WORLD METEOROLOGICAL ORGANIZATION

GLOBAL CRYOSPHERE WATCH (GCW)

IMPLEMENTATION PLAN

Version 1.4

(1 March 2014)

DOCUMENT VERSIONS

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0.3	J. Key	31 Jan 2012	Additional recommendations and task from GCW Implementation Meeting report.
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1.4	J. Key	1 Mar 2014	Updated based on EC-PORS-5 feedback: restructured the implementation section; new framework figure; revised partnership criteria

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1 PURPOSE OF THIS DOCUMENT

This document describes the implementation of the World Meteorological Organization's Global Cryosphere Watch (GCW). The focus of the plan is on the GCW organizational structure and key activities during the development and implementation phase (2012-2019), as presented in the GCW Implementation Strategy that was approved by the 15th World Meteorological Congress. The document provides background information for senior representatives of National Meteorological and Hydrological Services (NMHS) and related institutions on GCW, applications of cryosphere data, a conceptual framework, an operational structure, near-term tasks, milestones and deliverables, management, indicators of success, partnerships, and an indication of resources. This plan will be periodically updated as GCW evolves over the coming years.

2 INTRODUCTION

The cryosphere collectively describes elements of the Earth System containing water in its frozen state. It includes solid precipitation, snow cover, sea ice, lake and river ice, glaciers, ice caps, ice sheets, permafrost, and seasonally frozen ground. The cryosphere is global, existing not just in the Arctic, Antarctic and mountain regions, but also in various forms at all latitudes and in approximately one hundred countries. The cryosphere provides some of the most useful indicators of climate variability and change, yet is one the most under-sampled domains of the Earth System. Improved cryospheric monitoring and integration of that monitoring is essential to fully assess, predict, and adapt to variability and change in the Earth's weather, climate and water cycles.

The cryosphere, its changes, and its impacts have received increased attention in recent years. Today it receives constant coverage by the media, creating a demand for authoritative information on the state of the world's snow and ice resources from polar ice to tropical glaciers, based on data from the paleoclimate record, current observations, and future projections. WMO, with the co-operation of other national and international bodies and organizations, and using its global observing and telecommunication capability, is in a position to provide an integrated, authoritative, continuing assessment of the cryosphere – a Global Cryosphere Watch (GCW).

2.1 Rationale for GCW

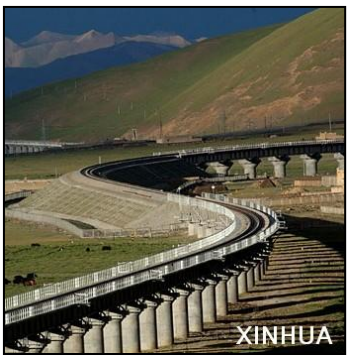
WMO's ability to support ongoing development and delivery of weather, climate, and water services contributes to ensuring the sustainable development and well being of nations. GCW will provide, directly or indirectly, data, information, products and analyses that will help Members and partners provide needed services to the wider user community. GCW will help us understand, assess, predict, mitigate, and adapt to climate variability and change and improve weather forecasting and hazard warnings, thus helping reduce the risk of loss of life and property from natural and human-induced disasters. It will contribute to improved management of energy and water resources, including flood forecasting and hydropower production, help support sustainable agriculture, and improve our ability to monitor and conserve biodiversity. Cryosphere information is required for infrastructure design in cold climates, improved management and protection of terrestrial, coastal and marine ecosystems, and an improved understanding of environmental factors affecting human health and well being. The cryosphere impacts all nations, their people and their economy.

Changes in the cryosphere have been shown to contribute to global climate variability and change. Albedo changes from the loss of sea ice and snow cover, along with accelerating methane emissions from thawing permafrost, are heating the planet at a rate equivalent to approximately 3 billion metric tons of CO_2, comparable to about 42% of US global warming emissions. The emission of GHGs and changes in albedo from a melting Arctic are projected to more than double the Arctic's contribution to global warming by 2100.

Sea level rise is a major concern for coastal regions, especially heavily populated zones, and is critical for a number of small island nations. Although the volume equivalent of glaciers in terms of global sea level rise is small (0.5 m) compared to that of the ice sheets of Greenland (7 m) and Antarctica (about 70 m), their melt contribution to sea level rise during the second half of the 20th century was 2.5 times more than the loss of ice from the Greenland and Antarctic ice sheets.

The amount of snow and the rate of snowmelt can govern the timing and characteristics of runoff. In the western United States as much as 75% of water supplies come from snowmelt, and most central Asian countries/regions rely on meltwater for agriculture and industry. Many countries rely on snowmelt forecasts to predict river runoff, determine flood potential, and to provide flood alerts. Mountain glaciers are an important water resource for many communities and they play a vital role in local hydrological cycles. Changes in the cryosphere affect hydropower operations in alpine and continental regions.

Wave-induced undercutting of permafrost leads to coastal erosion by the action of waves and currents. Shortened periods of seasonal ice-cover, and later development of the fast ice and its earlier break up, expose coastlines to more severe storms that occur during transition seasons. Local coastal losses to erosion of the order of 30 metres per year have been observed in some locations in both Russian Federation (Siberia) and Canada.



Transportation is directly impacted by changes in snow cover, fresh-water and sea ice extent and thickness, and the degradation of permafrost. Persistent reductions in Arctic multi-year sea ice cover would benefit marine transportation and related socio-economic developments, but present a risk for marine ecosystems. Thawing of permafrost can lead to the degradation of roads, railroads and northern airstrips. Snowfall frequency and magnitude directly affect road and rail traffic and aircraft operations with significant cost implications to national economies. River and lake-ice provide winter roads for access to remote areas.

The design of buildings and infrastructure in cold climates must consider the presence of permafrost and seasonally frozen ground. Knowledge of thermal and ground ice conditions is critical for land use planning and engineering design in permafrost regions. The development of oil and gas deposits in ice-covered seas and shelves depends on the ice regime and the presence of icebergs, which together determine the economic feasibility of exploration and production projects.

Other sectors such as wildlife, recreation, and tourism are significantly affected by short-term and long-term changes in snow and ice conditions. Cryosphere-related hazards include avalanches, catastrophic spring floods from the rapid melting of snow, the high variability of lake break-up and freeze-up dates that have significant short and long term impacts, including increased risks, and hence costs, for the insurance industry.

Cryosphere data and products support the development and delivery of climate, weather and water services by Members, including in the key GFCS areas of food security, water, health, and disaster risk reduction. Snow and ice data are required for weather and climate research and in many types of practical applications such as engineering, services to society, and various types of land- and marine-related resource management. The performance of numerical weather forecasts strongly depends on the accuracy of initial conditions for predictive models, including snow and ice conditions. Ice services provide forecasts for navigation and offshore activities. Cryospheric data play a critical role in climate reanalyses, as input to the assimilation systems and for verification of model fields.

GCW will provide information for decision making and policy development related to climate, water and weather, for use in real time, for climate change adaptation and mitigation, and for risk management. Over time, this information will become more service-oriented. During initial GCW consultation, Members emphasized the regional and global impacts of the cryosphere, particularly:

- Sea level rise threatens vital infrastructure, settlements and facilities of small island states and low-lying coastal zones;
- Changes in sea-ice affect access to the polar oceans and surrounding seas, in turn affecting economic development, accessibility to resources, navigation, tourism, marine safety and security. Declining summer sea-ice may also impact ocean circulation and weather patterns in the mid-latitudes;
- Permafrost thawing impacts infrastructure and is a potential major source of methane, a greenhouse gas;
- Changes in the cryosphere have major impacts on water supply, food production, availability of potable water, freshwater ecosystems, hydropower production, and the risk of floods and droughts;
- Natural hazards such as icebergs, avalanches and glacier outburst floods create risks for transportation, tourism and economic development;
- Cryospheric data and information are required for improved numerical weather prediction and climate monitoring and prediction in polar and alpine regions as well as globally;
- Changes in large-scale dynamics have major, and currently not well-predicted, impacts on climate in North America, Europe and Asia.

GCW will provide a mechanism to translate user needs into observational requirements, and requirements into observing system design, implementation, integration, and data.

2.2 Mission and Objectives

GCW will be an international mechanism for supporting all key cryospheric in-situ and remote sensing observations. To meet the needs of WMO Members and partners in delivering services to users, the media, public, decision and policy makers,

> *GCW will provide authoritative, clear, and useable data, information, and analyses on the past, current and future state of the cryosphere.*

In its fully developed form, GCW will include observation, monitoring, assessment, product development, prediction, and research. It will provide the framework for reliable, comprehensive, sustained observing of the cryosphere through a coordinated and integrated approach on national to global scales to deliver quality-assured global and regional products and services. GCW will help bridge the gap between research and operations, between scientists and practitioners.

GCW will organize analyses and assessments of the cryosphere to support science, decision-making, environmental policy and services through, inter alia, its foundational support to the Global Framework for Climate Services (GFCS), the Global Integrated Polar Prediction System (GIPPS) including its WWRP Polar Prediction Project (PPP) and WCRP Polar Predictability Initiative (PPI), and the Polar Regional Climate Centres (PRCCs) and Polar Climate Outlook Forums (PCOFs).

To meet these objectives, GCW implementation will encompass:

- *Requirements:* Meet evolving cryospheric observing requirements of WMO Members, partners, and the scientific community, by contributing to the WMO Rolling Review of Requirements (RRR) process.

