ANNEX C: NETWORKS

This annex provides some information on those networks that are managed or associated with GCOS. Not all networks that contribute to observing the global climate system are addressed. Sections A and B discuss those networks that report to GCOS, while section C discusses the Global Ocean Observing System (GOOS) that reports to Intergovernmental Oceanographic Commission (IOC).

TABLE OF CONTENTS: ANNEX C

C.a GCOS Atmospheric Networks

This section discusses only those atmospheric networks that are managed, monitored or directly report to GCOS. The broader observing system also contributes to GCOS goals but is monitored or managed by other programs including the WMO Integrated Global Observing System (WIGOS) and the Global Atmosphere Watch (GAW). The implementation of WIGOS including WIGOS Data Quality Management System is adding considerable value for many observing programs which do not directly report to GCOS.

C.a.i GCOS Cooperation Mechanism (GCM)

The GCOS Cooperation Mechanism (GCM) is the system improvement and resource mobilization activity of the GCOS programme established following a decision by the United Nations Framework Convention on Climate Change (UNFCCC) Subsidiary Body for Scientific and Technological Advice (SBSTA) in 2004 (UNFCCC Decision 5/CP.5) in order "to enable developing countries to collect, exchange, and utilize data on a continuing basis in pursuance of the UNFCCC". Approximately 4 million USD has been raised to accomplish projects dedicated to improving climate observation systems and since 2016, 0.5 million USD (compared to 1.2 million USD 2010-2015) has been invested in the following projects:

- Support for the ongoing operations of the GCOS Upper Air Network stations at Yerevan, Armenia; Nairobi, Kenya; Gan, Maldives; Dar Es Salaam, Tanzania.
- Engagement of a consultant based in Harare, Zimbabwe, to assist in the re-establishment of surface climate stations in Chad (new instrumentation incorporating a non-mercury temperature sensor).
- Support to the CATCOS project, funded by the Swiss Agency for Development and Cooperation that supports ongoing operations and emergency maintenance in over 10 countries.
- Financial support to Colorado State University, in support of the expansion of the Community Collaborative Rain, Hail and Snow Network (CoCoRahs) in the Bahamas (Volunteer Rain Gauge Network).
- New instrumentation for a candidate Baseline Surface Radiation Network observatory in Peru.
- Equipment (Camera's, copiers and shelving) for a data rescue project in Botswana.

C.a.ii GSN and GUAN

Climate and climate change research and applications require historical observational data from sources well distributed across the globe. In particular, it is of major importance that data from different locations and times are comparable or can be made comparable. In practice, meteorological measurements are made at thousands of places all over the world, more or less regularly. The most essential subset of these observing stations is operating under the regime coordinated by the World Meteorological Organization (WMO), involving clear commitments regarding the site, the exposure of instruments, error handling, units of measurement, coding and exchange of reports. In practice, this WMO Global Observing System (GOS) is implemented by National Meteorological and Hydrological Services (NMHSs) of WMO Members. The original prime purpose of the system was the provision of data in support of weather observation and forecasting, but it of course serves many other potential users particularly in this case climate and climate change research.

Many requirements for climate applications and research are satisfied very well by the GOS. The needs of the climatological and the synoptic communities have much in parallel.

In most situations where climate research notes shortcomings in the available data sets, synoptic meteorology suffers from the same problem. To date, no new system has proved to be competitive with the radiosonde system with regards to accuracy, vertical resolution/range and consistency. Radiosondes also provide main meteorological variables (temperature, wind and humidity) all together. They have been operated since about 1940, and the results should remain valuable for climate research in future. This implies that a minimum configuration of stations should be preserved well into the 21st century, at least until about 20 years after other new systems may have taken over the basic tasks. Even in that case, this minimum configuration may be useful for a longer time for calibration and validation procedures.

In order to serve specifically the needs of global climate applications, two networks of observing stations were established in 1995 as Global Climate Observing System (GCOS) Baseline Networks, mainly on the basis of existing GOS networks. These are:

- The GCOS Surface Network (GSN) (1022 stations as of 01/04/2020, see
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- Figure ***28.* 2020 - GCOS Surface Network (GSN) – 1022 stations**
-)
- The GCOS Upper-Air Network (GUAN) (177 stations as of 01/04/2020, see Figure 29)

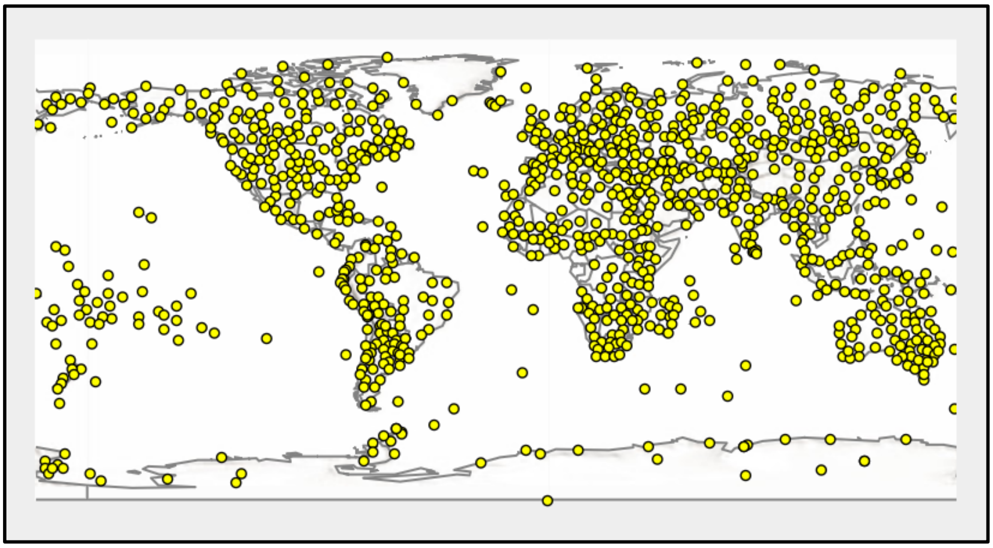

Figure 28. 2020 - GCOS Surface Network (GSN) – 1022 stations

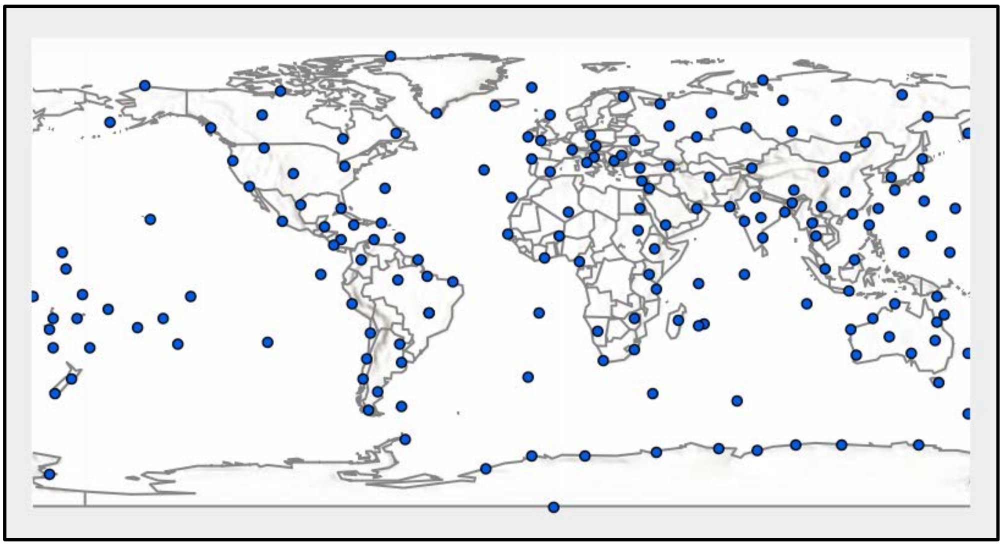

Figure 29. 2020 - GCOS Upper-Air Network (GUAN) – 177 stations

These networks form a minimum configuration required for global applications. Regional climatic needs can be much more extensive, and it is anticipated that such needs will be served by more dense networks on a regional basis, possibly with more extensive requirements for observing programmes and specifications.

