Towards a global land surface climate fiducial reference measurements network

Caterina Tassone[1], Howard Diamond[2], Andrew Harper[3], Andrea Merlone[4], Victor Venema[5],

Introduction

Continuous, high-quality, scientific observations of the global environment are critical for defining the 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 for documenting changes in the Earth's biological and physical systems, and understanding 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. Furthermore, informing mitigation and adaptation decisions requires the integration and availability of these data on an ongoing basis. 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.

Climate Observations

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 Organizations and the United Nations Environment Program. At the 3rd World Climate Conference that took place in Geneva, Switzerland, in early September 2009, a number of prominent speakers, including the Chair of the IPCC Dr. Rajendra Kumar Pachauri, took the podium to talk about the importance of climate observations.

Climate observations encompass a broad range of environmental observations, including routine weather observations collected consistently over a long period of time; observations collected as part of research investigations to elucidate processes that contribute to maintaining climate patterns or their variability; 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 observations of climate proxies, collected to extend the instrumental climate record to remote regions and back in time.

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

[1] Global Climate Observing System, World Meteorological Organization, Geneva, Switzerland
[2] NOAA/OAR/Air Resources Laboratory, Silver Spring, USA
[3] The National Institute of Water and Atmosphere Research (NIWA), Auckland, New Zealand
[4] Istituto Nazionale di Ricerca Metrologica and Istituto di Scienze dell'Atmosfera e del Clima del Consiglio Nazionale delle Ricerche, Torino, Italy
[5] Meteorological Institute, University of Bonn, Bonn, Germany

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 (Trenberth, K. E., 2008).

Satellite observations alone are not sufficient for climate monitoring; they require in situ measurements for calibration and validation. In situ observations are required for the measurement of parameters that cannot currently be measured from space (e.g., near-surface atmospheric variables, biodiversity, groundwater, carbon sequestration at the root zone, atmospheric surface pressure, the vertical distribution of winds 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.

The limited quality of present surface, atmospheric, and terrestrial measurements for climate detection and attribution has become particularly apparent during the deliberations of past IPCC assessments and include a lack of interagency, national, and international standards in instrument technologies; poor instrumentation and maintenance and changes in station siting; insufficient or unknown instrument calibration. The lack of agency, national and international intercomparisons and inadequate funding contribute to the problem.

It has become increasingly evident that the quality of data gathered for routine weather prediction limits their use for climate science purposes. This is due to operational meteorological requirements being driven primarily by temporal resolution and low data latency, while determination of climate trends is based directly upon measures of atmospheric changes that are consistently gathered over long periods of time to study much smaller changes. 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. The requirements for climate observations in some areas go well beyond those for weather observations, and climate data collection and data processing is distinctly different from that minimally required for meteorological data.

Surface Reference Observations

Prediction of the earth's climate requires homogenized accurate historical analysis based on climate-quality observations. However, owing to imperfect measurements and ubiquitous changes in measurement networks and techniques, there remain important uncertainties in some of the details of these historical changes, especially for variables that have low correlations between stations such as precipitation, wind and humidity. Implementing and maintaining a suitable stable and metrologically well-characterized global climate reference network, will provide future generations with access to a set of long-term observations of Essential Climate Variables (ECV) that will enable them to make more rigorous assessments of climate change and variability, and provide the strong evidence basis that is essential to inform adaptation decisions, and to monitor and quantify the effectiveness of internationally agreed mitigation steps.

The Global Climate Reference Network will provide a temporally stable high-quality backbone of the Global Climate Observing System and will be the reference network of a tiered network (fig.1), consisting of three tiers: the reference, the baseline and the comprehensive network (Thorne et al., 2017). As part of a tiered system a reference network would only need to have about 200 stations well spread over all climate regions.