- *Integration:* Provide a framework to assess the state of the cryosphere and its interactions within the Earth System, emphasizing integrated products using surface- and space-based observations while including a mechanism for early detection of, and support for, endangered long-term monitoring.
- *Standardization and assessment:* Enhance the quality and "authority" of data by improving observing standards and best practices for the measurement of essential cryospheric variables, by addressing potential differences and inconsistencies in current practices, and by fully assessing error characteristics of in situ and satellite products.
- *Access:* Improve exchange of, access to, and utilization of observations and products from WMO observing systems and those of its partners.
- *Coordination:* Foster research and development activities and coherent planning for future observing systems and global observing network optimization, especially within the WMO Integrated Global Observing System (WIGOS), by working with all WMO Programmes, technical commissions (TCs), regional associations (RAs), partner organizations and the scientific community.

The observing component of GCW is a component of WIGOS. Implementation is directly linked to the WIGOS Implementation Plan (WIGOS-IP) and the evolution of the global observing systems. GCW will coordinate relevant cryospheric activities with the Global Climate Observing System (GCOS), which includes the climate-related components of the Global Ocean Observing System (GOOS) and the Global Terrestrial Observing System (GTOS), hence enhancing GCOS support to the UNFCCC. The WMO Information System (WIS) will provide a vehicle for data and products collection and dissemination within and outside the WMO community. Through WIGOS and WIS, GCW will also provide a fundamental contribution to the Antarctic Observing Network (AntON) and the Global Earth Observation System of Systems (GEOSS).

GCW will contribute to the observational activities for the cryosphere identified in the GFCS Implementation Plan, its Annexes and its compendium of projects to provide essential data and products needed for services required by GFCS users.

2.3 Project Phases

2.3.1 GCW Definition Phase (2007-2011)

Following a review of the feasibility study for developing and implementing GCW within WMO, EC-LXI in 2009 endorsed the next steps for developing GCW with the guidance of EC-PORS. In 2011, Cg-16 decided to embark on the development of the Global Cryosphere Watch as an IPY legacy with a view towards achieving an operational GCW.

Extensive consultation contributed to the rationale, concept, principles and characteristics of GCW as well as the engagement of WMO Programmes and TCs, key partners from other agencies, institutes and organizations, and the scientific community who could contribute to the development and implementation of GCW. Pilot and demonstration projects were identified to test GCW implementation.

2.3.2 GCW Development and Implementation Phase (2012-2019)

The Development and Implementation Phase, undertaken between 2012 and 2019, will be led by the GCW Steering Group (GSG) and coordinated with WMO constituent bodies and partners. It will focus on developing and implementing GCW through tasks and activities described in this GCW Implementation Plan and in GCW workshop reports. This Implementation Plan (IP) is a living document and will be regularly reviewed and updated. Initial timelines and deliverables are given in the *Deliverables and Milestones* section.

2.3.3 GCW Operational Phase (2020 onward)

Once the framework is established, GCW enters its Operational Phase. It will continue to evolve to improve service delivery and support decision-making in response to the needs of users and technological opportunities.

3 IMPLEMENTATION

3.1 Conceptual Framework Overview

The framework, or conceptual model, for GCW is given in Figure 1. It illustrates the "why, what, and how" of GCW operation. GCW's governance will be integrated with WMO structures and interfaced with those of partner organizations. The GCW Steering Group (GSG) and Task Teams (TT) are central to GCW operations. The GCW Steering Group will provide high-level guidance on GCW development and implementation and will steer the activities of its Task Teams. The GSG currently reports to the WMO Executive Council through the Panel of Experts on Polar Observations, Research and Services (EC-PORS) and provides recommendations for GCW development and implementation for consideration by the WMO Executive Council and the WMO Congress. Task Teams are responsible for implementing the tasks identified in this implementation plan, in workshop reports, and by sponsors, partners, the scientific community, and users of GCW products and information. Regional groups will be formed where it will foster multi-national collaboration between Members with interests in the same region, e.g., in Asia for Third Pole issues and for the pan-Arctic for high latitude northern issues.

GCW data include basic measurements and higher-level products. The GCW Portal (http://gcw.met.no) is a web interface that contains information about datasets (metadata), but generally not the data themselves. Instead, it links to data that are stored at partner data centres and therefore functions as a catalogue. It is WIS compatible. Information and analysis products will be derived from surface and satellite observations, operational products, reanalyses, and research datasets. The GCW website (http://globalcryospherewatch.org) is the window to GCW, providing information on the program itself, activities, cryosphere news, products and information, observing networks and systems, guidelines and standards, and reference and outreach material such as a comprehensive cryosphere glossary. It is the key GCW outreach mechanism – it provides the "Watch" and complements the portal in supporting cryosphere services.

Collaboration and cooperation through partnership is essential. Cryospheric data, information, products and knowledge will be provided not only from National Meteorological and Hydrological Services (NMHSs), but also from national and international partner organizations, agencies, and the scientific community. National weather and ice services, space agencies, and research groups are critical to the development, implementation and success of GCW. They not only provide the basic observations for GCW, but also contribute the development of measurement practices, observational requirements, and product selection.

GCW will include an effective interface with the user community. Capacity building and training will be included in all aspects of the GCW framework.

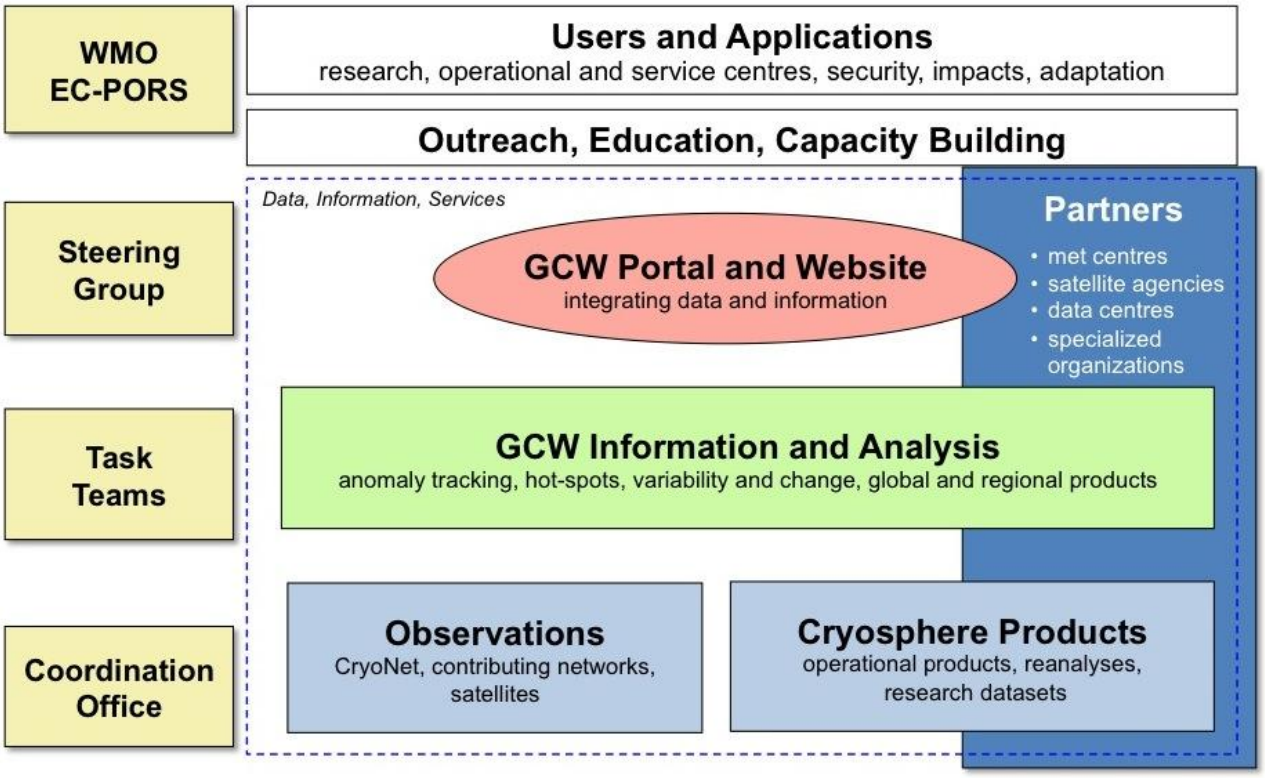


Figure 1: Conceptual Framework for GCW operation.

3.2 The GCW Steering Group (GSG) and Task Teams

3.2.1 GCW Steering Group

The GCW Steering Group (GSG) will provide high-level guidance on GCW implementation and further development. It will be concerned with process and general direction more than specific actions. It will establish GCW Task Teams, provide oversight of the Teams and provide guidance on the conduct of GCW Pilot and Demonstration Projects. The GSG is comprised of experts from EC-PORS, relevant WMO Programmes, TCs and co-sponsored programmes, and from partners and contributors. EC-PORS appoints its chair and vice-chair. The GSG reports to EC-PORS on GCW activities and provides recommendations for GCW development and implementation for consideration by the WMO Executive Council and the WMO Congress. The GSG liaises with GCW focal points as well as representatives of partner organizations and will provide annual reports to all stakeholders, as appropriate through GCW website and/or newsletter.

3.2.2 Task Teams

Three of the six GCW Task Teams address capabilities and needs for surface-based and satellite observations. These include the *CryoNet Team*, the *Requirements and Capabilities Team*, and the *Infrastructure and Practices Team*. The *Products Team*, the *Portal Team*, and the *Outreach Team* address products and services. They decide, in consultation with the Steering Group and all teams, which products and services GCW will provide. They facilitate the harmonization of products (e.g., multiple sea ice estimates), facilitate product intercomparisons, develop data policies for GCW, including data exchange by WMO Members, and work with the other teams to facilitate interaction between the operational and research communities.

Team members will be selected experts nominated by sponsors, partners and contributors to GCW. Teams and sub-groups may be joint working groups with GCW partners and contributors. Task teams, their scope, and activities will evolve as GCW moves toward the operational phase.