C.a.iii GSN

The following statistics (Figure 30 – 2019 and Figure 31– 2011 to 2019) are an annual summary of the monthly CLIMAT messages in the GCOS Climate Archive (National Climate Environmental Information, NCEI, US). According to the GCOS requirements, a fully compliant GSN/RBCN (Regional Basic Climatological Networks) shall have 12 CLIMAT (monthly climatological summary) reports. The colours in the plots represent the percentage of stations that are compliant and those that are partially or non-compliant.

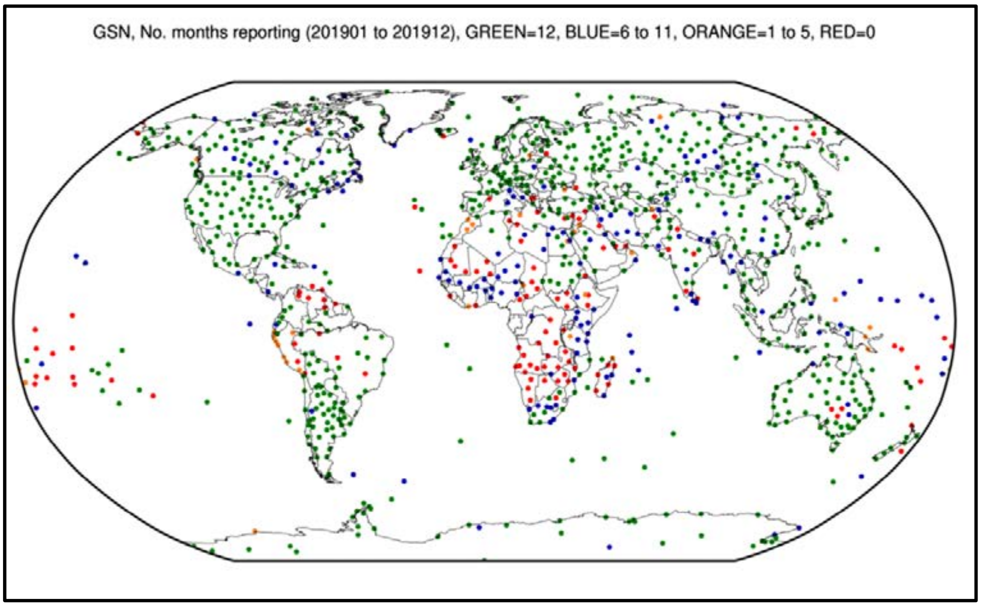

Figure 30. GSN NCEI CLIMAT availability monitoring 2019

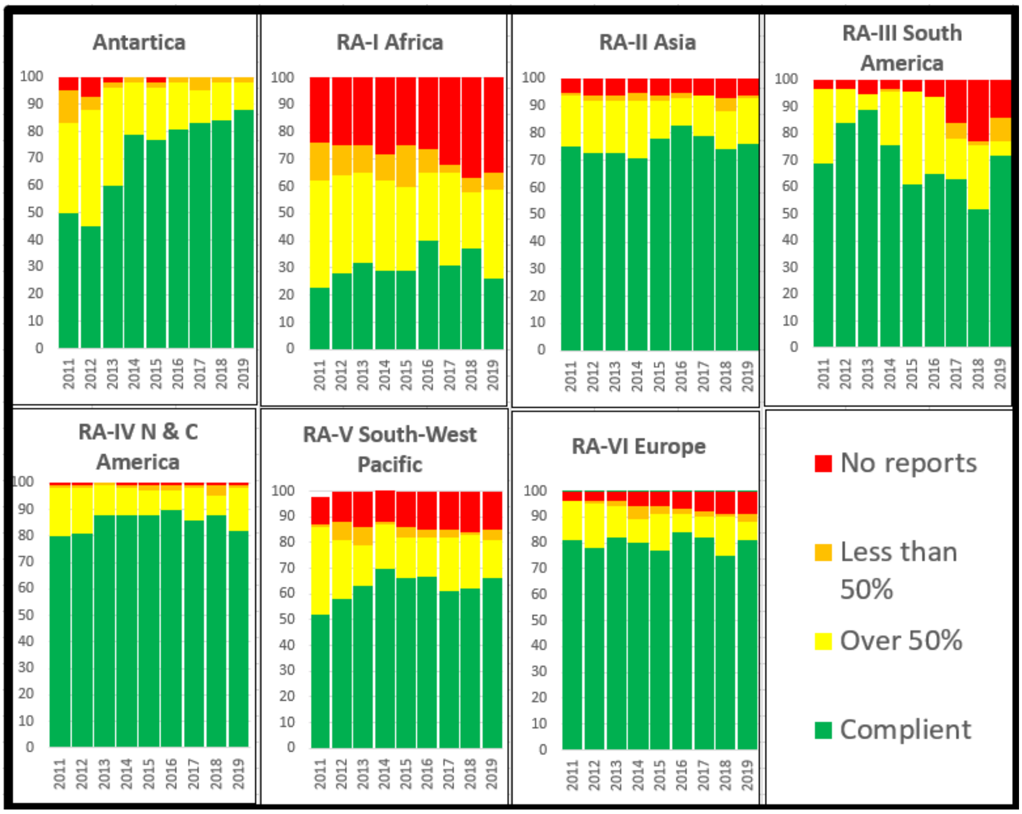

Figure 31. GSN NCEI CLIMAT availability monitoring statistics 2011-2019

RA-I (Africa, see Figure 4) was the poorest performing region in 2019, with only 26% of stations meeting the minimum requirement, and 35% not providing any CLIMAT messages. This has not significantly changed, for better or worse, over the last 9 years. Thus, whilst this continues to reinforce the need for GCOS to focus its support in this region, it also highlights that recent efforts to improve these statistics have had little impact.

C.a.iv GUAN

Figure 5 shows the 2011 to 2019 annual statistics for the GCOS Upper-Air Network (GUAN) monitoring against the GCOS minimum requirements (25 daily soundings to at least 30hPa per month) for each region, according to the monthly statistics provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) (2019); National Centers for Environmental Prediction NCEP) (2011 to 2018); and NCEI (2011-2012).

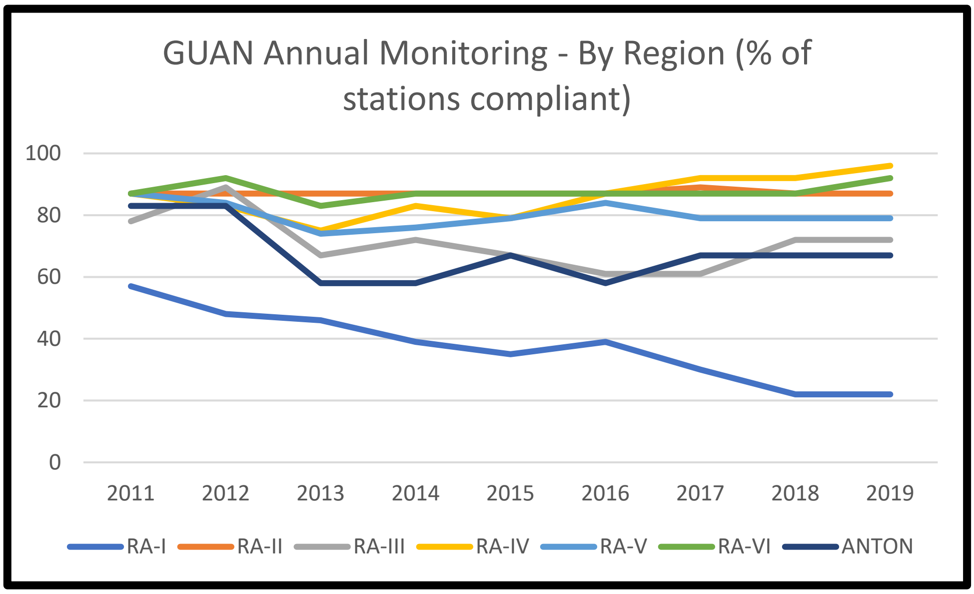

Figure 32. GUAN availability monitoring statistics 2011-2019

In RA-I, only 22% of the GUAN stations have met the minimum requirement for 2019, and RA-I continues, by some margin, to be the worst performing region. This very poor, and not improving (same as 2018 and 8% down on 2017) performance is mainly associated with the necessary funding required to operate and maintain an upper-air station. Communication with the station at a technical level to establish the cause of the poor performance continues to be a challenge and often means that relatively simple issues can go unaddressed for long periods of time. In addition, there are an increasing number of stations that have problems and failures with their hydrogen generator systems which has resulted in a period of long-term inactivity.

