are present
- Survey?

9. CONCLUSION

On the last day, a preliminary list of ECVs to be monitored at the sites was discussed, together with possible stations that could be used as pilot station in the preliminary phase of the implementation (Annex 8).

The meeting agreed on a draft work plan presented by Howard Diamond. The output of the meeting will consist in a single document including the benefits, requirements, network design, governance and management.

The meeting was closed at 11:30 am on the 3rd November 2017.

References

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Peter Thorne et al., 2018: Towards a global land surface climate fiducial reference measurements network. *International Journal of Climatology*. ID: JOC5458, DOI: 10.1002/joc.5458

ANNEX 1: AGENDA

Day 1: Wednesday, 1 st November 2017 (Benefits, Requirements)					
Time		ITEM	N°	Presenter	Targeted outcome
09:00–09:20	Opening	Opening of the Meeting	1.	Howard Diamond	
		Welcome	1.1		
		Introductions	1.2	All	
		Adoption of Agenda	1.3		
		Conduct of the Meeting	1.4		
09:20–09:40		Review Terms of Reference/ Expectations for the Meeting	2.	Caterina Tassone	
		Expected outcome of the meeting	2.1		Agreed expected outcome
09:40–10:00		Benefits and Expectations of/for a Surface Reference Network	3.		
		Vision for the Surface Reference Network (main points from paper)	3.1	Peter Thorne	
10:00–10:20	Benefits	Benefits nationally, regionally and global: What is a reference network and what does it do? What could it be, including spatial characteristics of network?	3.2	Howard Diamond	
10:20–10:40		Coffee Break			
10:40–11:00		Members are asked to write down the three most important benefits of a SRN in their view which will then be structured/grouped	3.3	All	
11:00–12:00		Plenary discussion on benefits.	3.4	All	From the notes, the secretariat will produce draft list of benefits
12:00–13:30	Lunch				
13:30–15:00	Requirements	Requirements	4.		
		Requirements from an atmosphere perspective	4.1	Phil Jones	
		Requirements from a land perspective	4.2	Nigel Tapper	
		Requirements from a satellite perspective	4.3	Bojan Bojkov providing slides (?)	
		Requirements from an metrological perspective (CIMO)	4.4	Andrew Harper	
		Requirements from CCI perspective	4.5	Peer Hechler	
15:00–15:20	Coffee Break				
15:20–16:20		Breakout session: Three groups discuss and draft requirements	4.6	All	Based on previous presentations, come up with key requirements for a GSRN
16:20–17:15		Report of groups and discussion	4.7	All	Draft requirements (satellite requirements will be added by Boris)
17:15–17:30	Wrap-up session				
17:30	End of day 1				
19:30	Dinner				

Day 2: Thursday, 2nd November 2017 (Network: design, governance, management, implementation)

Time		ITEM	N°	Presenter	Targeted outcome
09:00–09:45	Network design	Network design	6.		
		Design principles of the GSN	6.1	Tim Oakley	
		Design principles of the GRUAN	6.2	Peter Thorne	
		Design principles of the USCRN	6.3	Howard Diamond	
09:45–10:20		Breakout session: Three groups draft a concept for a GSRN	6.4	All	
10:20–10:40		Coffee Break			
10:40–12:00		Report of groups, discussion and summary	6.5		Draft proposal(s) for general network design and strategy/work plan how to finalize network design
12:00–13:30		Lunch			
13:30–14:00	Network governance	Network governance	7.		
		Governance of GSN, GRUAN and USCRN: Organigram of each network is shortly presented as introduction of discussion	7.1	Tim Oakley, Peter Thorne, Howard Diamond	
14:00–15:00		Plenary discussion on governance structure	7.2	All	Draft proposal for network governance and strategy/work plan how to finalize network governance
15:00–15:20		Coffee Break			
15:20–15:50	Network management and implementation	Network management	8.		
		Network management of GSN, GRUAN and USCRN: Management concept is shortly presented as introduction of discussion	8.1	Tim Oakley, Peter Thorne, Howard Diamond	
		Breakout session: Same groups as in 6.4 draft management concept for network	8.2	All	
16:30–17:00		Report of groups, discussion and summary	8.3		Draft proposal(s) for network management and strategy/work plan how to finalize network management
17:00–17:20	Network governance, management and implementation	Implementation/ Pilot sites	9.		
		Vision on the implementation of GSRN	9.1	Howard Diamond	
17:20–17:45		Discussion on implementation/pilot sites		All	Draft proposal(s) for Implementation and pilot sites.
17:45		End of day 2			

Day 3: Friday, 31st March 2017 (... , Closure)

Time		ITEM	N°	Presenter	Targeted outcome
08:30–9:00		Engagement with other parties	10.		
		Discussion on engagement of GSRN with other parties: e.g. WMO, CBS, CIMO, CCI, WIGOS, BIPM	10.1	Open discussion. A.Merlone to introduce interaction with BIPM, others	Defined position of GSRN in the existing observation landscape
90:00–10:00		Open questions and way forward	11.		
		Discussion on how to tackle other open questions that might not have been discussed yet: siting, cost, lead center, funding; Decide on work plan	11.1		Work plan
10:00–10:15		Coffee Break			
10:15–11:45		Review of actions and deliverables	12.		List of Actions
11:45–12:15		Wrap-up and closure of meeting	13.		
12:15		End of Meeting			