The *CryoNet Team* will be responsible for the establishment and subsequent operations of the core GCW surface-based observational network, called CryoNet. It will define the types of sites in cold climate regions, on land or sea, operating a sustained, standardized programme for observing and monitoring as many cryospheric variables as possible. The team will also develop a network strategy and formal procedures for becoming part of the GCW network, evaluate selected sites, and determine data availability. It develops relevant material to be included in the WMO Technical Regulations and in the WIGOS Manual. The GSG and EC-PORS consider their recommendations on selected sites, proposed and/or developed best practices for CryoNet stations, and associated data policy and data management practices, including archiving, data sharing and data exchange and interoperability arrangements. The *CryoNet Team* will specify a core set of measurements for each site type. An example for land sites where snow is the primary parameter is given in Appendix 1.

The *Infrastructure and Practices Team* will conduct an inventory of measurement methods and infrastructure at sites that measure components of the cryosphere. It will compile best practices, guidelines, and standards, facilitate instrument intercomparisons, and promote interaction and collaboration between the scientific and operational communities. This includes consideration of data homogeneity, interoperability, and compatibility of observations from all GCW observing and monitoring systems and derived cryospheric products.

The *Requirements and Capabilities Team* will assess user needs, periodically review and update observing system requirements and capabilities and contribute to the WMO Rolling Review of Requirements database and liaise with the Polar Space Task Group (PSTG). The team will engage with the user community to help determine which cryospheric data types are most important, to identify the spatial, temporal, and knowledge gaps, and to address other aspects of data usability such as error assessments and data formats. Users will be engaged through dedicated workshops and comprehensive surveys. Requirements may vary regionally.

The *Products Team* will identify key GCW datasets. This includes the development of an inventory of candidate in situ and satellite products for GCW that are mature (product quality) and generally accepted (credible) by the scientific community. The team will facilitate the harmonization of products (e.g., multiple sea ice estimates), facilitate product intercomparisons, and oversee development of data policies for GCW. The team will have sub-groups as required, including the *Snow Watch Group, Snow Data Access and Exchange Group* and *Terminology Group.*

The *Portal Team* is responsible for the ongoing development and operation of the GCW Portal and its Data Catalogue as well as the GCW information website. The Team will evaluate candidate products, including meteorological data, and prepare an initial plan for development including linking to data contributors, testing by partners, working with national focal points, and developing documentation for outside use. It will work through interoperability issues with data centres and other programmes.

The *Outreach Team* will be an authoritative voice on cryosphere issues, be available to speak to the media and policymakers, provide guidance for outreach products, facilitate training of students and early career scientists, work with social media (blogs, Facebook, Twitter), and issue semi-annual or annual newsletters. GCW will have numerous, diverse stakeholders both within WMO and with its partners. GCW will establish an effective communication, outreach and education strategy in collaboration with WMO Members, Programmes, RAs, TCs, co-sponsors and partners. It will take advantage of outreach programmes developed and effectively deployed through IPY and with organizations such as Association of Polar Early Career Scientists (APECS) and the Global Learning and Observations to Benefit the Environment program (GLOBE) program. A

variety of outreach materials will be developed to educate the general public, Members, funding agencies, and policy-makers on the cryosphere and its importance to society. Materials include posters and other educational material for elementary and high school classes, a GCW brochure, a semi-annual or annual, newsletter, an online photo and video library, and information on the current state of the cryosphere. Social media (Facebook, Twitter) will also be used.

3.3 WMO Members, Focal Points, Commissions, and Panels

Interested WMO Members have provided focal points for the development of GCW. The focal points are formally nominated by the Members' Permanent Representatives with WMO. There may be more than one per country. Focal points may be from outside the Member's National Meteorological and Hydrological Service (NMHS), recognizing that other bodies may have operational and/or research responsibilities for the cryosphere. The focal point(s) will liaise with the GCW Task Teams and regional groups. They will serve as the national contact(s) for, and contribute to, the development and implementation of GCW and its activities locally, nationally, regionally and globally. They will liaise with national bodies that have responsibilities for information, products and services related to the cryosphere, engage national representatives of international organizations partnering with GCW, identify national and regional cryosphere-related issues, needs and gaps, engage their WMO Regional Association, identify needs and opportunities for capacity building and resource mobilization. More information on focal point responsibilities is given in the *GCW Focal Points Terms of Reference* (see http://www.wmo.int/pages/prog/www/OSY/Reports/GCW-IM-1_FinalReport_rev1.pdf). To date over 30 countries from all WMO Regions identified contacts for the development and implementation of GCW.

GCW will engage WMO co-sponsored programmes, technical commissions (TCs), Regional Associations (RAs), inter-governmental bodies, and scientific bodies that have cryospheric interests and responsibilities. WMO's co-sponsored programmes are essential partners. WCRP/CliC coordinated the development of the GCW feasibility study and co-led with SCAR the development of the Integrated Global Observing Strategy Partnership (IGOS-P) Cryosphere Theme (hereinafter "CryOS"). The WMO-IOC-UNEP-ICSU Steering Committee for GCOS endorsed the creation of GCW as a mechanism for integrating cryospheric observations. Potential co-sponsorship of GCW is an option. Memorandum of understanding or agreements would have to be established among all sponsors, as appropriate.

3.4 Collaboration and Co-operation with Other International Programs

GCW is an initiative sponsored by WMO in which WMO and partners individually and collectively contribute to GCW's Mission and objectives. Collaboration, cooperation and commitment are essential to successful conduct of GCW activities at the international, regional and national levels. From the very beginning of GCW, partnerships were being developed, with government agencies and other institutions that measure, monitor, or archive cryosphere data and information from in-situ and satellite research and operational networks and model sources, and with international bodies and services involved in cryospheric observations, services, or research. These include, but are not limited to, the International Permafrost Association (IPA), the World Glacier Monitoring Service (WGMS), a service of the International Association of Cryospheric Sciences (IACS), the Scientific Committee for Antarctic Research (SCAR), the Global Precipitation Climatology Centre (GPCC), and the US National Snow and Ice Data Center (NSIDC). Additionally, international organizations, such as the International Council for Science (ICSU), the Intergovernmental Oceanographic Commission (IOC) and International Hydrological Programme (IHP) of UNESCO, and regional bodies such as the International Centre for Integrated Mountain Development (ICIMOD) are being engaged in the development and implementation of GCW.

EC-PORS has facilitated engagement of organizations with polar interests in the development of GCW. EC-PORS has members from the Arctic Monitoring and Assessment Programme (AMAP), the International Arctic Science Committee (IASC), and SCAR. Through the EC-PORS Antarctic Task Team, GCW has direct linkages to the Antarctic Treaty Consultative Meeting (ATCM). WMO's Polar Space Task Group (PSTG), which reports through EC-PORS, provides engagement of CEOS and major satellite operators like CSA, ESA, EUMETSAT, JAXA, NASA, and NOAA.

Programmes such as GCOS, GOOS and GTOS (the Global Climate, Ocean, and Terrestrial Observing Systems) have contributed to the development of GCW. GTOS and GCOS, currently through the Terrestrial Observations Panel for Climate (TOPC), guide the development of global terrestrial networks for climate (GTNs) and for permafrost, glaciers, hydrology, run-off, and lakes (GTN-P, GTN-G, GTN-H, GTN-R, GTN-L). GCW will work with the GCOS Secretariat, GCOS Panels and implementing bodies. The Joint WMO/IOC Technical Commission on Oceanography and Marine Meteorology (JCOMM), particularly through its Expert Team on Sea Ice and the Data Buoy Cooperation panel (DBCP) are contributing to the development of the sea ice observing component of GCW. Additional contributions on sea ice measurements and polar ocean observing systems will come from regional organizations such as the Arctic Ocean Science Board (AOSB), EuroGOOS, and the newly established Arctic GOOS Regional Alliance, and professional consortia like the International Ice Charting Working Group.

Examples of collaborative activities with these programmes and partners include:

- coordination of GCW development and implementation,
- compilation and development of manuals on best practices for cryospheric measurements and observation,
- coordinated observing, capacity building and training with their existing networks,
- development of community monitoring of the cryosphere,
- co-publication of glossaries of cryospheric vocabulary and terminology,
- development of satellite, in situ, and other product inventories relevant to GCW,
- joint intercomparison of products,
- development of regional GCW activities and fostering the transfer of research observations to operations, thereby ensuring sustainability,
- training and outreach in snow and ice measurement, and
- advising on outreach materials and methods.

GCW will not assume the mandate of any of its partners/collaborators and will avoid duplication of effort. Instead, GCW will enable partners/collaborators to exercise their mandate effectively. Close collaboration between research scientists and "practitioners", who are often scientists themselves but working in operational services, is one of the key aims of GCW. This can be facilitated by collaboration between GCW and its partners in addressing the above noted tasks.

Criteria for GCW partnership are given in Annex 3.

3.5 Observations

The core GCW surface-based observational network, called *CryoNet*, will be comprised of sites with varying capabilities. It will build on existing cryosphere observing programmes and promote the addition of standardized cryospheric observations to existing facilities in order to create more robust environmental observatories.

Three types of sites are envisioned, based on the number and type of cryosphere measurements, non-cryosphere measurements, and the length of record: "baseline", "reference", and "integrated" sites (Figure 2). The CryoNet Team determines the required capabilities for each type of site. Baseline and references sites generally only measure properties of the cryosphere, though basic

surface meteorology might be included. Reference sites have a long-term (at least 10 years) record. Integrated sites are, in the context of GCW, generally single sites that measure a robust set of cryosphere, atmosphere, and/or ocean characteristics, depending on the location. They may, however, be comprised of multiple sites in a homogenous region. They are particularly important for the study of feedbacks and complex interactions between the atmosphere, cryosphere, biosphere and ocean.