The performance in all other Regions was relatively stable throughout the period (2011 – 2019), with RA-IV showing a slight improvement and RA-III & ANTON (Antarctica network) showing a deterioration between 2012/2013.

Completely 'Silent' (zero reported TEMP observations) stations is the worst level of performance and indicates significant gaps in operational capability. In 2019, 12 of the GUAN stations (7%) were 'Silent', which was the highest since this monitoring was started in 2011. It was 11 in 2018 and 2017, 7 in 2016 and 2015, 3 in 2014 and 2013, 4 in 2012 and 5 in 2011.

Figure 33 shows monthly GUAN monitoring provided by ECMWF, with the example showing stations compliant in reporting soundings to at least 30hPa for January 2020.

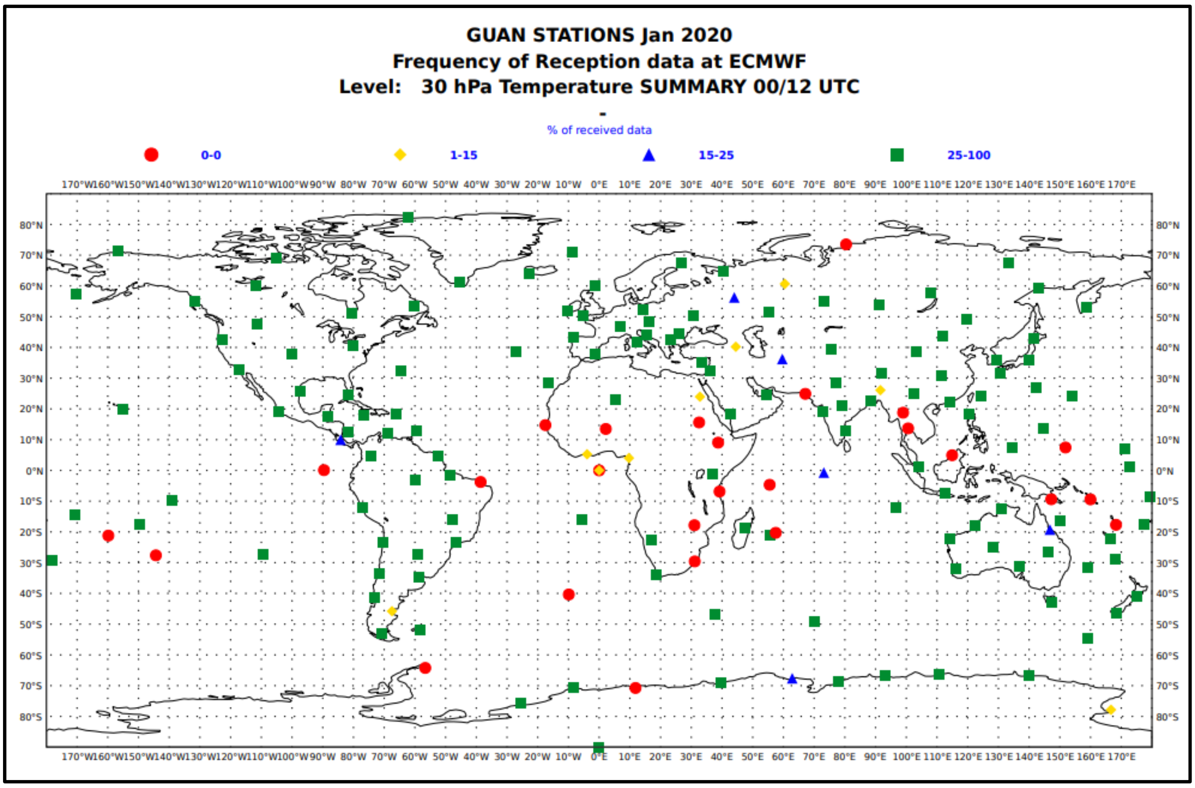

Figure 33. ECMWF GUAN Monitoring 30hPa January 2020

C.a.v GCOS Reference Upper Air Network (GRUAN)

GRUAN aims to provide fully metrologically traceable measurements of the atmospheric column characteristics at a globally representative set of locations. The network is managed on a day-to-day basis by the Deutscher Wetterdienst (DWD) who host the Lead Centre with oversight from the AOPC sponsored working group on GRUAN. Data are conceived to be valuable for climate monitoring, satellite cal/val, and process studies amongst others.

Over the past 5 years considerable progress has been made in the implementation of GRUAN including the provision of a greatly improved public portal at www.gruan.org . The network has expanded considerably to include several stations in regions that were previously under-represented including the first stations in the tropics and in Antarctica. Challenges remain in identifying and instigating stations in Africa and South America. Data products presently exist for two sonde models with several additional data streams close to completion including for the Global Navigation Satellite Systems Integrated Water Vapour (GNSS-IWV) – the first non-sonde product. GRUAN also provides long-term frostpoint hygrometer measurements at a number of its sites. The phasing out of the R23 coolant under the Kigali amendment is a major challenge that the network has taken a leading role in addressing.

The positive impact of GRUAN can be evidenced via the large number of publications which have used the data, a finite sample of which is maintained on the network website. Development of GRUAN products has also led to improvements in several radiosonde instruments that have gone on to benefit GUAN and the broader global radiosonde network. GRUAN participants have also been instrumental in several projects such as the European Union H2020 GAIA-CLIM project and the Copernicus Climate Change Service contract concerned with assuring access to baseline and reference observations.

Figure 34. GCOS Reference Upper Air Network (GRUAN)

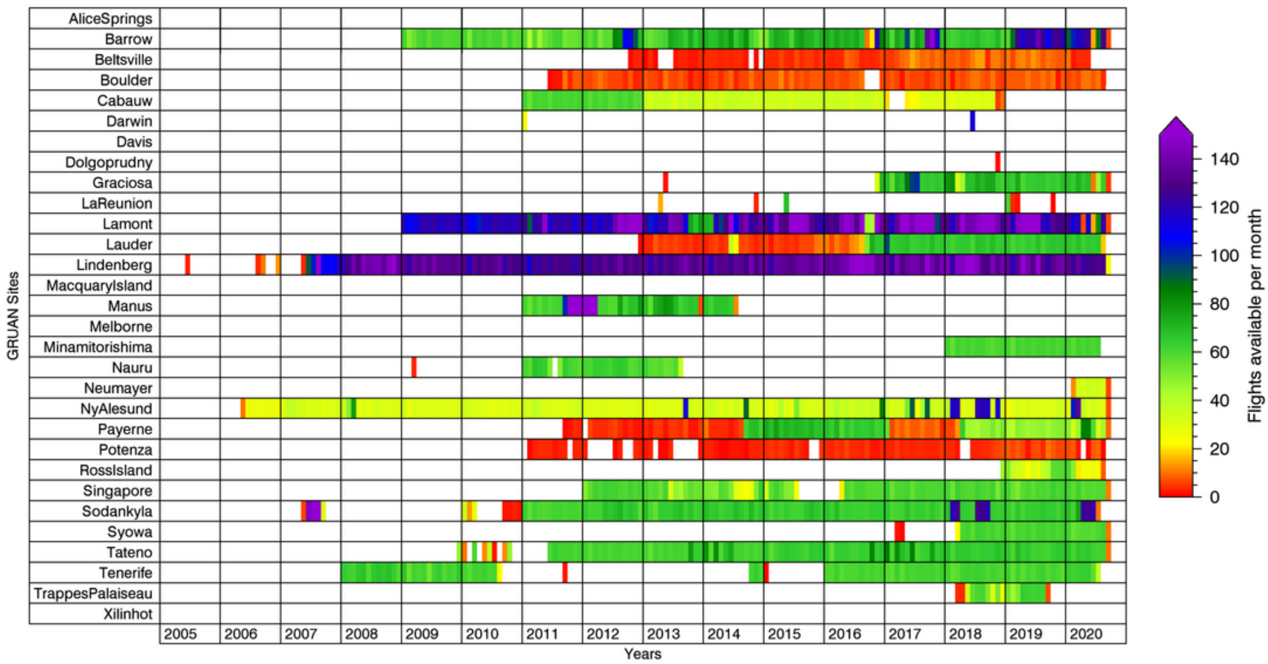

Figure 35. GRUAN Radiosonde launches (total: 109950 flights at 6 September 2020)

C.a.vi Baseline Surface Radiation Network (BSRN)

BSRN is a project of the Data and Assessments Panel from the Global Energy and Water Cycle Experiment (GEWEX) under the umbrella of the World Climate Research Programme (WCRP) and as such is aimed at detecting important changes in the Earth's radiation field at the Earth's surface which may be related to climate changes.