ANNEX 2: TERMS OF REFERENCE

GCOS AOPC Task Team on the instigation of a GCOS Surface Reference Network

Background

AOPC-22 (Exeter, UK, March 2017) agreed on the creation of a dedicated task-team to scope a potential GCOS global surface reference network. The potential for such a network has been proposed by the GCOS AOPC and by the Commission for Climatology. A white paper has been developed by members of the community at the request of these parties, and is to be submitted for publication. This Task Team is charged with taking this forward towards practical implementation providing a concrete roadmap as to what would be required and to canvas stakeholders. Working models on which to base deliberations include the GCOS Reference Upper Air Network, US Climate Reference Network, and Global Cryospheric Watch.

Membership

Chair – Howard Diamond – USA

AOPC Representative – Phil Jones – UK

GRUAN Representative – Peter Thorne – Ireland

GSN Representative – Tim Oakley – UK

CBS/WIGOS/CIMO Representative – Andrew Harper – New Zealand

NMHS Representative – Jiankai WANG – China

BIPM representatives – Andrea Merlone – Italy

Climate scientist representatives – Victor Venema – Germany

TOPC – Nigel Tapper – Australia

Satellite – (Bojan Bojkov – Germany)

Region I representative – Rachid Sebbari – Maroc

GCOS Secretariat – Caterina Tassone

WMO Secretariat – Peer Hechler

Proposed Terms of Reference (as approved by AOPC-22 and email June 2017)

Scientific charge

1. Create a scientifically robust basis for a proposed network spatial composition, taking into account fairness in national contributions and the need for globally representative measurements;
2. Accounting for stakeholder needs including inter-alia climate monitoring, process understanding and understanding remaining measurements (including space-borne measurement systems), define a robust siting rationale;
3. Propose a phased implementation that ‘starts small, but starts’ and builds over time to a holistic set of measurements of all relevant ECVs at each site to the extent practicable;
4. Alight on a potential governance structure in collaboration with key stakeholders;
5. Propose one or more management options that undertake day-to-day operational oversight and ensures a globally traceable, comparable network of measurements, recruiting possible host institutions;
6. Provide indicative costings on the proposed solutions sufficient to inform a decision as to whether to move forwards;
7. Address additional needs identified by the group and agreed with AOPC as they arise.

Modus Operandi

1. The task team shall exist for an initial period of two years;
2. The task team shall work primarily remotely, facilitated by GCOS secretariat. It is expected that an initial ‘in person’ meeting will be organized to discuss and agree the work-plan and deliverables, further meetings will be decided as required;

3. Within 3 months of the initiation of the task-team a detailed work plan and deliverable will be agreed;
4. The task team shall work in conjunction with relevant groups within WMO to ensure broad buy-in including CCI, WIGOS and CBS;
5. The task team chair shall be expected to report annually on progress to AOPC by means of a brief written report and, if support available, verbal reporting in person;
6. The task team shall be expected to lead the production of a final report (implementation plan) which may form the basis for a decision as to whether, and if so how, to proceed with a GCOS Surface Reference Network.

Background documents

White paper

http://ane4bf-datap1.s3-eu-west-1.amazonaws.com/wmocms/s3fs-public/ckeditor/files/12_reference_networks_white_paper.pdf?X5m5GtgVl1hoc0qAYiJ3mZEK8K_22O5R

GRUAN documentation

The GCOS Reference Upper-Air Network (GRUAN) GUIDE,
https://library.wmo.int/opac/index.php?lvl=notice_display&id=15182

The GCOS Reference Upper-Air Network (GRUAN) MANUAL
https://library.wmo.int/opac/index.php?lvl=notice_display&id=15181

GCOS Reference Upper-Air Network (GRUAN): Justification, requirements, siting and instrumentation options - *April 2007*
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Bodeker, G.E., S. Bojinski, D. Cimini, R.J. Dirksen, M. Haeffelin, J.W. Hannigan, D.F. Hurst, T. Leblanc, F. Madonna, M. Maturilli, A.C. Mikalsen, R. Philipona, T. Reale, D.J. Seidel, D.G. Tan, P.W. Thorne, H. Vömel, and J. Wang, 2016: *Reference Upper-Air Observations for Climate: From Concept to Reality*. *Bull. Amer. Meteor. Soc.*, **97**, 123–135, doi: 10.1175/BAMS-D-14-00072.1.

USCRN

Diamond, H.J., T.R. Karl, M.A. Palecki, C.B. Baker, J.E. Bell, R.D. Leeper, D.R. Easterling, J.H. Lawrimore, T.P. Meyers, M.R. Helfert, G. Goodge, and P.W. Thorne, 2013: *U.S. Climate Reference Network after One Decade of Operations: Status and Assessment*. *Bull. Amer. Meteor. Soc.*, **94**, 485–498, doi: 10.1175/BAMS-D-12-00170.1.