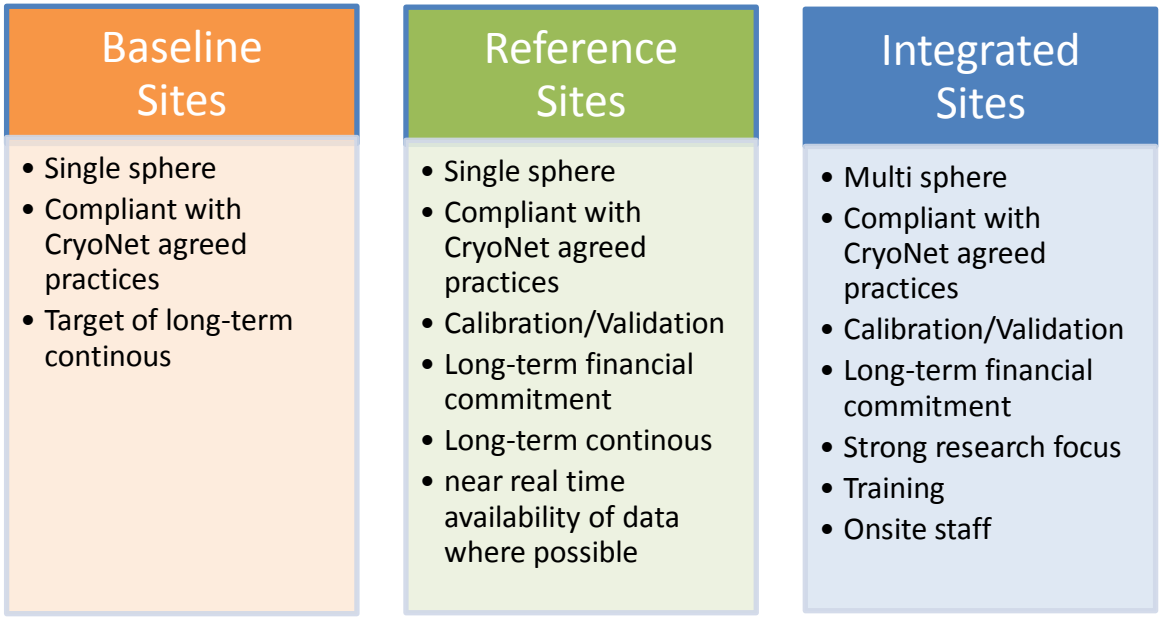


Figure 2: Properties of the different CryoNet site types.

As encouraged by GCOS, GCW will facilitate the establishment of high-latitude sites with co-located measurements of key variables, especially permafrost and snow cover, thus enhancing GCOS/GTOS Networks for Permafrost (GTN-P), Glaciers (-G) and Hydrology (-H) and including the measurements of solid precipitation. GAW stations and WCRP/Coordinated Energy and Water Cycle Observations Project (CEOP) reference sites in cold climates are potential candidates. Community monitoring also offers new network opportunities for GCW.

Members, through their GCW focal points, and participants in CryoNet workshops have recommended potential sites. Many Members have proposed contributing to GCW through their sites in China, Finland, the US, Austria, and Asia. For example, China has established supersites in the “Third Pole” region where the High Asian cryosphere (HAC) serves as the Asian “water tower” for over a billion people. Finland has the Sodankylä-Pallas site in the boreal forest. Its infrastructure is designed for integrated monitoring of soil-snow-vegetation-atmosphere interaction and provides reference measurements for satellite sensors and model development on a continuous basis. Some of the atmospheric observatory sites operated by the International Arctic Systems for Observing the Atmosphere (IASOA) program are being expanded to include measurements of surface properties, including permafrost, making them ideal for inclusion in CryoNet. Current IASOA member observatories include Barrow-U.S., Eureka and Alert-Canada, Summit-Greenland, Ny-Alesund-Norway, Abisko-Sweden, Pallas and Sodankylä-Finland, Tiksi and Cherski-Russia, and the Arctic Drifting Station-Russia.

GCW will drive performance and provide motivation for high quality observations. Being a CryoNet site means being part of an international, operational, global observing system and thus providing observations of known quality for research and knowledge beyond a site’s local region.

Satellite agencies, particularly through the WMO Polar Space Task Group (PSTG), and modelling groups such as ECMWF will provide guidance in the development of the surface observing network, given the importance of in situ observations for the validation of satellite products and model parameterization.

3.6 Products

The *Products Team* will encourage and support, where possible, workshops for intercomparisons of similar products to assess quality and to ensure the authoritative basis for products. For example, as a direct outcome of a recommendation of the First GCW Snow Watch Workshop, ESA has offered to organize and support a *"Satellite Snow Products intercomparison and evaluation EXercise – SnowPEX*" project to be carried out by a team of international experts. The project will intercompare and validate current global/hemispheric satellite snow products for assessing their quality and for better quantifying the uncertainty of long term trends of the seasonal snow pack deduced from satellite data.

Such activities complement some intercomparisons conducted previously. The WCRP/SCAR/IASC Climate and Cryosphere Project (CliC) sponsored a workshop on the evaluation of satellite-derived sea ice extent and concentration products. This task was identified as a pilot project in the initial GCW feasibility study. The results of the intercomparison will provide valuable information to GCW on the many available products and on the process for determining "authoritative" information. Similarly, the WCRP Observation and Assimilation Panel (WOAP) held a workshop on essential climate variables (ECVs), where it was proposed to create an inventory of satellite and in situ ECV products with information on product maturity, accuracy, users, applications, and adherence to the GCOS guidelines for ECV datasets. Efforts such as these are important steps in enhancing product usability.

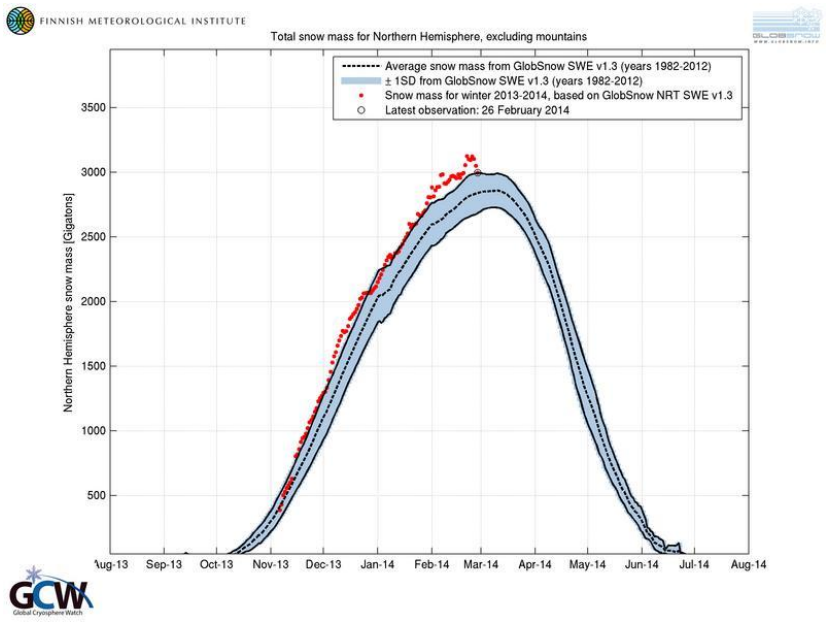


Figure 3: Example of a product for monitoring snow water equivalent. (GCW/FMI)

High-level monitoring products will complement the more basic observational datasets provided by GCW and its partners. The *Snow Watch Group* has stimulated the development of new daily "trackers" for Northern Hemisphere snow extent and snow water equivalent. Snow trackers have

been developed for GCW by the Finnish Meteorological Institute and by Environment Canada. Figure 3 shows the GCW/FMI tracker for snow mass over the Northern Hemisphere (excluding mountains). All products are available in near real-time on the GCW website. Satellite, in-situ and operational NWP analyses contribute to the development of these snow products.

For satellite products, the Polar Space Task Group of EC-PORS, with its direct connection to Space Agencies, will work with GCW to identify new products to support GCW pilot projects and services.

3.7 Data Portal and Website

GCW data and information are available to WMO Members, their partners, and users through two components (Figure 4). One component, the GCW information website, provides project information, near real-time graphics illustrating the state of the cryosphere, scientific assessments, cryosphere news, observational requirements, measurement standards, and documents. The other component is the data portal (http://gcw.met.no) and its Data Catalogue. The main purposes of the Data Catalogue are (a) to provide an overview of datasets relevant to GCW (b) to provide access to datasets wherever possible (e.g. real time data streams, archive access), (c) to connect GCW with WMO Information System (WIS) and (d) to provide distributed Data Management (e.g. metadata driven, currently not hosting data).

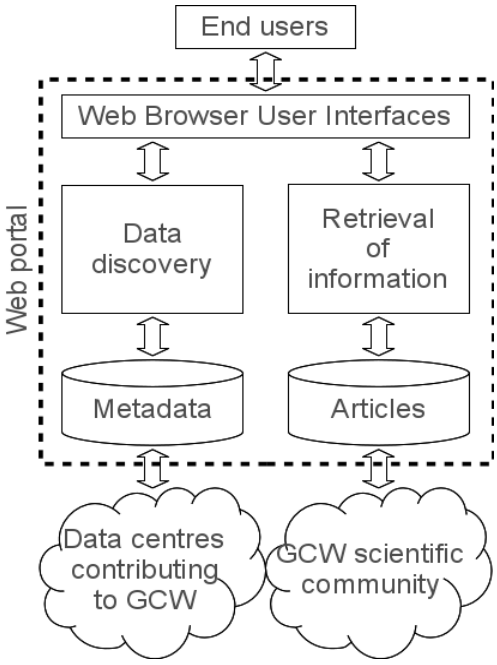


Figure 4: The GCW web portal has two components. One addresses editorial information (right) and the other addresses datasets (left).