The data are of primary importance in supporting the validation and confirmation of satellite and computer model estimates of these quantities. At a small number of stations (currently 59 active stations) in contrasting climatic zones, covering a latitude range from 80°N to 90°S (Figure 36) solar and atmospheric radiation is measured with instruments of the highest available accuracy and with high time resolution (1 to 3 minutes).

In 2004 the BSRN was designated as the global baseline network for surface radiation for GCOS. The BSRN stations also contribute to the Global Atmospheric Watch (GAW). Since 2011 the BSRN and the Network for the Detection of Atmospheric Composition Change (NDACC) have reached a formal agreement to become cooperative networks. Since 2018, 8 new stations have been assessed and subsequently added to the BSRN.

Figure 36 Baseline Surface Radiation Network (BSRN) – October 2020.

Figure 37 shows the number of completed data records for BSRN stations in the World Radiation Monitoring Center (WRMC) archives. These numbers are evident of the significant increase in the number of stations and associated data records (now in excess of 12,000 monthly datasets) since 1992. Since 2010 the data records have levelled off around 50 to 55 stations, and whilst there is a significant drop in the data archives from 2018, this is primarily due to the usual delay in receiving the quality checked data, which has been further impacted in 2020 due to the COVID-19 restrictions.

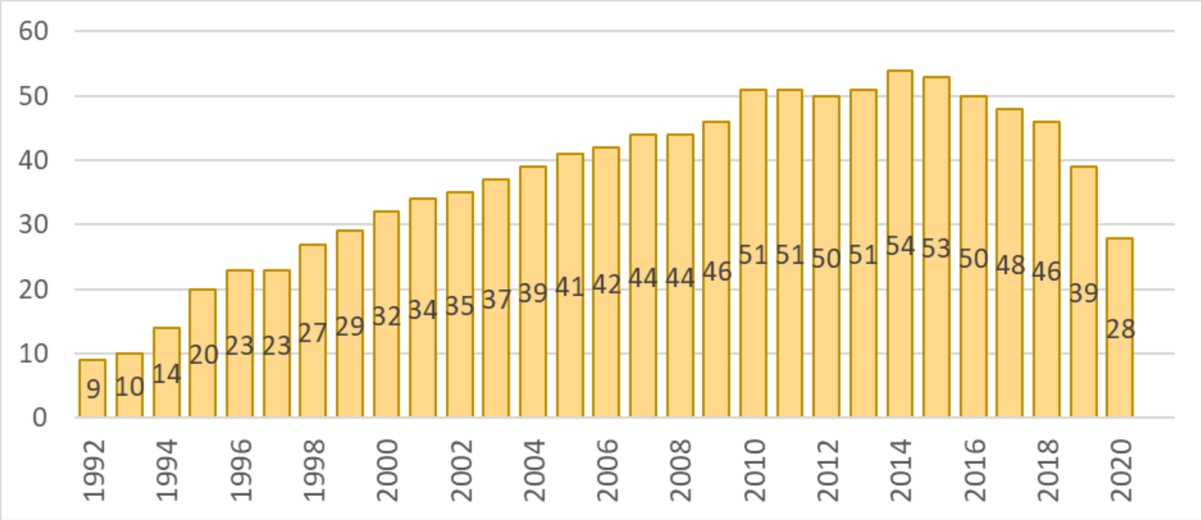

Figure 37. BSRN stations with completed records in the WRMC archives.

C.b Status of Terrestrial Networks reporting to GCOS

C.b.i Global terrestrial Network for Hydrology (GTN-H)

Established in 2001, the Global Terrestrial Network - Hydrology (GTN-H) is a federated network of data portals that provide water-related terrestrial observational data on a global scale.

GTN-H is a joint project of the WMO and GCOS. GTN-H also supports Group on Earth Observations / Integrated Global Water Cycle Observations Community of Practice (GEO/IGWCO-CoP) with the observations and findings from its various data centers, including runoff, lakes and reservoirs, precipitation, groundwater, soil moisture and water quality, or hydrogen and oxygen isotope content in rivers and precipitation. The main objective of GTN-H is to make data from existing global hydrological observation networks available and enhance their value through integration. GTN-H supports current and emerging technologies and standards, best practices and available infrastructure, and develops global and regional data products. GTN-H thus underpins the generation of datasets suitable for:

- Research in the areas of global and regional climate change
- Environmental Monitoring
- Hydrology and water resource management

The configuration with its contributing data centres and networks is explained in Figure 38. The different members provide for their respective Essential Climate Variable (ECV) datasets that represent the observational baseline for many water-related global assessments. GTN-H with its federated member strongly supports the ambitions of the TOPC and provide experts or ECV stewards for the TOPC on a regular basis. Data and information provided by GTN-H global data centres continue to be essential sources for information for United Nations, regional and national programmes and projects in support of development and science. During the 18th Congress of WMO in 2019, the significance of the existing global water data centres and GTN-H as their coordinating mechanism was highlighted as a fundamental pillar to support the GCOS Implementation Plan and recognized as major hydrological initiatives to WMO in hydrological data operations and management (Resolution 25, Cg-18).

In 2017, the International Centre for Water Resources and Global Change (ICWRGC, a UNESCO category 2 centre hosted by the German Federal Institute of Hydrology) has been mandated by GCOS and WMO to host GTN-H – with certain advantages for the GTN-H network. In 2014, when establishing ICWRGC, located at the German Federal Institute of Hydrology (BfG) in Koblenz, Germany, the management of the German Secretariat National Committee for the International Hydrological Programme (IHP) of UNESCO and the Hydrology and Water Resources Programme (HWRP) of WMO was integrated into ICWRGC. GTN-H can now benefit and contribute to our network with a long-term perspective, reaching from GCOS and WMO to the Food and Agriculture Organization (FAO), UNESCO, UN Environment Programme (UNEP) and to the Group on Earth Observations (GEO). Additional information may be found at www.gtn-h.info.