<https://www.ncdc.noaa.gov/crn/documentation.html> - USCRN documentation

Global Cryosphere Watch

http://globalcryospherewatch.org/cryonet/site_types.html

ANNEX 3: BENEFITS OF A GLOBAL CLIMATE OBSERVING SYSTEM

Continuous, high-quality, scientific observations of the global environment are critical for defining the current state of the Earth's integrated environmental system, in particular, the constantly changing conditions of the atmosphere, hydrosphere, and biosphere. A historical continuum of high confidence data is essential to document changes in the Earth's biological and physical systems, and understand the causes of these variations and their interrelationships. An accurate understanding of these relationships is also crucial for building, initializing, and evaluating the models used to predict the state of the Earth's future environmental system. Building this knowledge base requires systematizing historical data and paleoclimatic reconstructions to modern scientific standards, as well as in quantifying the ever-shifting present. The fidelity of predictions of the future is directly related to such a knowledge base being in place, sustained over a long time period and having sufficient accuracy.

Informing mitigation and adaptation decisions requires the integration and availability of these data on an ongoing basis. It also requires that related socioeconomic measurements are made and available in ways that facilitate whole-system analyses of societal and environmental interactions. In the same way that economic decisions are based upon a broad and carefully developed set of indicators (e.g., GDP, unemployment, etc.), climate-related decisions should be informed by a set of indicators that indicate changing environmental conditions and vulnerability to inform adaptation and mitigation decisions at local to international scales. Data management is a critical aspect of any systematic observing effort.

Climate observations of the present, in particular, encompass a broad range of environmental observations, including (1) routine weather observations, which are collected consistently over a long period of time; (2) observations collected as part of research investigations to elucidate processes that contribute to maintaining climate patterns or their variability; (3) highly precise, continuous observations of climate system variables (e.g., atmospheric, oceanic, and terrestrial) collected for the express purpose of documenting long-term (decadal to centennial) changes; and (4) observations of climate proxies, collected to extend the instrumental climate record to remote regions and back in time. However, many of these observing systems, particularly those of non-satellite based atmospheric and terrestrial networks have been in severe decline in quality and overall scientific veracity over the past few decades. As a result our observations have been crippled and we have an impaired vision of whatever the future might be. There is a great distinction between observations made for daily or weekly weather forecasts, and the observations required to detect long-term climate change and in this case the issue of calibration is critical. Small changes over a long time are characteristic of climate change but they occur in the midst of large variations associated with weather and natural climate variations, such as El Niño. Yet the climate is changing and it is imperative to track the changes and causes as they occur and identify what the prospects are for the future—to the extent that they are predictable. The kind of sustained observations required for climate detection and attribution of climate are unique and again, calibration is the key factor.

Satellite observations alone are not sufficient for climate; they require in-situ measurements for calibration and validation. In-situ observations are required for the measurement of parameters that cannot be estimated from space platforms (e.g., biodiversity, groundwater, carbon sequestration at the root zone, and subsurface ocean parameters). They also provide long time series of observations required for the detection and diagnosis of global change, such as surface temperature, precipitation and water resources, weather and other natural hazards, the emission or discharge of pollutants, and the impacts of multiple stresses on the environment due to human and natural causes. To meet the need for the documentation of global changes on a long-term basis, integrated observations from both research and operational systems are required. The goal of a sustained observation and monitoring program is to ensure a long-term, high-quality record of the state of the Earth system's climate, its natural variability, and changes that occur.

This deep deficiency in the science and calibration quality of present surface, atmospheric, and terrestrial measurements for climate detection and attribution has become particularly marked during the deliberations of the past two or three IPCC assessments—that is, at least for the past several decades. These past major climate science deficiencies include a lack of interagency, national, and international

standards in instrument technologies; poor instrument and degraded station siting; poor field maintenance; insufficient or absent instrument calibration intervals; a lack of agency, national and international intercomparabilities; and inadequate funding.

Of late it has also become increasingly evident that data gathered for traditional meteorological purposes do not always have the high-quality required for climate science purposes. This is due to operational meteorological needs being based more on relative change over short periods of time, while climate calculations of trends are based directly upon measures of atmospheric changes that are consistently gathered over long periods of time. This last point needs to be studied further to determine the full range of implications for the organization and priorities of various national atmospheric and terrestrial data collection institutions and organizations. Climate data are not necessarily meteorological data, and climate data collection and data processing is distinctly different from that minimally required for meteorological data.

The late Professor Bert Bolin, who was the Head of the Intergovernmental Panel on Climate Change (IPCC), stated in “The Report to the Seventh Session of the Subsidiary Body for Scientific and Technical Advice on behalf of the IPCC” (October 1997):

“The current global observational network is declining. If this decline is not stopped we may, say, twenty years from now, be in a worse situation than today, when trying to determine to what extent and how climate is changing. We will have less capability of clarifying to what extent an ongoing climate change might be the result of human activities or be an expression of natural variability in the climate system. A continuous close observation of the climate system is an absolute requirement for dealing adequately with the climate issue” .

Unfortunately the deficiencies noted by Prof. Bolin and also documented by the U.S. National Academy of Sciences’ National Research Council in its 1999 report entitled, “Adequacy of Climate Observing Systems” remain in place today, and in many cases were exacerbated by the world economic crisis with more observing stations closing because countries (developed and developing) cannot shoulder the costs of continuing to operate them on a sustained basis.