The data management component is in part an enabling service for the information component in the sense that it identifies relevant datasets and their location and provides an interface that can be utilized in the evaluation or description of GCW data and products.

GCW data management will integrate cryospheric datasets at national, regional and global scales. It will provide access to data and information on past, present and future cryospheric conditions. In order to achieve this, the data portal needs to be attached to real-time and near real-time data management systems and to data archives. While interfacing with existing data management

systems, GCW will respect partnership, ownership, and data-sharing policies of its partners. As a consequence, the functionality implemented through the GCW web portal will allow new types of information to be widely distributed, such as real-time cryospheric “hot news” (e.g. extremes, physical or socio-economic impacts, and new research results).

GCW itself will produce few low-level datasets, but instead relies on distributed data management technologies and partners to establish the GCW catalogue, which will publish WIS-compliant descriptions of GCW data and products into WMO’s Global Information System Centers (GISCs) catalogues. This will create a unified interface to datasets in an otherwise fragmented terrain. No data will be kept in the GCW catalogue without an agreement with the data producer. GCW data management follows a metadata-driven approach where datasets are described through metadata exchanged between contributing data centers and the GCW catalogue.

The ingested metadata will be harvested from project specific, national and international catalogues. In addition to harvesting existing catalogues, the data management part of the GCW portal will facilitate forms for submission of metadata on datasets not handled by existing catalogues. Currently only a limited number of catalogues are integrated, but dialogues on integration have been established with a number of catalogues (Figure 5). Quite frequently this involves some degree of adaptation of systems on either side in this exchange of metadata.

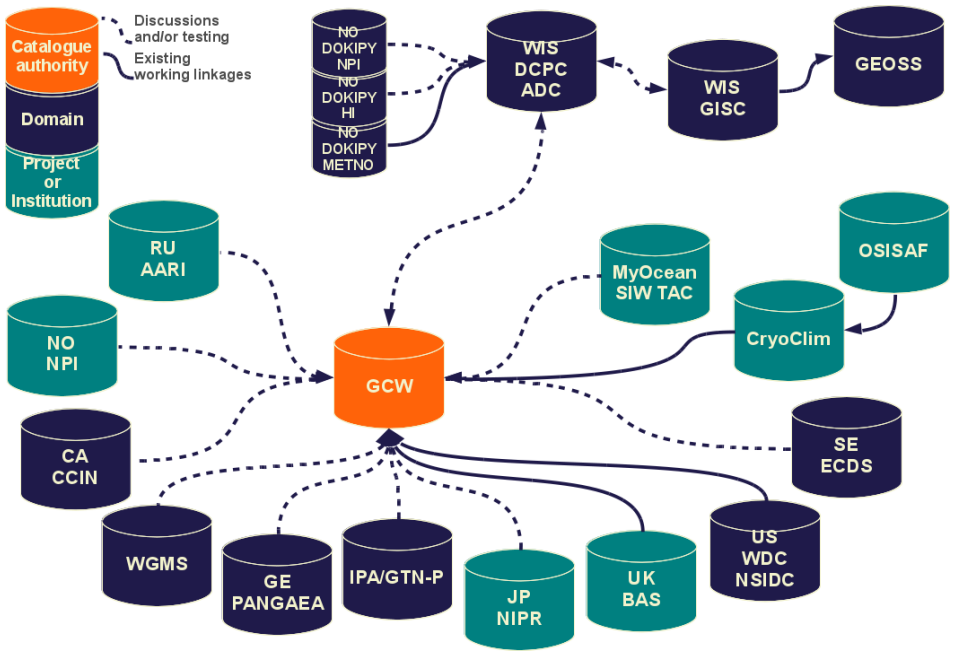


Figure 5: Data centers being addressed within GCW data management currently or in the short term. Solid lines indicate existing linkages; dashed lines indicate ongoing discussions and/or testing.

There are technological considerations for catalogue interoperability, involving exposing metadata using standard interoperability interfaces and documentation standards (e.g. OAI-PMH, OGC CSW, ISO23950, ISO19115, GCMD DIF). There are relevant frameworks for catalogue interoperability including WMO Information System (WIS), ICSU World Data System (WDS), Group on Earth Observation (GEO).

The GCW web portal has been developed by the Norwegian Meteorological Institute (METNO), building on their web-based tool for searching data. IPY data centres/portals, such as METNO, Canadian Cryosphere Information Network (CCIN), British Antarctic Survey (BAS), and US

National Snow and Ice Data Centre (NSIDC) are already interoperable. This approach will facilitate seamless access with NMHSs and external data centres holding relevant cryospheric data and information at the national or global scale.

The GCW information website has been developed and implemented (http://globalcryospherewatch.org, Figure 6). The purpose of the website is to provide a centralized point of access for background and operational information, observational user requirements, the state of the cryosphere, news and "hot topics", meeting information, GCW documents, outreach material, a description of the contributing observing networks and their capabilities, information on standards and best practices, and data policies. It links to the METNO data portal. The website is an information resource; the portal is a metadata and data resource.

Figure 6: GCW website homepage.

3.8 Other Tasks and Projects

The Integrated Global Observing Strategy Partnership (IGOS-P) Cryosphere Theme (CryOS) provides a framework for developing and implementing GCW. Developed through widespread consultation within the global cryosphere community, it details observational capabilities and requirements and gives recommendations for filling gaps. It proposes measures to develop and coordinate cryospheric components of WIGOS, GCOS/GOOS/GTOS and other systems, so that cryospheric products will meet most user requirements within approximately 10-15 years.

GCW will directly address some CryOS recommendations. These include, but are not limited to, the revision of observational requirements, further development of measurement methods, and the compilation of a consistent, multi-language cryosphere glossary.

3.8.1 Observational Requirements

Observational requirements and capabilities will be periodically updated based on evolving user needs, instrumentation, and error analyses. GCW observational requirements will be formulated based on various sets of existing user requirements. In particular, the IGOS Cryosphere Theme Report contains the most comprehensive set of observational capabilities and requirements for the cryosphere. It is available at http://igos-cryosphere.org/.

GCW observational requirements will become part of the WMO Rolling Review of Requirements (RRR) and will be accessible through the WMO's Observing Systems Capability Analysis and Review Tool (OSCAR). A cryosphere theme has been created in the RRR. The RRR is specified in the Manual on the Global Observing System (WMO-No.544), elaborated in the Guide to the Global Observing System (WMO-No. 488), and described further on the WMO website at http://www.wmo.int/pages/prog/www/OSY/GOS-RRR.html.

GCW will also promote the use of observing system simulation experiments (OSSE) to evaluate gaps in the spatial distribution of measurement sites. Optimizing an observing network requires the use of numerical models to establish observing priorities and identify gaps.

3.8.2 Measurement Practices

The *Infrastructure and Practices Team* will review existing instrument and observing methods and practices for the cryosphere in the *Guide to Meteorological Instruments and Methods of Observation* (CIMO Guide), and consider whether the CIMO Guide should be expanded to include instruments for the cryosphere. GCW partners have, or are in the process of developing, specific manuals for components of the cryosphere. The *Infrastructure and Practices Team* will develop a similar compilation of other existing documents on best practices, guidelines and standards that are in use in the cryosphere community. A *GCW Manual* will provide a consolidated document complementing current material in the *WIGOS Manual*, the CIMO Guide and partner's manuals. All standard practices will be documented in the *WMO Technical Regulations*.

Formal instrument intercomparisons should be conducted to determine and intercompare performance characteristics of instruments under field or laboratory conditions and to link readings of different instruments, helping to ensure data compatibility and homogeneity. The current WMO Solid Precipitation Intercomparison Experiment (SPICE) (including snowfall and snow depth) is of direct relevance to GCW and is a demonstration project for GCW. It provides an excellent example of the process to conduct a formal instrument field intercomparison for use by Members and the science community. GCW integrated CryoNet sites could also be suitable instrument intercomparison sites.

3.8.3 Terminology

The *Products Team* has a *Terminology Group* that will identify current cryosphere glossaries and develop and evaluate terminologies, vocabularies, and ontologies. It has focus areas for snow, sea ice, ice sheets, glaciers, permafrost, and climate modelling. The GCW glossary currently on the website has over 2100 cryosphere terms from several different sources, including WMO's METEOTERM database. Expert teams will oversee the population and acceptance of terms. Ultimately, with the help of Members, the goal would be to make the glossary available in other UN languages.

3.8.4 Other

Other GCW projects will focus on regional or national contributions to standardization, integration and interoperability. Projects will involve contributions of WMO Members, Programmes and TCs, and contributing partners. Projects that contribute to demonstrating GCW's operation include:

(a) CIMO's Solid Precipitation InterComparison Experiment (SPICE) including snowfall, and snow depth measurements;
(b) Norway's CryoClim initiative to develop new operational services for long-term systematic climate monitoring of the cryosphere;
(c) ESA's "Global Monitoring of Essential Climate Variables" programme (Climate Change Initiative) for the cryosphere;
(d) Services provided by the World Glacier Monitoring Service (WGMS), University of Zurich, Switzerland, which is operated under the auspices of the International Council for Science World Data System (ICSU/WDS), International Association of Cryospheric Sciences of the International Union of Geodesy and Geophysics (IUGG/IACS), UNEP, UNESCO and WMO;
(e) Activities of the Nordic Centre of Excellence (NCoE): SVALI - Stability and Variations of Arctic Land Ice;
(f) USGS Benchmark Glacier Programme and the IPY Data and Information Service (IPYDIS) global partnership of data centres, archives, and networks creating interoperability between cryosphere data centres in Norway, USA, Canada and the UK;
(g) Svalbard Integrated Arctic Earth Observing System (SIOS), a Norwegian-initiated project to create an international research infrastructure on the Svalbard archipelago; SIOS will develop and implement methods for building observational networks;
(h) Canadian Cryosphere Information Network (CCIN), which also supports the Polar Data Catalogue;
(i) ECMWF's initiative to improve global weather and climate predictions through improved snow processes, modelling and reanalysis, and assimilation of non-real-time snow depth data.