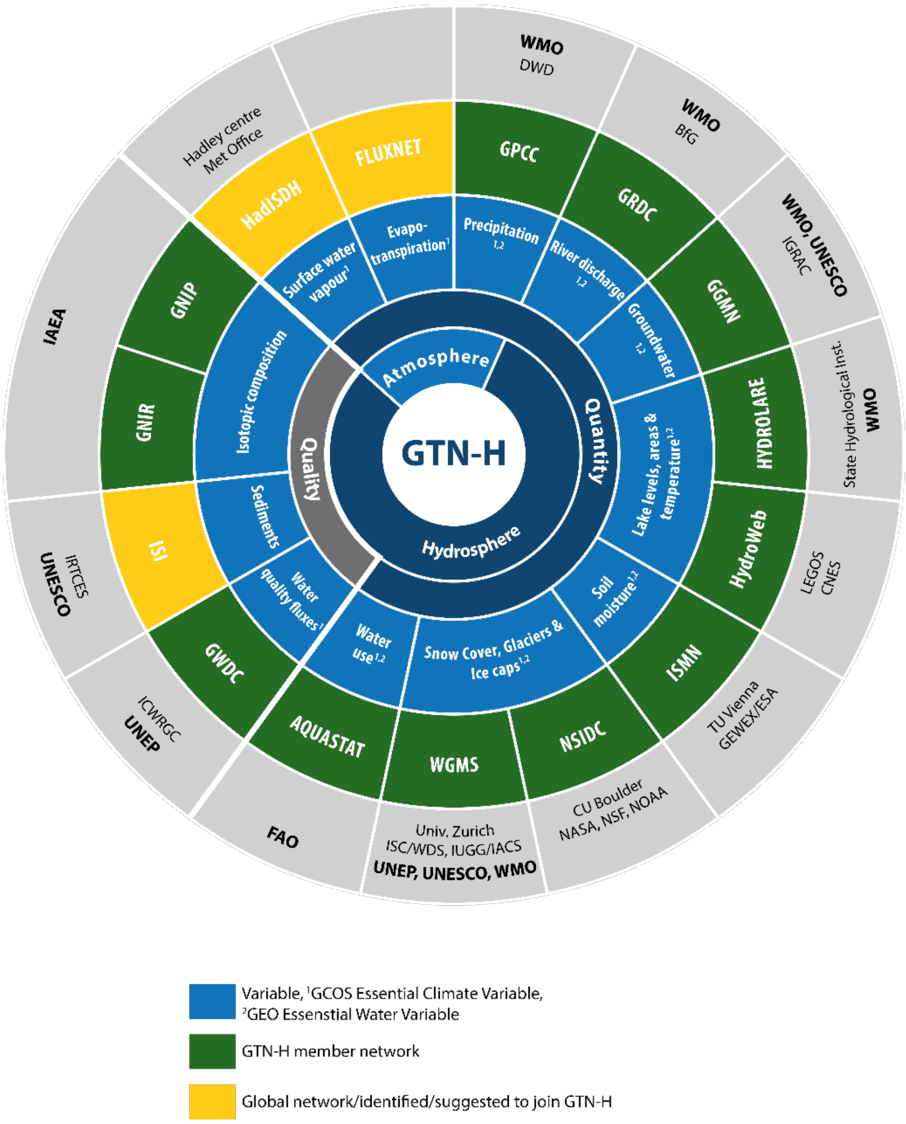

Figure 38. Configuration to the GTN-H with its contributing data centres and networks

C.b.ii Global Terrestrial Network for Glaciers (GTN-G)

Among the first Global Terrestrial Networks, the Global Terrestrial Network for Glaciers (GTN-G) was established in 1998 (Haeberli, 1998). GTN-G is led by the World Glacier Monitoring Service (WGMS) in close collaboration with the US National Snow and Ice Data Center (NSIDC) in Boulder and the Global Land Ice Measurements from Space (GLIMS) initiative. GTN-G has become the framework for the internationally coordinated monitoring of glaciers in support of the UNFCCC. GTN-G and its operational bodies are periodically evaluated through the GTN-G Advisory Board, under the lead of the International Association of Cryospheric Sciences (IACS). GTN-G has no dedicated budget and, hence, fully depends on the funding situation of its operational bodies (i.e., a few full-time equivalents in total).

GTN-G has developed an integrated, multilevel strategy for global glacier observations and is based on a system of tiers of the Global Hierarchical Observing Strategy (Haeberli et al., 2000). It combines process-oriented in situ studies on single glaciers (e.g., glaciological mass-balance measurements) with satellite-based coverage of large glacier ensembles in entire mountain systems (i.e., glacier inventories, combined with digital elevation models from geodetic surveys). In a recent study, Gärtner-Roer et al. (2019) assessed the status of national implementations of this international monitoring strategy to make the data easily accessible to a broader audience, to identify gaps in the monitoring setup, and to guide countries in improving their monitoring schemes. Unfortunately, those countries with the highest glacier coverage are not the ones with the best developed monitoring networks. This observational bias needs to be addressed by capacity building and twinning for in situ measurements whereas remote sensing can help to improve the observational coverage in space and time.

Over recent years, GTN-G has made great progress in increasing the accessibility of glaciological data and information and, hence, provides an important service to the scientific community, national and international agencies, and to the wider public. As such, NSIDC and GLIMS successfully merged the existing glacier inventories, streamlined data delivery, and released new versions of the Randolph Glacier Inventory (RGI, RGI Consortium, 2017). At the same time, the WGMS was able to further extend the compilation and computation of glacier volume changes using space-borne sensors within the framework of ESA's Climate Change Initiative (CCI, CCI+) and Europe's Copernicus Climate Change Service (C3S). These efforts resulted in a strong and ongoing improvement of the observational coverage in many regions (Figure 12). At the same time, the database infrastructure of WGMS needs to be modernized and upgraded in order to deal in an efficient manner with the tremendous increase in data from remote sensing. The migration to a new Fluctuations of Glaciers database infrastructure is a key task for the coming years. This progress has been achieved thanks to the available funding of the GTN-G bodies and to the collaboration with the glaciological community, often through IACS working groups (https://cryosphericsciences.org/).

GTN-G managed to building up an unrivalled collection of global glacier datasets thanks to the long-term commitment of its operational bodies and a well-established international collaboration network. The GTN-G datasets provide, despite remaining limitations, the observational baseline for global assessments on glacier distribution (e.g., RGI Consortium 2017, Farinotti et al., 2019a) and changes (e.g., Marzeion et al., 2014, Zemp et al., 2015, 2019) as well as on related impacts on local hazards (e.g., Haeberli & Whiteman, 2015), regional water availability (e.g., Huss and Hock, 2018, Farinotti et al., 2019b), and global sea-level rise (e.g., Hock et al., 2019, Marzeion et al., 2020, Zemp et al., 2020).

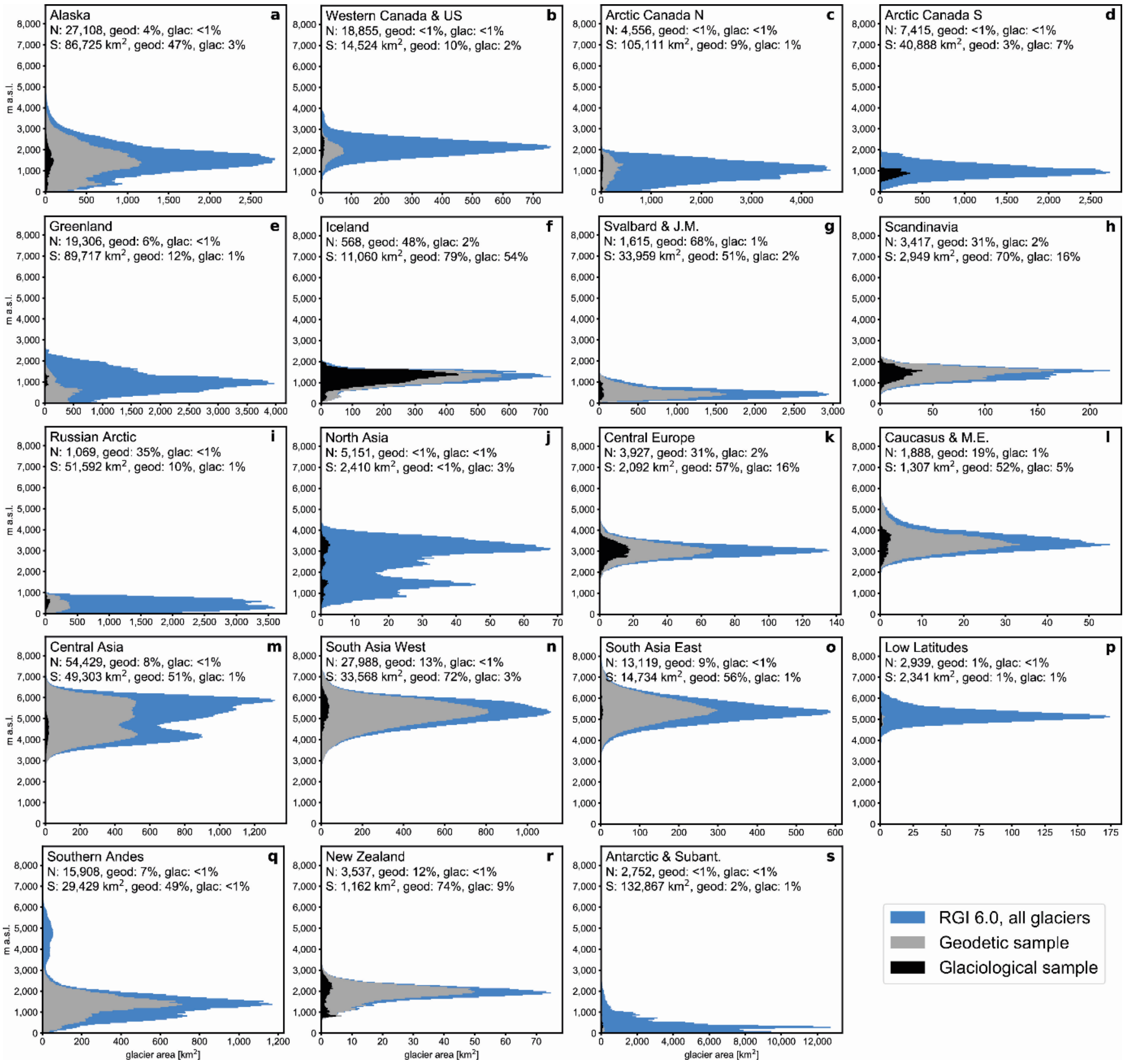

Figure 39. Observational coverage of glacier monitoring. For each region, glacier hypsometry from the Randolph Glacier Inventory (RGI 6.0, blue) is overlaid with the (relative) observational coverage from glaciological (black) and geodetic (grey) methods, with values for the total number (N) and total area (S) of glaciers.