In October 2016, the international Global Climate Observing System (GCOS) program produced an updated Implementation Plan known as [GCOS-200](#) that has several hundred specific actions recommended for the period from 2016-21 that if fully implemented will ensure that countries have the observational information needed to understand, predict, and manage their response to climate and climate change over the 21st century and beyond. It will address the commitments of the Parties under Articles 4 and 5 of the United Nations Framework Convention on Climate Change (UNFCCC) and support their needs for climate observations in fulfilment of the objectives of the Convention as well in supporting evolving climate information services it supports in efforts such as the Global Framework for Climate Services (GFCS) which was established at the 3rd World Climate Conference in 2009. The need for high-quality reference networks such as the one discussed here is to ensure that what is measured is valid and based in well-vetted scientific principles.

A critical challenge is to maintain current observing capabilities that already exist. For example, a critical non-satellite climate observations dataset that has been at risk throughout its lifetime is the 60-year record of carbon dioxide (CO₂) measurements at the Mauna Loa Observatory (MLO) in Hawaii. The Mauna Loa CO₂ dataset was begun by Dr Charles David Keeling of Scripps Institution of Oceanography in 1957 as part of the International Geophysical Year (IGY). The resulting dataset is one of the world’s most well-known, and the derived meaning of increased atmospheric CO₂ and climate warming is universally referred to as the Keeling Curve [see <http://www.mlo.noaa.gov/lowhome.htm> for more information]. At the time of Dr Keeling’s initial efforts, little was known of the climatic importance of CO₂ in the atmosphere and no reliable atmospheric record of CO₂ atmospheric composition changes over time existed. Indeed, many scientists were not certain that one could detect meaningful patterns such as seasonal changes, hemispheric differences, and fossil fuel emissions with measurements of such a low- concentration that we

now take for granted and have used for achieving a far greater understanding of the Earth system as a whole.

The early measurements by Dr Keeling began what was to become a coordinated global monitoring network involving scientists and agencies from countries around the world. Information derived from this network, which now includes the monitoring of many greenhouse gases, isotopes, and other tracers, has been crucial for informing national and international assessments of global climate change, not the least of which are the IPCC assessment reports. Today, Dr Keeling's records at MLO, as well as at the South Pole are still maintained. The Keeling time series records have been augmented substantially by NOAA and others since the 1970s, with parallel measurements at these sites and a global network of over 60 sites where continuous or weekly measurements are made. It is clear the Keeling Curve has proven invaluable to science, and this value is in the sustained and continuous nature of the data over the past 50 years. For example, if the measurements had ended after only 25 years of operation, we would at this time be at a great loss to track a critical climate variable such as CO₂, and only time will tell about what the Keeling Curve will look like on its 100-year anniversary in 2057; as such the importance for maintaining such long-term and sustained high-quality reference climate observations cannot be overstated.

The global climate community has recognized the need for sustained and robust observations for many years, and this has been expressed in any number of documents and reports from the UNFCCC, the Intergovernmental Panel on Climate Change (IPCC), the World Meteorological Organization, United Nations Environment Program, etc. At the 3rd World Climate Conference that took place in Geneva, Switzerland, in early September 2009, a number of very prominent speakers took the podium to talk about the importance of climate observations. At that conference, the Chair of the IPCC, Rajendra Kumar Pachauri, made the following strong statement concerning the importance of climate observations that should be heeded:

"I think there is still time to see that these are addressed before Copenhagen. I want to also highlight the fact that we are very grateful to the WMO and its partners for the observations that they have collected over the years. Indeed as far as the work of the IPCC is concerned it has been supported immensely by the data and by all the observations in its assessment. One of the major findings that we had in the Fourth Assessment Report is the fact that "Warming of the climate system is unequivocal as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global sea level". And, "I think, this is essentially highlighting the importance of observations. Since the conference that we are attending today is primarily focused on the value of information and science, may I say that as far as observations on issues related to climate change are concerned they have enormous value. But we need to make these efforts wider, deeper, more detailed and comprehensive. We know, for instance, that extreme events are on the increase but we need to collect information from across the globe so that science can address this issue on the basis of authentic and continuous information on the subject. We know that floods, droughts, heatwaves, extreme precipitation events are increasing and will continue to increase in intensity, frequency and duration".

Since the Global Climate Observing System was established at the 2nd World Climate Conference some progress has been made in advancing in-situ observing, there are still some major deficiencies that still need to be addressed and continually develop to the detriment of the overall global observing system. Climate observing systems need to be funded on a sustained and robust basis in order for the state of the climate system to be properly monitored. Much like in human health, until the patient's condition is properly monitored, there is no way to assess his/her condition in order to go down a path of proper mitigation and/or adaptation, and the same is true for the planet's climate.

ANNEX 4: LISTS OF BENEFITS OF A GSRN

The global climate community has recognized the need for sustained and robust observations for many years. Annex 3 gives an extensive summary on the importance and implications of a sustained observing system. At the same time, it has also become increasingly evident that data gathered for traditional meteorological purposes do not always have the high-quality required for climate science purposes. This is due to operational meteorological needs being based more on relative change over short periods of time, while climate calculations of trends are based directly upon measures of atmospheric changes that are consistently gathered over long periods of time. Climate data collection and data processing is distinctly different from that minimally required for meteorological data and the kind of sustained observations required for climate detection and attribution of climate are unique, with calibration being one of the important factors. The need for high-quality reference networks such as the one discussed here is the key to ensure that what is measured is valid and based in well-vetted scientific principles.