GCW will build on existing programmes and projects, but additional pilot and demonstration projects should be established in different regions, including alpine areas, central Asia (notably the "Third Pole"), the tropics, and Antarctica.

3.9 Prioritization of Tasks

Tasks will be prioritized based on meetings with partners and the cryosphere community, regional and international cryosphere conferences and workshops, and Task Team meetings and workshops. The tasks will be discussed with the Steering Group to determine priorities and budget allocation. For example, the First GCW Implementation Meeting (November 2011, Geneva) was effectively a meeting of an ad hoc GCW community of practice. Near-term tasks were suggested, discussed, and prioritized. Similarly, tasks for the surface network and for snow products were prioritized in the First CryoNet workshop (November 2012, Vienna) and the First Snow Watch Workshop (Toronto, January 2013). Workshops such as these are needed on an ongoing basis to provide guidance on GCW development and implementation.

3.10 Capacity Building

GCW must develop an effective capacity building strategy. A coordinated capacity building effort should respond to the needs at national and regional levels, as identified by Members, which would assist all countries in improving and sustaining observation and exchange of cryospheric data and information. For developing and the least developed countries there is a need to ensure access to, and effective utilization of, observations, data and products, related technologies and new knowledge. For example, information on potential sea level rise, loss of mountain snow and ice, including tropical glaciers, and improved understanding of the impact of cryospheric changes

in the Antarctic on extreme weather and climate in tropical and sub-tropical regions has been identified by Members as a need to which GCW can contribute.

Human resources are critical to the success of the program. GCW will continue to explore ways to entrain new expertise into the program as part of its capacity building effort.

Capacity building will be coordinated with existing WMO efforts and will take advantage of mechanisms established by WIGOS and other WMO Programmes, RAs, TCs, and GCW partners.

4 DELIVERABLES AND MILESTONES

Upon approval and within available resources, GCW will address tasks associated with the key deliverables and milestones. Figure 7 shows the key milestones and timelines. The aim is to begin to implement tasks now, recognizing the complexity of engaging NMHSs and their national partner agencies, national and international institutes, and the scientific community.

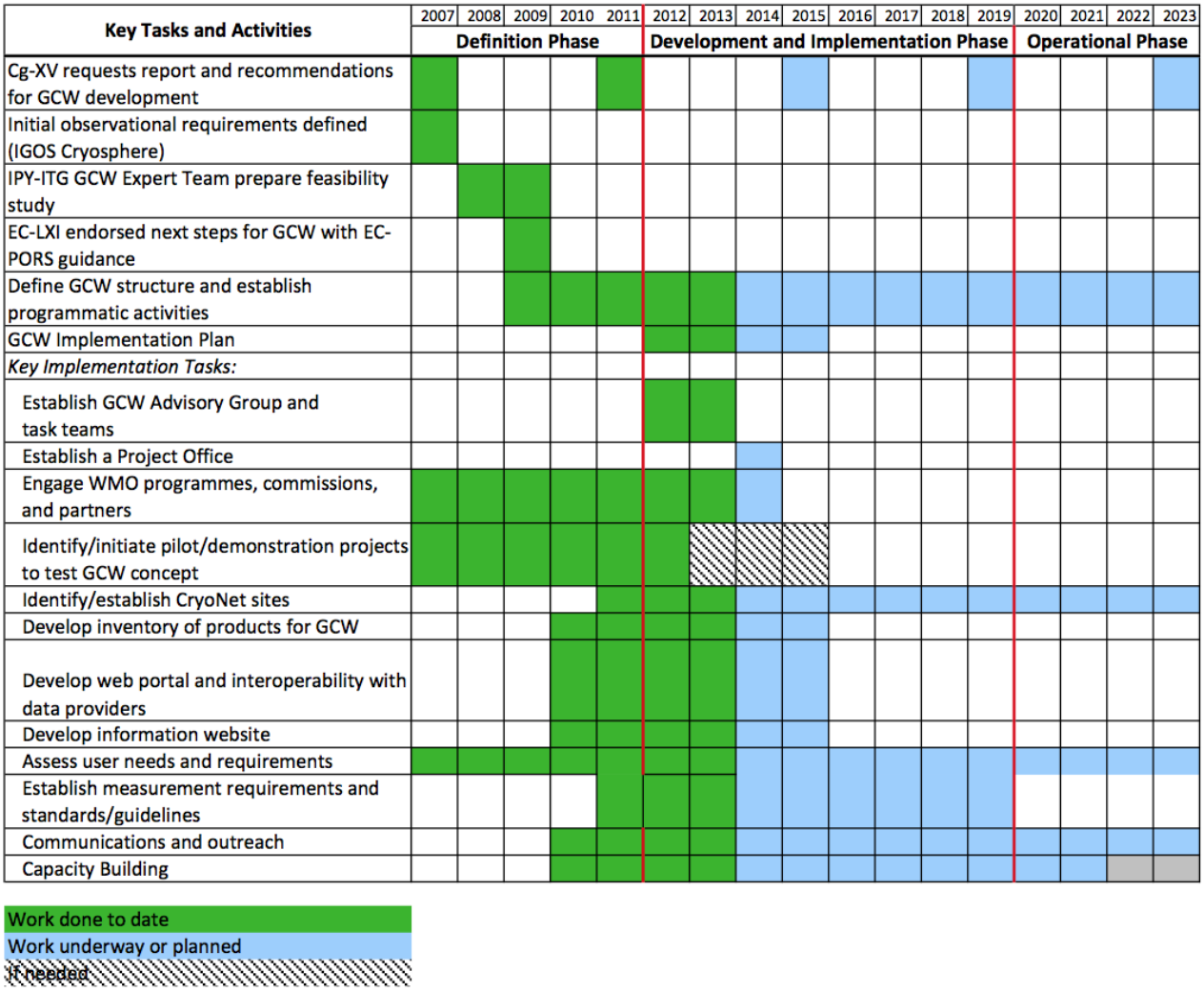


Figure 7: GCW Milestones and Deliverables as agreed by Cg-XVI.

Key implementation activities are given in Table 1. Some of these were described earlier in this Plan. The responsible GCW Task Teams and relevant outside groups that are expected to contribute (data centres, national agencies, etc.) are listed. The approximate implementation timeframe for each activity is also given.

Table 1. Key GCW Implementation Activities

(Global activities shaded yellow, regional shaded green, national shaded grey)

Task #	Activities	Responsibilities		Time Frame
		Lead	Other Stakeholders	
1. Governance				
1.1	Create GCW Steering Group (GSG)	EC-PORS	-	2014
1.2	Establish Task Teams	GSG	-	2013-2014
1.3	Establish national GCW groups	Members	-	2014-2015
1.4	Define a GCW WMO Programme	EC-PORS, GSGG	-	Before Cg-XVII
1.5	Annual assessment of progress (indicators of success)	GSG	Task Teams	Annually
1.6	Integrate GCW objectives into WMO SOP 2016-2019	EC-PORS, Secretariat, GSG		2014-2015
2. Observing System and Products				
2.1	Select appropriate CryOS recommendations for GCW implementation	GSG, TT	-	2012
2.2	Initiate pilot and demonstration projects	Teams	Members	2012-2016
2.3	Create an inventory of the current network and measurement practices	Infrastructure and Practices Team	NMHSs, research partners	2012-2015
2.4	Establish a network of surface sites (CryoNet)	CryoNet Team	NMHSs, research institutions	2012 onward
2.5	Select candidate products for GCW	Products Team	Focal Points	2012-onward
2.5.1	Perform satellite and in situ product intercomparisons	Products Team	PSTG, Focal Points, NMHSs	2014-onward
2.5.2	Historical data sets (data rescue; e.g., snow depth)	Products Team	NMHSs, data centres	2014-onward
2.6	Develop and implement data portal	Portal Team	MetNo, NSIDC	2012-onward
2.7	Asess user needs and requirements; contribute to RRR	Requirements & Capabilities Team	NMHSs	2012-2015
2.8	Establish best practices and measurement standards	Infrastructure and Practices Team	NMHSs	2012-onward
2.9	Evaluate existing terminologies or glossaries; create or update as necessary	Products Team	Members, UNESCO, research partners	2013-onward
2.10	Annual State of the Cryosphere assessments	Products Team	-	Annually
3. Capacity Building				
3.1	Provide assistance to Members to introduce and implement GCW nationally			Ongoing
3.2	Develop GCW guidelines, training materials, and other relevant documentation			Ongoing
3.3	Develop partnerships with NMHs and international bodies.		NMHSs, international bodies such as IPA, GCOS, IASC, etc.	Ongoing
4. Outreach				
4.1	Develop information website	Portal Team, Outreach Team	-	2012-2013
4.2	Create outreach materials (handouts, brochure, newsletter, etc.)	Outreach Team	-	2012-2015

5 GCW MANAGEMENT AND OVERSIGHT

GCW requires cooperation, collaboration and coordination within WMO and with external partners, for which working arrangements between WMO and partners would be established.