(Source: Zemp et al., 2019[67])

C.b.iii Global Terrestrial Network for Permafrost (GTN-P)

The Global Terrestrial Network for Permafrost (GTN-P) is the primary international programme concerned with monitoring permafrost parameters. GTN-P was developed by the International Permafrost Association (IPA) under GCOS and the Global Terrestrial Observing Network (GTOS) in 1999, with the long-term goal of obtaining a comprehensive view of the spatial structure, trends, and variability of changes in the active layer thickness and permafrost temperature.

[67] https://doi.org/10.1038/s41586-019-1071-0

The data management system of the GTN-P oversees permafrost data submission, archival, storage, and dissemination of a wide range of permafrost data. The aim of the GTN-P database is to include a wide range of permafrost data. The GTN-P database is the free, open-source central database for permafrost monitoring parameters. The data management system is organized along a controlled vocabulary in order to reduce ambiguity and the contribution to common grounding and shared understanding. It also links to the permafrost thesaurus, a glossary of nearly 600 permafrost-related terms. The work on a permafrost ontology, an organized vocabulary showing the interrelationships of terms, is in progress.

C.b.iv Global Observations of Forest Cover and Land-use Dynamics (GOFC–GOLD)

Global Observations of Forest Cover and Land-use Dynamics (GOFC–GOLD) is a coordinated international program working to provide ongoing space-based and in situ observations of the land surface to support sustainable management of terrestrial resources at different scales. The GOFC–GOLD program acts as an international forum to exchange information, coordinate satellite observations, and provide a framework for and advocacy to establish long-term monitoring systems. It was established as a part of a Committee on Earth Observation Satellites (CEOS) pilot project in 1997, with a focus on global observations of forest cover. Since then, the program has expanded to include two Implementation Teams: Land Cover Characteristics and Change, and Fire Mapping and Monitoring. In addition, two working groups—Reducing Emissions from Deforestation and Forest Degradation (REDD), and Biomass Monitoring—were also formed. GOFC– GOLD activities are guided by an executive committee, primarily with support from NASA and the European Space Agency (ESA). Another key activity of GOFC-GOLD is the coordination of Regional Networks, which involve local data providers, data brokers and data users .

The GOFC-GOLD Land Cover Project Office (LC-PO) manages the Land Cover Characteristics and Change Implementation Team of GOFC-GOLD. It was established as a technical panel of the Global Terrestrial Observing System (GTOS), and now reports to TOPC and GCOS as GTOS is no longer operational. It provides the platform for international communication and cooperation for actors involved in global earth observation including data producers (e.g. space agencies, land cover facilities, operational service mechanisms including Copernicus), the scientific community, and data users (FAO and other UN organizations, the European Economic Area (EEA), global climate and land use assessment communities (i.e. the Intergovernmental Panel on Climate Change (IPCC), Global Land Programme (GLP) etc.). These activities improve the value of current and future land monitoring datasets for a multitude of applications and contribute to the overall goal of operational observations of the land surface.

The LC-PO's activities for the GOFC-GOLD REDD working group have been implemented recently through the of Global Forest Observations Initiative (GFOI) from GEO. The LC-PO lead the R&D component of GFOI which is another major international coordination initiative. The main aim is to support REDD+ countries in developing their national forest monitoring capacities. the key role of the R&D component to achieve the objectives of GFOI starting from assessing country needs and defining R&D priorities, stimulating dedicated research, synthesizing research findings to improve guidance (i.e. GOFC-GOLD Sourcebook, www.gofcgold.wur.nl/redd/) and training materials (GOFC-GOLD training materials http://www.gofcgold.wur.nl/redd/training-materials/), and feeding back into country capacity developing processes.

Other recent significant objectives of GOFC-GOLD are to maintain and develop participation of the LC-PO in TOPC/GCOS meetings. Prof. Herold is member of TOPC and together with Sarah Carter is responsible for land cover and biomass ECVs.

The ESA supported the GOFC-GOLD LC-PO for 6 years (2011-2016) at Wageningen University (under GOFC-GOLD land cover team co-chair Prof. Martin Herold) and this period followed 6 years of operation at the Friedrich-Schiller-University (FSU) in Jena.

The last meeting of the GOFC-GOLD LC IT was held in 2016, and several new directions which the forest/land monitoring and the global land cover research communities should take were identified since the official launch of the UN Sustainable Development Goals (SDGs) including the need to cater for non-climate users, and the outcomes of the UNFCCC COP-21 (Paris Agreement). The need to provide contributions to international initiatives such as the SDGs has been recently achieved through the team's participation as an expert member of Inter-Agency Expert Group (IAEG)-SDG geospatial working group (WG-GI) that is working on detailing and demonstrating the use of Earth Observation data for SDG assessment purpose and activities. A number of other key priorities were identified based on evolving needs of the field. The requirement to constantly update these through active participation in relevant networks and scientific communities is a constant challenge which the team is undertaking. The need to link LC-IT activities to broader GOFC-GOLD activities has also recently been identified, and efforts have been undertaken to revamp this network.

C.c Ocean Observations

This section draws from the Ocean Observing System Report Card 2020[68], published by the Global Ocean Observing System (GOOS) Observations Coordination Group (OCG).