The discussion on the specific benefits of a GSRN is summarized in the following list. Six major groups of benefits have been identified:

1. Relevance of “reference”-type measurements:
 - Having each single measurement traceable to an absolute standard allows moving from relative to absolute accuracy in measurements. Absolute characterization allows establishing the degree of comparability among measurements made in different places, in different times and with different equipment. It also gives a robust indication of the data quality, thanks to the absolute uncertainty evaluation associated to the measurements. Absolutely accurate measurements allow for spatially homogeneous datasets, which have immediate benefits in satellite validation;
 - Defined and agreed measurement standards. Such common instruments and measurement standards, related to internationally accepted standards, together with associated availability of defined standard procedures, establish a shared common practice and a robust comparability of observations, also of other non-reference networks. These serve to initiate an exercise to evaluate uncertainties. Full evaluation of uncertainty associated to measurements means moving from simply observing to understanding;
 - A reference network would produce precipitation and wind speed data that does not need to be statistically homogenized, which is very difficult for these parameters due to the low correlations between stations. For temperature and pressure a reference network would provide an additional line of evidence on changes that are independent of statistical homogenization, which improves climate data, but can only remove part of the originally present biases.
2. Underpinning existing networks:
 - Validation of the GSN (and broader surface network and CDRs derived therefrom) and a better understanding and quantification of the errors in the observed climatic changes;
 - Having long term homogeneous record will ensure better use of the data and serve to improve the quality of data from other networks;
 - Ensure standards on the global scale by looking at the reference stations to understand impact of changes (instruments, techniques, etc.) different type of changes;
 - The experience developed at reference stations can lead to procedural and instrumental improvements at baseline stations and a better understanding of the impact of changes (instruments, etc.) at the more numerous baseline stations;
 - Act as a validation goal to other stations at the national level;
 - Help with homogenization of data at neighboring stations.

3. Capacity building:
 - Exchange of knowledge and skills between institutes globally, around the world;
 - Being a member of a GSRN may attract funding and countries with difficulties in funding could find a benefit in having a station part of a GSRN.
4. Answer questions about long-term nature of climate change. Scientific value:
 - Having integrated measurements (many ECVs both from atmosphere and from terrestrial) at many sites will be crucial for better understanding climate changes and promoting novel avenues of research. If many terrestrial ECVs are also observed, then other applications would benefit such as biodiversity and ecosystem changes;
 - Increased accuracy and confidence in observed changes will allow us to answer new questions and open still unknown new fields of research;
 - Better understanding of the Global Cycles (e.g. Water, Carbon and Energy);
 - Attribution: accurate, stable long series will be the basis for attribution studies;
 - Calibration and validation of satellite will improve data quality and thereby help improve the understanding of the nature of climate change;
 - Measurements in complex environments (e.g. urban, coastal, mountain, polar and challenging seasonal cycle locations) will enable better understanding of impacts across domains;
 - Satellite measurements cannot be guaranteed to be continuous, and therefore a gap in the CDR could occur. With a GSRN in place, such gaps could be bridged;
 - Reference sites would provide desirable locations to base future field campaigns as they provide a pre-existing capability and a longer-term context in which to interpret the results including how climatologically representative the period of the campaign was.
5. Societal benefits:
 - Having reliable records for precipitation could be very important in broader matters (e.g., health related issues);
 - A similar reference network for urban observations could be important for characterization of heat islands;
 - An initial focus on temperature and precipitation would support plans to adapt to climate change to heat waves, flooding and drought.
6. Future looking:
 - Opportunity to introduce new types of observing equipment at the global level. These stations have to be built to have the flexibility to test and add, if needed, new instruments in the future;
 - Supersites can contribute in research on the evaluation of emerging technologies, improved measurement procedures and measurement principles.