5.1 Oversight

The WMO Executive Council, through its EC-PORS, will oversee GCW's development and implementation, recognizing that the structure of the Secretariat will have to adapt, as and when appropriate, to ensure optimal management of, and support to, the initiative. The GCW Steering Group provides high-level guidance and reports to EC-PORS on behalf of GCW.

5.2 GCW Project Office

A GCW Project Office is to support all GCW activities, including coordination with partners, monitoring of implementation, reporting and follow-up actions. It will provide support to national focal points and activities and will liaise with WMO and external programs and groups. The Secretariat should co-ordinate GCW inclusion in existing observing activities at the international and national levels and align its processes with their activities and frameworks. The Secretariat shall also pursue active linkages with WMO Programmes and with relevant international organizations. Some suggested tasks that the Secretariat could oversee, depending on available human resources are:

- Make available all relevant information to the GCW Steering Group, Task Teams, focal points, and GCW members
- Obtain, in coordination with Focal Points, nomination of national contacts from IASC, IACS, WGMS, IPA, SCAR, and others
- Periodically inform PRs on GCW activities and request nomination of focal points, as appropriate
- Support Focal Points in the development of national GCW activities
- Liaise with WMO on capacity building, resource mobilization, communication
- Liaise with UNESCO
- Liaise with WIGOS/WIS and GFCS teams, as needed
- Seek funding opportunities
- Maintain the Implementation Plan (with assistance from teams)
- Provide financial guidance and co-ordination
- Seek WMO and other support for GCW meetings, as appropriate
- Provide travel arrangements and support for GCW meetings, as needed

The Secretariat shall report on GCW activities to the Steering Group and to EC-PORS annually.
Several options were considered for coordination of GCW activities following a decision of Cg-XVI in 2011 to develop GCW. To this point, no offer has been received to host the Project Office or to support it through the seconded experts working remotely. Taking into account the cost involved in establishing support for GCW as soon as possible, it is recommended that GCW activities be coordinated by a Project Officer located in the WMO Headquarters in Geneva.

5.3 Meetings and Reporting

The GCW Steering Group shall report annually to EC-PORS, including recommendations for GCW development and implementation for consideration by the WMO Executive Council and the WMO

Congress, and provide annual reports to all stakeholders, as appropriate thorough GCW website and/or Newsletter. EC-PORS will provide guidance on GCW structure, tasks, and progress.

Implementation meetings will be held regularly (e.g. every two years based on consultations with partners) and possibly in conjunction with other international or regional meetings such as Regional Climate Outlook Forums or partner scientific conferences. The implementation meetings will include participants from a broad cross-section of the cryosphere community as well as national, institutional, and program focal points. All aspects of GCW implementation will be evaluated.

Workshops on various aspects of implementation, such as CryoNet development and product intercomparisons, will be held as needed. GCW task team members will participate in Polar Space Task Group, GCOS Steering Committee, and other relevant group meetings.

5.4 Indicators of Success

Metrics that could be used to evaluate the success of GCW include:

CryoNet:

1. Total number of sites in the network and the proportions of site types
2. Number of sites measuring each of the core set of measurements
3. Number of sites measuring cryospheric variables beyond the core set

Products:

4. Number of cryospheric “trackers”
5. Number of satellite products by cryospheric element
6. Satellite product inventory (percent complete)

Portal and website

7. Interoperability (number of data centres and/or percent complete)
8. Number of products available through the Portal
9. Number of near real-time products on website (all sources)
10. Number of users

Outreach and communication

11. Glossary development (percent complete)
12. Number of educational materials
13. Social media “friends”

Resources

14. Financial commitments by Members
15. Political and personnel commitments by Members

Other

16. Updates to RRR for observational requirements
17. Number of CryOS recommendations that have been implemented

6 RESOURCES

6.1 Funding

The successful launch of GCW depends directly on the availability of resources. Support of the definition phase has been through funding by Members to the GCW and EC-PORS Trust Funds (namely, part-time temporary staff and consultative meetings), supplemented by in-kind

contribution from Members for technical expertise. The Sixteenth WMO Congress approved basic support from the WMO regular budget.

However, additional resources will need to be provided through the WMO Secretariat for both staff and non-staff costs for the implementation and coordination that goes beyond the programmatic activities of the Secretariat to date. One full staff position, as a minimum, would be needed in the WMO Secretariat for GCW implementation activities. The GCW secretariat and operational budget require a core allocation from the regular WMO budget, with targeted funds from other sources including:

- GCW and EC-PORS Trust Funds to supplement the WMO regular budget;
- In-kind contributions, e.g. Task Office/activity funded by a Member(s);
- Staff secondments;
- Project Compendium that includes a request for GCW funding from voluntary contributions, seeking contributions totalling CHF2.4M for implementation of EC-PORS activities over four years, including GCW to support the Steering Group and expert teams in implementing GCW and provide some Secretariat support for GCW development, coordination and implementation.

7 REFERENCES

1. Resolution 60 (Cg-XVI) – Global Cryosphere Watch
2. IGOS, 2007. Integrated Global Observing Strategy Cryosphere Theme Report - For the Monitoring of our Environment from Space and from Earth. Geneva: World Meteorological Organization. WMO/TD-No. 1405. 100 pp.

APPENDIX 1: EXAMPLE OF MEASUREMENTS AT SURFACE LAND SITES

Examples of measurements made at sites where snow is the primary cryospheric element are given below. Glacier, ice sheet, permafrost, and sea ice sites will have different measurement requirements.

Example of measurements made at an integrated Site

Continuous automatic observations of the atmosphere at one or more locations

- Automatic synoptic weather station observations (including temperature 2 m, temperature ground, dew point temperature, air pressure, air relative humidity, wind speed, wind direction, precipitation, cloud height, amount of clouds, visibility, snow depth, prevailing weather code)
- Radiation observations (incoming and reflected)
- Precipitation
- Atmospheric soundings (troposphere and stratosphere)
- CO_2 and/or methane fluxes between the atmosphere and soil-vegetation system (preferably for different ecosystems)
- Water table depth on wetlands
- Aerosol optical depth
- Energy fluxes (sensible, latent and soil heat), evaporation/transpiration and soil respiration.
- Specific reference measurements for cryosphere monitoring satellite instruments

Regular manual observations of snow

- SWE and snow depth on snow pits (forest and bog sites)
- Snowpack layering and snow grain size on snow pits (visible snow grain size observations/photography and/or specific surface area (SSA) measurements)
- Soil frost depth
- Snow surveys (snow courses with a preferable length of some kilometers)

Continuous automatic observations of snow, soil, and permafrost at one or more locations

- Soil moisture profiles
- Soil temperature/soil frost profiles
- Snow depth and/or SWE
- Snow temperature profiles

Example of measurements made at a reference or baseline site

Continuous automatic data

- Soil moisture profiles
- Soil temperature/soil frost profiles
- Snow depth and SWE
- Snow temperature profiles
- Automatic synoptic weather station observations

Regular manual observations

- SWE and snow depth on snow pits (forest and bog sites)
- Snowpack layering and snow grain size on snow pits (visible snow grain size observations)
- Snow surveys (snow courses with a preferable length of some kilometers).

APPENDIX 2: LIST OF ACRONYMS

APECS	Association of Polar Early Career Scientists
Arctic-HYDRA	Arctic Hydrological Cycle Monitoring, Modelling and Assessment Program
BAS	British Antarctic Survey
CAS	WMO Commission for Atmospheric Sciences
CBS	WMO Commission for Basic Systems
Cg	WMO Congress
CEOP	Coordinated Energy and Water Cycle Observations Project
CHy	WMO Commission for Hydrology
CliC	Climate and Cryosphere Project
CryOS	Cryosphere Observing System, generally referring to the IGOS Cryosphere Theme
EC	WMO Executive Council
ECV	Essential Climate Variable
ESA	European Space Agency
GCOS	Global Climate Observing System
GAW	Global Atmosphere Watch
GCW	Global Cryosphere Watch
GEOSS	Global Earth Observation System of Systems
GFCS	Global Framework for Climate Services
GIPPS	Global Integrated Polar Prediction System
GLOBE	Global Learning and Observations to Benefit the Environment program
GOOS	Global Ocean Observing System
GSG	GCW Steering Group
GTN-G	Global Terrestrial Network for Glaciers
GTN-H	Global Terrestrial Network for Hydrology
GTN-P	Global Terrestrial Network for Permafrost
GTOS	Global Terrestrial Observing System
IACS	International Association of Cryospheric Sciences
iAOOS	The Integrated Arctic Ocean Observing System
IASSA	International Arctic Social Sciences Association
IASC	International Arctic Science Committee
ICSU	International Council for Science
IGOS-P	Integrated Global Observing Strategy – Partners
IICWG	International Ice Chart Working Group
IOC	Intergovernmental Oceanographic Commission
IPA	International Permafrost Association
IPY	International Polar Year 2007-2008
IUGG	International Union of Geodesy and Geophysics
JCOMM	Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology
NOAA	National Oceanic and Atmospheric Administration (USA)
NMHS	National Meteorological and Hydrological Service
NSIDC	National Snow and Ice Data Center (USA)
PCOF	Polar Climate Outlook Forum
PR	Permanent Representative
PSTG	WMO Polar Space Task Group
SAON	Sustaining Arctic Observing Networks
SCAR	Scientific Committee on Antarctic Research
SOOS	Southern Ocean Observing System
SSA	Specific Surface Area
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WOAP	WCRP Observation and Assimilation Panel
WCRP	World Climate Research Programme

WDS	World Data System of ICSU
WGMS	World Glacier Monitoring Service
WIGOS	WMO Integrated Global Observing System
WIS	WMO Information System
WMO	World Meteorological Organization

ANNEX 1: WMO DECISIONS ON GCW

Cg-XV (2007) welcomed the proposal of Canada that WMO would create a Global Cryosphere Watch, which would be an important component of the International Polar Year 2007-2008 (IPY) legacy and requested the WMO Inter-commission Task Group on IPY to establish an *ad-hoc* expert group to explore the possibility of such a global system and prepare recommendations for its development.