[68] https://www.ocean-ops.org/reportcard/

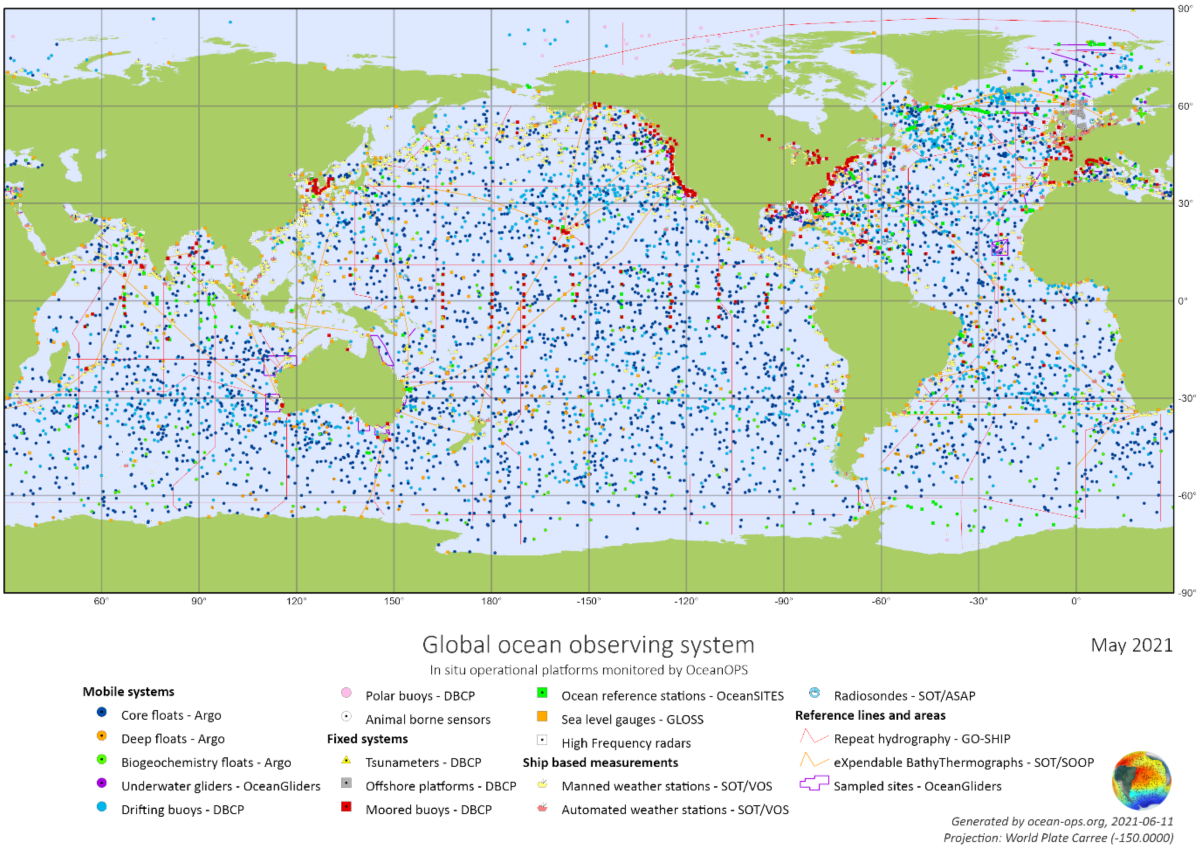

Figure 40. A global snapshot of the status of in situ observing platforms that are part of GOOS Observations Coordination Group networks, tracked by the OceanOPS centre

C.c.i Global in situ observing networks

In situ observations are made from a large variety of platforms, including research and commercial vessels, coastal stations, and autonomous platforms. GOOS tracks twelve global in situ observing networks that measure ECVs. Surface measurements of the ocean can be made by remote sensing, but they can only infer a few things about the deeper layers, which require in situ measurements.

These are:

The **Ship Observation Team (SOT)** consists of three networks involving vessels of opportunity from the maritime industry (container ships, tankers, etc.) as well as research or coast guard / maritime patrol vessels.

The **Voluntary Observing Ship Scheme (VOS)** complements sources of synoptic surface marine meteorological observations in coastal areas and the high seas. The ships supply marine meteorological observations, at appropriate quality and timeliness, for defined application areas in weather and marine services. There are currently approximately 2500 active VOS ships, which submit nearly 2 million observations each year. These operate in complement to the land based GCOS Surface Network (GSN).

Within the **Automated Shipboard Aerological Programme** (ASAP), ships provide upper-air observations of appropriate quality and timeliness for WMO defined application areas, such as forecasts and warnings to safeguard commerce and the protection of life and property at sea. The soundings are made using balloons (filled with helium gas) equipped with the required instruments and data telecommunication system. Around 5000 soundings are taken annually, a complement to the land-based GCOS Upper-Air Network (GUAN).

The **Ship of Opportunity Program (SOOP)** collects upper ocean temperature profiles and surface measurements. The network consists of collecting temperature profiles down to 800m across ocean basins as well as surface CO_2 and surface temperature and salinity data. SOOP can be divided into four sub-programs, each focusing on different variables and addressing various phenomena, therefore having a unique contribution: SOOP - Expendable bathythermographs measuring temperature in the upper 700 m of the ocean, SOOP-CO_2 for surface carbon, SOOP-BGC for other biogeochemical surface variables, and SOOP-Thermosalinographs measuring sea surface temperature and salinity.

The **Global Sea Level Network (GLOSS)** is a network of tide gauges delivering to specifications (data, timeliness, accuracy) for characterising Global Sea Level Changes. The main component of GLOSS is the 'Global Core Network' (GCN) of 290 sea level stations around the world for long term climate change and oceanographic sea level monitoring. It is designed to provide an approximately evenly distributed sampling of global coastal sea level variations. The GLOSS altimeter calibration (ALT) set consists mostly of island stations and will provide an ongoing facility for mission intercalibrations. The data is transmitted in Real time and Fast and in Delayed Mode.

The **Data Buoy Cooperation Panel** (DBCP) comprises the Global Drifter Array and the National/Coastal Moored Buoy Networks.

The DBCP **Drifting and polar buoys** is a network of surface lagrangian drifters equipped with a thermistor on the base of the surface hull to measure sea surface temperature, and a drogue centred at 15m below the surface such that the drifters follow the surface circulation. The drifters are the only source of global in situ air pressure data and the primary source of in situ sea surface temperature data for climate. A small number of drifters also report surface salinity and wind speed. The aim of the DBCP Global Drifters Array is to maintain a global 5x5 degree array of satellite-tracked surface drifting buoys. In addition, drifters are also deployed at higher latitudes, often on seasonal ice in the Arctic and Antarctic regions.

The DBCP **Moored buoys** encompasses moored buoys deployed, operated and maintained by a wide variety of organizations. They provide data in support of weather prediction, marine services, and research. Some of these networks have been in place for 40 years, and so provide valuable time-series for marine climate studies, in particular for wave climate.

The **OceanSITES** Open-Ocean Timeseries network aims to collect physical, biogeochemical, and biology/ecosystem data worldwide with **interdisciplinary moorings** taking long-term, high-frequency observations at fixed locations in the open ocean, covering the full-depth water column, the sea floor as well as the overlying atmosphere. OceanSITES has three types of sites: transport moored arrays, air/sea flux reference sites, and multidisciplinary Global Ocean Watch sites, which are operated in key regions of the global ocean. One of the main drivers for time series is to provide both monitoring and process observations with a temporal resolution from minutes to decades to detect, understand, and predict global physical, biogeochemical and ecosystem state and changes, including ocean warming, ocean carbon uptake/storage and acidification, ocean deoxygenation, but considering also the role of and impact on ecosystem.

Argo is a network of Quasi-Lagrangian profiling floats, which are capable of adjusting their buoyancy. The array of now almost 4000 floats provides 140,000 temperature/salinity (T/S) profiles and velocity measurements per year distributed over the global oceans at an average 3 degree spacing. Floats cycle to 2000m depth every 10 days. Other types of floats go deeper than 2000 m (deep Argo), and biogeochemical Argo (BGC Argo) is developing. Argo provides a quantitative description of the changing state of the upper ocean and the patterns of ocean climate variability from months to decades, including heat and freshwater storage and their transport. Argo data are being used to initialize ocean and coupled ocean-atmosphere forecast models, for data assimilation and for model testing. A primary focus of Argo is to document seasonal to decadal climate variability and to aid our understanding of its predictability.

The **Global Ocean Ship-Based Hydrographic Investigations Programme (GO-SHIP)** is an international network of global class research vessels engaging in repeated transect hydrographic surveys. GO-SHIP is the only comprehensive oceanographic program documenting, with high accuracy, ocean physical and biogeochemical changes throughout the water column, including for the deep ocean below 2 km. It also provides coincident, comprehensive, high quality of key carbon observations. The measurements taken are critical to validate new generation sensors including those on floats, gliders and buoys. GO-SHIP is aimed at understanding and documenting the large-scale ocean water property distributions, their changes, and drivers of those changes, addressing questions of how a future ocean that will increase in dissolved inorganic carbon, become more acidic and more stratified, less oxygenated, and experience changes in circulation and ventilation processes due to global warming, altered water cycle and sea-ice, will interact with natural ocean variability. An evolving objective is determining ecological changes, systematically studying large scale decadal changes in the ocean.

The **OceanGliders** network is an international array of autonomous underwater gliders, which measure physical variables such as pressure, temperature, salinity, and current, as well as biological variables relevant to the abundance of phytoplankton, zooplankton, fishes and ecologically important chemical variables such as dissolved oxygen. They can be deployed and recovered from a wide range of platforms, including small boats and chartered fishing vessels, which facilitates logistics. The glider program is designed as an array of long-term repeat sections in key areas over the global oceans, documenting the variability of the boundary circulation and addressing questions of how a future ocean will change in many respects and at many different scales.

The **Global HF Radar Network** uses coast-based high-frequency radar technology to measure surface currents, waves (height, direction, period) and wind. The network helps determine the movement of surface waters, providing critical information to support pollutant tracking, search and rescue operations, harmful algal bloom monitoring, vessel navigation, ecosystem-based management, and marine spatial planning. The Global HF Radar team works to connect the countries operating HF Radar while supporting the transition of these systems to a sustained effort. Assimilation of HF radar data into ocean models has significantly improved forecasting.