ANNEX 5: LIST OF REQUIREMENTS

GCOS Surface Reference Network (GSRN) – Key Attributes

1. Standards of observing practices (e.g., calibration, siting, instrumentation, and quality control);
2. Complementary measurement techniques are a critical characteristic for any reference system. For example, within GRUAN it is measurements of the same measures, and with different measurement techniques, that is pursued. In both cases the end result is a degree of redundancy, or complementarity, in measurements that builds confidence in the data which is what is required for the GSRN to succeed;
3. Comparability is essential to a reference network as sites should undergo a rigorous assessment process to ensure that the network is sufficiently similar to ensure comparability between sites;
4. Representativeness is a key property of a reference measurement station. A representative measurement reflects the nature of the measure and across a broader spatial and temporal domain than the immediate measurement location. If a fiducial reference measurement network's purpose is to help constrain and validate more regional measurements from other networks, or measurements from satellites, then it is important to choose sites which optimize the spatial representativeness of the measurements;
5. Facilitate the generation of homogenous long-term times series data (multi-decadal) – this is the ultimate goal of any reference observing system and is essential to be able to not only characterize climate change but in working as a reference standard to validate other more regional and/or local networks. For example, the USCRN is now used to validate long-term air temperature trends of other older less rigorous climate observing networks that aid in the validation of climate change studies;
6. Active management (e.g., certification of stations, resourced monitoring and fault resolution);
7. Free and open access to data and metadata, available in as near a real-time basis as possible; the ability to get quality controlled high-quality reference climate data out to both the scientific community as well as the general public is key to demonstrating trends in climate change that must be readily available for a wide range of societal and scientific applications;
8. Documented traceability and evaluation of measurement uncertainty is an absolute requirement for a reference-grade measurement is thus that it be made in such a way that after accounting for all sources of uncertainty it can be concluded that the true value of the measurand lies within the reported uncertainty interval with specified confidence, and that the measurement result is traceable to standards of the System of Units (SI) or other standards;
9. Instrument maintenance and calibration;
10. Stability (sites that are not expected to change the next century) & managed change;
11. A Dedicated Lead Centre is essential to overseeing the proper operation of the network; with over 10 years of experience by the GRUAN it is clear that it would not have made the great progress it has without such a dedicated center in order to oversee the breadth of activities from data management, to quality control, to instrumentation testing and calibration;
12. Sustainability goes without saying; without the ability to have an observing system that 50-100 years from now can instruct scientists and the public on the characterization of climate change, a reference network would serve no good purpose. This has to be an “all-in” proposition where countries dedicate the resources necessary for this to be done successfully;
13. Well defined measurements; fundamental variables (those necessary to be included in the GSRN), main variables (priority list of ECVs for the GSRN) and auxiliary quantities (quantities of influence to fundamental and main variables, not necessarily part of an ECV. They require lower level of calibration interval, maintenance and uncertainty evaluation);

14. Should The inclusion of research, super-sites and capacity building activities (ability to inter-compare instruments) is a key to ensuring that the network is diverse and able to be flexible in not only providing the high-quality climate data that is characteristic of a reference network, but also works to most effectively and efficiently taking advantage of existing resources;
15. Adhere to the GCOS Monitoring Principles as much as practically possible – The GCOS Monitoring Principles represent a solid requirements basis for all of GCOS; however, in operating a network, it is realized that there are times when some small compromises must be made in relationship to operational realities and considerations. Therefore, while stations should strive to follow the GCOS Monitoring Principles, there must be some leeway considered with respect to budgets and operational considerations, and the Governing Working Group and Lead Centre must be so consulted;
16. Part of a tiered network – benefit realizations from reference to baseline to comprehensive;
17. Integrated network delivering across a range of ECV's and experts (minimum number);
18. Scalability, both on a temporal as well as a spatial basis, is a key to any reference observing system. Such a system should a useful validation tool for both large scale and downscaled climate model reconstructions, ultimately enabling advances in model development. In the short-term it can help in validating diurnal, seasonal and process scales, longer-term it can help validate climate-timescale processes and trends;
19. Proactively consider colocation with existing stations and expertise;
20. Need for a common vocabulary, based on existing WMO and BIPM documents and definitions;
21. Draft and adopt GSRN guide and manual along the lines of what was done for the GRUAN with GCOS Publication 121; the criticality of such an organic document to fully document the requirements and operating philosophy of the network cannot be minimized;
22. Archival and Reprocessing of data. The ability to access to original level-1 data is a critical legacy to a generation of future scientists to allow them to apply new and innovative scientific techniques in order to best characterize climate. Such level-1 data is a critical resource that must be fully open and well-protected in an international data archive that provides the highest standards and precepts of data stewardship;
23. Relevant technical expertise – Both operational and scientific expertise, working in concert in order for a reference network to be successful. Engineers should engineer, and scientists should validate; and both professions must work hand-in-hand to ensure that the system is as robustly designed as possible as well as having well-vetted algorithms for the processing and quality control of the data;
24. Resourcing/Budget/Funding – Lead Centre and international oversight body in addition to site set-up and maintenance is a key to success. If this activity does not have a sustained and guaranteed (as best as possible) is critical; reference observing systems cannot be done on an ad hoc basis; and so unless a country stands up to fully staff a lead Centre, and unless Members commit to operating stations on a sustained basis, then this is all just an academic exercise. The track record for global sustained *in-situ* climate observing is frankly spotty at best, and so unless the WMO and its members are all in with the spin up, implementation, and long-term operation of a GSRN, then we are afraid that all of the good planning work done to date will have gone to waste.

ANNEX 6: DESIGN PRINCIPLES

Commonly Agreed to Top Design Principles

1. Adhere to GCOS Monitoring Principles;
2. Mixture of environments between complex environments (e.g., urban, coastal, mountain, polar, and challenging seasonal cycle locations) and more classical background reference station locations. No exclusion of complex environments, however, the initial focus is on the more classic pristine reference environments. Recognition of global climate regimes (e.g., Koppen-Trewartha) by ECV;
3. All instruments should follow rigorous maintenance and calibration procedures. All measurements should be associated with documented measurement uncertainties (this includes the instruments calibration uncertainty);
4. Complementary measurement is important to discover measurement errors and unknown long-term problems. This can be achieved by triple redundancy as in the USCRN or by multiple observational methods as in GRUAN;
5. Tiered approach to what ECVs are observed and how frequently;
6. Flexible partnerships in terms of station agencies (e.g., employment of super sites);
7. Free and open access to data and metadata;
8. Land changes within a 10 km radius of the station should be tightly monitored and reported;
9. Support funding and twinning from developed nations to support stations in least developed countries and SIDS;
10. Benefits for other climate related networks.