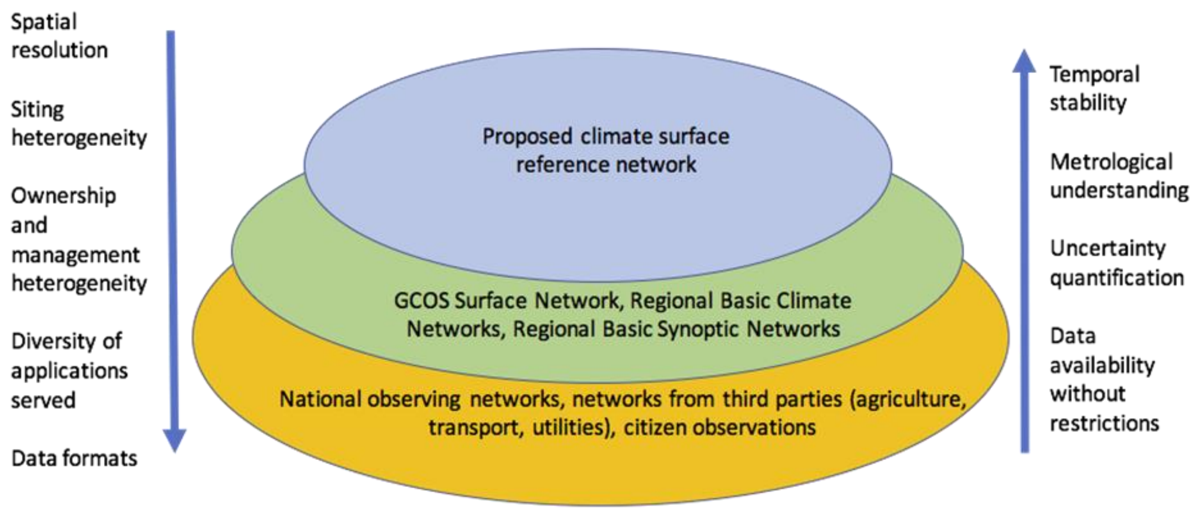

Figure 1: Conceptual outline of how surface observational capabilities for climate map onto the tiered system of systems approach of Thorne et al.(2017). The tiers from top to bottom are reference, baseline, and comprehensive. Arrows and associated text denote important facets of the measurements that increase as you move down tiers (left-hand side) or up tiers (right-hand side). The network types given for each tier are solely exemplars.

Since its establishment in 2008, the Global Climate Observing System (GCOS) Reference Upper Air Network (GRUAN) has made considerable progress based on the recognition that improved observations of atmospheric temperature and humidity are needed to address a number of fundamental issues, ranging from understanding upper tropospheric water vapor feedbacks in climate change to improved calibration of satellite soundings. Aiming for a similar approach to the measurement of surface parameters, GCOS Atmospheric Observations Panel on Climate (AOPC) agreed on the creation of a dedicated task-team to scope a potential GCOS global surface reference network (GSRN).

The scientific charge of this task team is to:

1. Create a scientifically robust basis for a proposed network spatial composition;
2. Define a robust siting rationale;
3. Propose a phased implementation that 'starts small, but starts';
4. Alight on a potential governance structure;
5. Propose options for operational oversight;
6. Provide indicative cost estimates.

The task team had its first meeting at Maynooth University, Ireland, in November 2017. The primary purpose of the meeting was to outline clear benefits for such a network and envision a strategy that will allow the group to undertake its tasks. Benefits, requirements, design principles and governance and management of a GSRN were discussed during the meeting.

The main benefits of having a GSRN identified by the participants were the improved confidence in our uncertainty estimates of global temperature changes, as well as a reduction in the uncertainties. In combination with standard measurements the modern GSRN data will also increase confidence in the historical records. Rigorously assembled time series from GSRN sites will lead to a better understanding of climate-related processes, extreme events, and will also be useful for assessing mitigation effectiveness. Observations from a GSRN will become a fundamental climate research resource and will lead, among others, to a better understanding of the global cycles of energy, water and carbon. Observations from a GSRN can be used to improve measurements made at non-reference sites and improve the characterization of their errors. Furthermore, reference quality measurements will provide a valuable dataset for calibration and validation of satellite observations. New technology and equipment can be tested at reference sites, which will also provide good locations for future field campaigns. This would benefit also other applications such as numerical weather prediction and disaster and emergency response systems.