The newly endorsed **Animal Borne Ocean Sensors (AniBOS)** network provides a cost-effective and complementary observing capability to the GOOS. AniBOS monitors several essential ocean and biodiversity variables, providing inputs to estimate global ocean indicators, contributing to the quantification of the upper ocean variability and yielding data for a range of operational oceanographic applications. Animal borne ocean sensors are used to retrieve a variety of variables in several chronically under-sampled regions. These variables include temperature and salinity profiles, but also fluorescence, oxygen or surface wave and wind activity. In the last decade, about 500,000 temperature-salinity-depth profiles were obtained in high latitudes, coastal shelves and tropical areas, all regions that are currently poorly covered by traditional observing platforms, greatly enhancing studies of climate variability and the delivery of information to inform climate prediction estimates at global and regional scales.

The network status table (below) was developed by the GOOS OCG technical coordinators at OceanOPS, OCG experts on data and best practices, the OCG executive board and network chairs, to provide messaging on the status of the GOOS OCG networks, in order to communicate on progress and issues, to an audience of both observing system implementers and those investing in the ocean observing system, such as policymakers or national funding bodies.

Table 5. Evaluation of the status of the GOOS Observations Coordination Group networks, based on criteria described below for the level of implementation against targets, data and metadata availability, and best practices published and available.[69] **All of these networks deliver ECVs for climate applications**

	Implementation	Data and metadata				GOOS delivery areas		
GOOS *in situ* networks	Status	Real time	Archived high quality	Metadata	Best Practices	Operational services	Climate (GCOS)	Ocean health
Ship based meteorological measurements – SOT/VOS	**	***	***	**	**			
Ship based aerological measurements – SOT/ASAP	*	***	-	**	*			
Ship based oceanographic measurements – SOT/SOOP	**	***	***	**	**			
Sea level gauges- GLOSS	***	**	***	*	**			

[69] https://www.ocean-ops.org/reportcard2021/

Drifting and polar buoys - DBCP	***	***	**	**	**			
Moored buoys - DBCP	**	***	**	**	**			
Long-term time series sites- OceanSITES	**	N/A	**	**	**			
Profiling floats - Argo	***	***	***	***	**			
Repeated transects - GO-SHIP	***	*	***	**	***			
OceanGliders	* Emerging	**	*	***	*			
HF radars	Emerging	***	***	*	***			
Biogeochemistry & Deep floats - Argo	* Emerging	***	*	***	**			
Animal borne ocean sensors - AniBOS	Emerging	***	**	*	**			

All twelve networks contribute ECVs and deliver for the requirements expressed by GCOS for climate. GOOS also tracks contributions of observing networks to requirements for applications in forecasting and early warning (operational services), as well as ocean health.

The criteria for rating in the table above are as follows:

The **implementation/status** rating is based on networks implementation plans and targets. These can be: 1) community widely-adopted targets (e.g., those identified in the GCOS Implementation Plan, the WMO Observing Systems Capability Analysis and Review Tool (OSCAR) database, or through OceanObs Community White Papers); 2) network self-declared targets; or 3) where no clear target exists ratings are based on network self-evaluation. When clear network targets exist, the operational status can be assessed, and the Key Performance Indicators at OceanOPS (www.ocean-ops.org > Metrics > KPIs) provide quantitative background metrics to assess activity.

*   activity <25% of target

**   activity between 25-75% of target

***   activity >75% of target

The rating for **real-time data** availability is based on distribution on the WMO Global Telecommunications System (GTS) with a given timeliness target for use in operational services.

*   embryonic real-time distribution: only a few operators in the network send data in real-time

** < 75% of platform data on the GTS, not using modern GTS templates

*** > 95% platform data on GTS, using modern WMO-approved BUFR templates that carry metadata and quality flags appropriate for use in research and climate applications

The rating for **metadata** is based on that required by OceanOPS for monitoring work, capturing a common set of information across all platforms and enabling an integrated view, using reference tables (WIGOS, Seadatanet, International Council for the Exploration of the Sea (ICES), etc.) as far as possible. The metadata required includes:

- a unique identifier or label (with a registration/certification process, e.g., WIGOS ID),
- the implementer (programmes, contacts, agencies, funding sources),
- operations at sea (ships/cruises), including deployment/retrieval dates, ship/cruise, latitude/longitude, etc. - these provide an important link between system elements,
- hardware: vocabulary to describe and group the platform types, models, etc.,
- sensors (including serial numbers) and parameters measured, which link to Essential Ocean Variable (EOV) and ECVs,
- telecommunications system used - useful to track data distribution, and follow market evolution,
- data available in real-time or delayed-mode, and
- other essential parameters as identified by the WIGOS metadata standard or network specific standards.

  * minimal metadata: we have a dot on the map, with a country but not much more, through a yearly update
  ** most of metadata needs covered with regular updates - i.e. medium monitoring capacity
  *** OceanOPS needs fully met, and metadata routinely updated. WIGOS ID allocation done and metadata submitted routinely to WMO WIGOS/OSCAR - i.e. advanced monitoring capacity.

The rating for **best practices** considers a number of things. The best practices of each network need to cover the observation ‘lifecycle’: including deployment and sampling, standard operating procedures, pre-mission preparation (*e.g.* calibration and validation), data retrieval and formatting, and primary quality control and secondary quality control for all the EOVs (and sub-variables) that they sample. Clear best practices are also needed around data documentation, access and archival. On top of having the best practices written, ratings were based on how easily-accessible they are outside of the observing network community. The frequency of the updates has also been considered. For example, the scoring could be 2 stars meaning best practices were in place but only accessible through meeting reports which are difficult to find on various websites. Alternatively, 2 stars may be that 2 or 3 manuals are easily available but do not cover the whole observing lifecycle, or they are very outdated.

The table above does not consider the status of observing networks that primarily measure biological and ecological ocean ECVs. Work in progress shows that only 7% of the global surface ocean is covered by active, long-term, systematic biological observations measuring ocean biological and ecological ECVs. However, only 32% of these programs had publicly accessible and open data, with capacity, cultural, and technological barriers to making this data available.

C.c.ii Ocean ECV satellite constellations

The Ocean Observing Report Card identifies the adequacy of past and planned satellite missions for ocean ECVs, based on the requirements of the GCOS Implementation Plan.

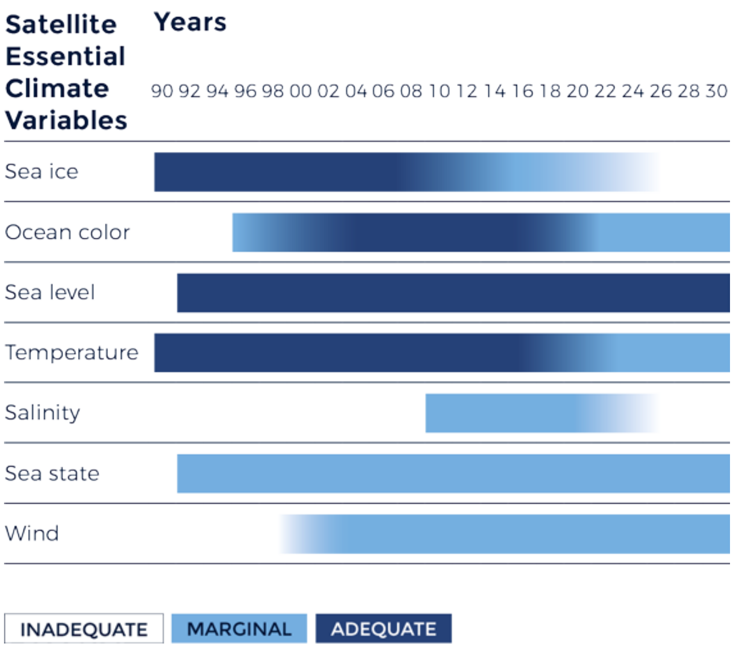

Figure 41. Identifies the adequacy of past and planned satellite missions for ocean ECVs, based on the requirements of the GCOS Implementation Plan