Several experts were involved in the preparation of the Feasibility Study "Global Cryosphere Watch: Background, Concept, Status, Next Steps" that formed a basis for the Report on "Global Cryosphere Watch (GCW): Background, Concept, Status, Next Steps" submitted to EC-LXI for information. This study was based on the Integrated Global Observing Strategy Partnership (IGOS-P) Cryosphere Theme (hereinafter "CryOS"). EC-LXI endorsed the next steps for developing GCW based on the report's suggestions and requested EC-PORS to provide guidance and momentum for the implementation of GCW.

EC-LXII, noting the ever-increasing interest in the cryosphere globally and the requirement for authoritative information, agreed that the GCW initiative was even more timely and that there was an urgency to move forward with an implementation strategy to be developed under the auspices of EC-PORS and submitted to Cg-XVI for consideration. The Council strongly urged Members to support GCW activities, including the provision of support for meetings and workshops, and contributions to the GCW Trust Fund to provide secretariat support for the development of GCW.

Cg-XVI (2011) approved the GCW Implementation Strategy, urging Members and international partner organizations and programmes to collaborate actively in, and give all possible support to, the development and implementation of this initiative, and to support GCW. Congress requested the Executive Council to establish a mechanism to steer and monitor the activity and to achieve the broadest possible collaboration and cooperation, to ensure the active participation and representation of the principal bodies concerned and also the participation, as appropriate, of technical experts and representatives of agencies undertaking observing and research initiatives relevant to the cryosphere, and to submit a comprehensive report including an updated implementation plan of GCW to the Seventeenth WMO Congress.

GCW and the WMO Strategic Plan

The cryosphere, by its nature, is intrinsically interdisciplinary. In the context of the WMO Strategic Plan 2012-2015, GCW is a crosscutting activity contributing to all five priority areas and to achieving the expected results of all Strategic Thrusts. It cuts across all the WMO technical departments (Observing and Information Systems, Research, Climate and Water, Weather and Disaster Risk Reduction Services), joint sponsored activities (e.g. WCRP, GCOS) and WMO TCs. GCW will:

- Enhance capabilities to produce better climate predictions and assessments, hydrological forecasts and assessments, weather forecasts and warnings;
- Provide the mechanism to integrate the atmospheric, terrestrial (including hydrology) and marine cryosphere Essential Climate Variables (ECVs) within GCOS;
- Coordinate cryospheric observations of WMO and other agencies and organizations;
- Be built as a part of the WIGOS and WIS.

ANNEX 2: CRYOSPHERE OBSERVING SYSTEM GAPS

While there are numerous snow and ice surface measurement sites across the Arctic, Antarctic and high-altitude alpine regions, the spatial coverage is sparse compared to lower latitudes. Furthermore, operations at existing stations are, in general, not well coordinated. There is a need to improve the coordination of resources provided by national and international agencies responsible for cryospheric observations, and to facilitate the transition of research-based products into sustained monitoring systems. There is also a need to standardize the types and methods of measurements at surface stations, so that a consistent set of snow and ice properties is available globally.

The satellite observing system for the cryosphere is robust, and missions planned for the next 10-20 years will provide even greater capabilities. There are, however, some potential gaps that will be detrimental to long-term monitoring. In particular, the current gap in laser altimetry and the potential near-future gap in gravity measurements will impact ice sheet and glacier monitoring and change assessment. Even for systems that are robust, such as passive microwave, there needs to be long-range planning to assure continuous coverage and overlapping operational periods for sensors to assure inter-satellite calibration, which is crucial for high-quality climate records. Additionally, there are some critical parameters that are difficult to measure from space, notably sea ice thickness, snow water equivalent, and accumulation on glaciers, ice sheets, and sea ice.

Table A2.1 provides a summary of the observing system for many snow and ice properties and a qualitative assessment of their maturity. It lists the measurement approach for the major variables, the status of the networks (operational or research), a qualitative assessment of how well each is meeting the measurement requirements, and major issues. Airborne measurements are not addressed. There are many shortcomings in the cryosphere observing system that give rise to sometimes-large uncertainties.

Table A2.1. Observational readiness of many snow and ice measurements for the observing system overall. Green: satisfies requirement (roughly 85%+); blue: meets requirements most of the time (70%+); yellow: meets requirements some of the time, or only for specific conditions; red: does not meet requirement. O: operational, R: research, C: commercial, L: long-term (20+ yrs) record.

	In Situ	**Satellite**	**Major Gaps in Observations**
Ocean:			
Sea ice extent	coastal radar (R), ship observations	passive microwave (O, L); scatterometer (R)	In situ is coverage is sparse and incomplete
Sea ice concentration	ship observations	passive microwave (O, L)	Potentially large uncertainties in satellite retrievals in some conditions (e.g., melt)
Sea ice thickness	ice-profiling sonar on moorings (O); mass balance buoys (C), electromagnetic sleds (R)	optical, laser & radar altimeter (R)	Satellite methods are still developing; snow depth on ice is an unknown
Sea ice motion	drifting buoys (O, L); coastal radar (R)	passive and active microwave (O, L); optical (R); radar (R)	In situ measurements are sparse
Snow depth on sea ice	depth gauge (R)	passive microwave (R); altimeter (R)	Satellite method is limited to first-year ice with potentially large uncertainties; in situ data are sparse
Sea level	tide gauges (O, L); bottom pressure recorders (C)	altimeters (R)	

Surface temperature	drifting buoys (O, L)	optical (O, L)	Uncertainty in satellite estimates due to cloud cover
Albedo	radiometers (O, L)	optical (O, L)	Sparse in situ coverage; significant uncertainty
Terrestrial:			
Snow cover extent	manual observations, depth gauge (O, L)	optical (O, L)	Large uncertainty in relating point measurements of extent to large areas
Snowfall/solid precipitation	catchment, optical, and other gauges	(none)	Lack of standardized measurement systems and practices
Snow depth	depth gauge (O, L)	optical (R)	Satellite method is limited to tall-grass prairie
Snow water equivalent	various methods (O)	passive microwave (R)	In situ coverage is sparse
Freshwater ice (lake and river ice) extent	visual observations (O, L)	optical (R)	Declining observation network
Glacier, ice cap, ice sheet mass balance	various methods (R)	radar (R), gravity (R)	Sporadic coverage
Glacier length, area	surveys (R, L)	optical (R)	Incomplete coverage
Glacier, ice cap, ice sheet motion	GPS (R)	InSAR, optical (R)	Sporadic coverage
Permafrost: ground temperature	boreholes (O, L)	(none)	Large portions of the Arctic not covered
Permafrost active layer thickness	boreholes, probes (O, L)	passive microwave (R)	Large portions of the Arctic not covered
Surface temperature	thermisters, thermocouples (O, L)	optical (O, L)	Satellite method is clear sky “skin” temperature
Surface albedo	radiometers (O, L)	optical (O, L)	Sporadic in situ coverage; significant uncertainty

ANNEX 3: GCW PARTNERSHIP CRITERIA

International Partners:

1. Any international organization, professional union, association or data centre that is actively involved in cryosphere activities, that has a willingness to contribute tangibly to the implementation of the WMO GCW initiative, and that is active internationally in structure and membership, is invited and encouraged to become an "International Partner" of GCW.

2. A formal statement of intent to be a GCW International Partner should be sent to the WMO GCW Secretariat for consideration by the WMO GCW Steering Group. The statement should address how the organization will contribute to GCW implementation and to GCW Team activities. Requests are reviewed and endorsed formally. In accepting Partner status, special attention will be given to the following criteria:

   a. Extensive global networks of members or partners or a high global presence or visibility, through regional or country offices, on measurement, research, product generation, or data archival and distribution activities;
   b. Specific expertise with a strong emphasis on cryosphere issues in their organizational mandate;

3. The Partner organization should appoint one focal point and one alternate as principal contact persons for GCW. The full contact information of the focal point and the alternate should be provided to the WMO GCW Secretariat. The focal point (or alternate of the Partner) is eligible to participate in GCW Steering Group meetings.

4. After clearance through the GCW Secretariat, each Partner may display GCW visual identifier(s) and link to the GCW website on its own website. Each Partner will have their logo on the GCW website with a link to the Partner's website. Partners will have an opportunity to display information on the GCW web-page, but only if it is directly related to activities that are part of the agreed GCW Implementation Plan and Task Team activities.

5. A Partner may only use the GCW visual identifier(s) in relation to activities that are part of the GCW activities.

6. Each Partner should provide on an annual basis a short assessment on their Partner status with the Global Cryosphere Watch and how they are engaged in activities with the GCW.

7. Any Partner may at any time withdraw from the Partner status with the GCW by giving notice to that effect to GCW Secretariat.

8. Partnerships will be re-evaluated every four years. Ineffective partnerships will be terminated.

National and Regional Partners:

9. Organizations with a single country or regional cryosphere focus will be considered for "National Partner" or "Regional Partner" status. Requirements for this status is as outlined for an international partner, but at the national or regional level.

10. Partner status will not normally be granted to any state or government agency.

11. NMHSs and their national collaborators in cryosphere initiatives who make tangible or in-kind contributions to the development, implementation, and operation of GCW contribute to GCW as a Member of WMO and will be considered "contributors" rather than partners.


GCW
Global Cryosphere Watch