Reference stations for climate must be designed and implemented to specific requirements. The most important requirements are: standards of observing practices such as calibration, siting, instrumentation and quality control; instrument maintenance and calibration; comparability between sites; stability of the sites and managed change. A number of mandatory, primary variables must be measured at the required level of quality. Other quantities, influencing factors on the measurement quality and contributing to the uncertainty of the primary ones must also be recorded, for correcting algorithms in data processing. All the measurements made at a climate reference stations must have fully documented traceability and an associated measurement uncertainty budget must be provided. This can be achieved for instance by triple redundancy as in the US Climate Reference network (USCRN) or by multiple observational methods as in GRUAN. In order to fully assess comparability across the network, a common approach in understanding and evaluating uncertainty is needed for each measured quantity. The GSRN task team will provide tables to assist station managers and staff in completing, at best achievable level, the uncertainty budget for each measurement made at the station. This will include contributions from the calibration, the quantities of influence, the measurand characteristic and variability, measurement dynamics and site characteristics.

In designing the reference stations and network, the GSRN task team agreed on the following key principles. The network should adhere to GCOS Monitoring Principles and data and meta data have to be freely and openly available. Locations of the station will include both classical background reference sites and sites in complex environments (e.g. urban, coastal, mountain, polar, and challenging seasonal cycle). However, the initial emphasis will be on the reference environments. The initial selection of sites will include a list of already-established high-quality sites where co-location of GSRN activities could occur. Such high-quality sites are currently operated, for example, by GRUAN, the Baseline Surface Radiation Network (BSRN), the Global Atmospheric Watch (GAW), the Global Cryosphere Watch (GCW), the Atmospheric Radiation Measurement (ARM), CloudNet, the Commission for Instruments and Methods of Observation (CIMO) test beds and Lead Centres, the National Ecological Observatory

Network (NEON), the Terrestrial Ecosystem Research Network (TERN), FluxNet, as well as several high quality national reference networks (e.g., the Australian Bureau of Meteorology Reference Climate Stations and the USCRN). Complementary measurements should be made as they are important to discover measurement errors and unknown long-term problems. The GSRN is the reference element of a tiered network that consist of other existing surface observing networks in the WMO system, and its design and implementation will be consistent with the WMO Observing Network Design Principles (WMO 1160, Manual on WIGOS, Annex 2.1).

A preliminary list of ECVs to be monitored has been drafted and consists of the atmospheric ECVs: air temperature, precipitation, surface pressure, wind speed and direction, relative humidity, surface radiation, and of the terrestrial ECVs: land surface temperature, soil moisture, snow/ice, albedo, river discharge, ground water depth, glacier area and mass change. Soil temperature should be included in the measurements, even though is not an ECV. At some of the sites ECVs may be measured by instrumentation owned and operated by separate agencies, thus requiring flexible partnerships and collaboration mechanism.

As common terminology must be adopted, a specific vocabulary is being prepared by the GSRN task team. It includes already defined terminology from the Guide to the Expression of Uncertainty in Measurement (GUM) and the International Vocabulary of Metrology (VIM), specific definitions for the purpose of the GSRN and is in line with WMO adopted terms. The adoption of common terminology and measurement procedures will benefit the ongoing discussions within GCOS and CIMO for the improvement and revision of best practice guidelines.

The task team agreed on a work plan to 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 to the establishment of the GSRN. The concept note will include a proposed list of steps to follow in the GSRN implementation.

References

Thorne, P. W., Madonna, F., Schulz, J., Oakley, T., Ingleby, B., Rosoldi,M., Pappalardo, G. (2017). Making better sense of the mosaic of environmental measurement networks: A system-of-systems approach and quantitative assessment. Geoscientific Instrumentation, Methods and Data Systems, 6, 453–472. https://doi.org/10.5194/gi-2017-29.

Trenberth, K. E., 2008: Observational needs for climate prediction and adaptation. WMO Bulletin, 57 (1), 17-21.