ANNEX 7: GOVERNANCE AND MANAGEMENT

Governance Principles

1. A Lead Centre and dedicated Program Manager need to be defined;
2. Agreed delegated governing body (e.g., GSRN Steering Committee) consisting of representatives (GCOS, BIPM, WMO Technical Commissions, network and user representatives);
3. Terms of Reference for delegated governing body and Lead Centre.

Management Principles (to clarify responsibilities of governing body; lead center(s) and national authorities, respectively)

1. Should not be detrimental to what we already have;
2. Dedicated resources;
3. Active management of the network;
4. Need for Lead Centre) (with possibly sub-centres perhaps by WMO Region) overseen by a Working Group with regular annual meetings and coordination via teleconference in between;
5. Consistent data processing, which can be local or centralized;
6. Centralized, long-term, archiving of data and metadata, at appropriate levels for the instrumentation and in agreement with the data policy;
7. Standardized data format(s);
8. Assurance process for the data, metadata, uncertainty and traceability;
9. Full compliance with the WIGOS Metadata standard;
10. Well defined terminology and methodology (i.e. GUM, VIM);
11. Need for Lead Centre and sub-lead centres, and a network/programme manager;
12. All processes and procedures will be documented;
13. Active outreach to a wide audience of users;
14. Communication, reporting and feedback;
15. Cross-cutting with other networks (i.e. GSN, RBON, Ecological networks...);
16. Site certification similar to the GRUAN Process.

ANNEX 8: PRELIMINARY LIST OF ECV TO BE MONITORED

Preliminary list:

Atmospheric ECVs

Air temperature
Precipitation
Pressure
Wind speed and direction (10 m)
Relative humidity
Surface radiation (down and up)

Terrestrial ECVs

*Land Surface Temperature
*Soil moisture (standard WMO depths)
*Soil temperature (standard WMO depths)
*Snow/ice (SWE)
*Albedo
*also in conjunction with satellite derived data to a certain degree

River discharge
Ground water
Glacier

Potential sites

Co-location where possible with GRUAN, BSRN, GAW, GCW, ARM, CloudNet sites, CIMO test beds and Lead Centres, NEON, TERM
All climate regions

RA-I

De Aar (SA, BSRN)
Gobabeb (Namibia, BSRN)
Ilorin (Nigeria, BSRN)
Tamamrasset (Algeria, BSRN)
Addis Ababa (Ethiopia)

RA-II

Tiksi (Russia, BSRN, CRN)
Xilinhot (China, GRUAN, CMA testbed)
Tsukuba (Japan, RIC)
Gandhinagar (India, BSRN candidate)

RA-III

Buenos Aires (Argentina)
Petrolina (Brazil)
Punta Arenas (Chile)
Paramaribo (Suriname)

RA-IV

Boulder (USA)
Alert (Canada)
Barrow (USA)
Table Mountain (USA)

RA-V

Lauder (NZ)

Darwin (AUS)

Nadi (Fiji)

Sumatra (Indonesia)

RA-VI

Lindenberg (Germany)

Payerne (Switzerland)

Camborne (UK)

Sodankyla (Finland)

Ny-Ålesund (Norway)

ANTARCTICA

Scott Base/Arrival Heights (NZ)

Rothera (UK)

South Pole (USA)

Vostok (Russia)

Mirny (Russia)

ANNEX 9: TIERED NETWORK APPROACH

The climate is observed by many networks. The Global Climate Station Network would be the stable backbone of this network of network, which is displayed in Figure 1 as a tiered network (Thorne et al., 2017a). Each of these networks has its own strengths and weaknesses. There is synergy in organizing these networks intelligently and combining the datasets in a smart way.

The main strength of the reference network is its stability and sophisticated characterization of the uncertainties of the absolute values and relative changes. The main strength of the other networks is their large number of stations, which is important to reduce sampling errors and study spatial/synoptic phenomena. It should be possible to make a highly accurate analysis of global or continental climatic changes where the long-term variability is mostly determined by the reference network and the short-term variability is estimated using all stations.

Reference stations will play an important role in finding potential problems with the homogeneity of other networks. Also not finding differences is important independent evidence that greatly enhances trust in the observed changes: After only a decade of observations the US Climate Reference Network could provide independent evidence of the veracity of the normal national warming estimates from homogenized data by comparing the reference stations with its neighbours (Leeper et al., 2015) and by comparing the two lower US average temperature signals (Hausfather et al., 2016). In countries with a high station density, such as the USA, statistical homogenization can remove a large part of any temperature trend biases (Williams et al., 2012), but if the signal-to-noise ratio (SNR) is lower the power of statistical homogenization quickly drops (Lindau and Venema, submitted 2017). The SNR will be lower for networks with a lower station density and for other variables, such as precipitation, humidity, wind speed, cloud cover, insolation, etc. Those are the cases where reference stations bring most value.

Because of the large uncertainty of station trends, it will require multiple comparisons to see any network-wide problems. For individual stations the uncertainty in the trends, even after statistical homogenization, is considerable. For example, in the benchmarking study by Venema et al. (2012) the best homogenization algorithms were able to reduce the temperature trend uncertainty down to 0.3°C per century and for precipitation to 7 mm per century for typical European networks.

For single non-reference stations, a nearby reference station can thus provide more accurate long-term trends. This benefit will be limited to stations that are expected to have a similar regional climate signal. Reference stations can also play a small role as homogeneous comparison (reference) stations in the homogenization of nearby stations, but for statistical homogenization strong cross-correlations are important and this role will thus be limited to a small number of other stations.

Reference stations will not only have more accurate measurements, but also often higher resolution measurements and once the network is mature will observe more variables to get a complete view of the climate system. This allows for higher quality computations at reference stations that can be used to bias correct simpler computations in other stations. For example, Almorox and Griesser (2016) compute the evaporation with the Penman–Monteith equation in a small number of stations with comprehensive measurements to bias-correct evaporation estimates at other stations with the simpler Hargreaves–Samani equation. Somewhat similarly Vose et al. (2003) used a small subset of hourly measurements to compute time of observation biases for other stations having only daily measurements.

The presence of a reference station may also improve the observation of the non-reference stations by facilitating the adoption of better protocols, as well as improved observational and organizational practices. Reference stations functioning as super sites can also be used to better test new instruments and thus improve the other networks.

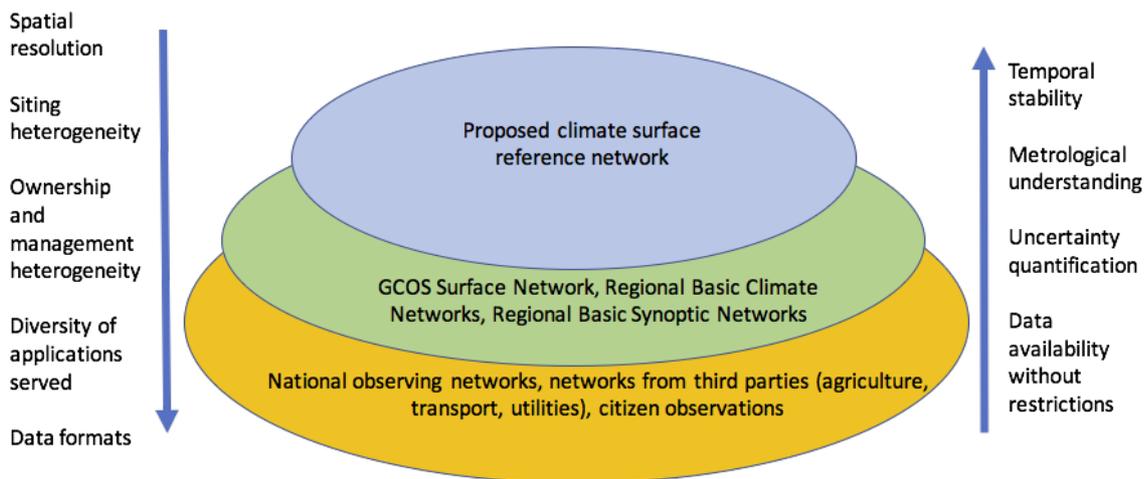


Figure 1

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ANNEX 10: CCI PERSPECTIVE FOR A GSRN

Basically, climate-relevant observations are required for a wide range of climate applications and services, spanning from local to global geographical scales throughout the entire time continuum (historic past to present). WMO, through its Technical Commissions including CCI defined a hierarchy of meteorological observing station types at national scale that allows for an adequate density of observations, including synoptic stations (at least hourly observations basically for real-time weather analysis and forecasting), principal climatological stations (with at least three observations a day and hourly readings) and ordinary climatological stations (with at least one observation a day and daily readings of temperature and precipitation extremes). Specific networks have been defined by both WMO and GCOS on regional and global scales, usually based on existing national meteorological observing stations (RBSN, RBCN, GSN, etc).

It has been acknowledged that national observing networks, in practice, are subject to change in terms of site relocations, site closures, significant changes in station environment (urbanisation), changes in instrumentation and observing practices etc. As a consequence, time series data from surface observations show many inhomogeneities that complicate or exclude analyses of climate evolution.

Therefore, the category of Reference Climatological Stations (RCS) have been defined and implemented, that would generate homogeneous long-term observational data to allow for the analysis of climate change as well as for synergy with time series data from other station types. WMO made it mandatory for each Member to operate at least one RCS to ensure the Member's ability to analyse and take into account climate evolution. RCS, by definition, should operate under almost unchanging observing conditions with unavoidable change being well documented, accompanied by appropriate parallel measurements.

The evolution of WIGOS allows for a review and integration of the above station categories and networks. Considering this opportunity and welcoming the concept of tiered networks, CCI promotes the establishment of one type of reference stations as part of the overall observational capability that integrates and meets GCOS and CCI requirements at global, regional and national levels.

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