WORLD METEOROLOGICAL ORGANIZATION

GLOBAL CRYOSPHERE WATCH (GCW)

IMPLEMENTATION PLAN

Version 1.7

(19 April 2016)

DOCUMENT VERSIONS

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0.2	J. Key	25 Jan 2012	Major modifications based on 1st implementation meeting (working groups, impacts; structure and timeline figures); revised and expanded tasks
0.3	J. Key	31 Jan 2012	Additional recommendations and task from GCW Implementation Meeting report.
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	Godøy		steering group and team structure; updated milestone/task timelines; updated data portal and website section; updated structure figure; additions on snow chemistry
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1.7	J. Key, W. Shöner, C. Fierz, M. Citterio, M. Ondráš	19 Apr 2016	Minor editing of Team descriptions; revised station and type concepts; included station requirements; revised partnerships section; updated glacier and ice sheet volume equivalent values; updated Figures 2, 3, 5; added the outcome of Cg-17; added acronyms; updated timelines; added two teams

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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 Sixteenth 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 is a component of the Earth System that includes snow cover, sea ice, lake and river ice, glaciers, ice caps, ice sheets, permafrost, seasonally frozen ground, and solid precipitation at the surface[1]. 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 paleoclimate records, 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 on-going 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

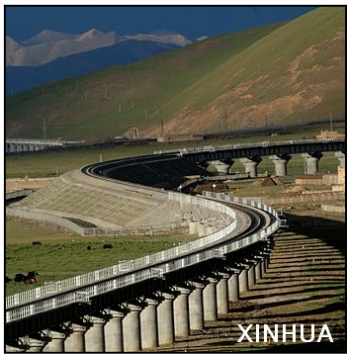
[1] While components of the *cryosphere* are often defined to contain frozen water, permafrost can be "dry". The GCW definition includes components of the cryosphere that occur on or beneath the earth's surface, or that are measured at the surface in the case of solid precipitation. It therefore excludes ice clouds.

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 potential sea level rise is small (0.41 m) compared to that of the ice sheets of Greenland (7.4 m) and Antarctica (58.3 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. The contamination of these glaciers by anthropogenic aerosol pollutants poses a threat to population centres that rely on them for potable water. 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, glacial lake outburst floods, 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, and contamination of, 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, and research. GCW will have a positive impact on prediction, thus supporting assessments of the future state of the cryosphere. 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.
- *Observing network design and evolution:* Based on the *Requirements* and *Standardization* objectives, the GCW core observing network (CryoNet) will be designed to provide global compatibility of cryospheric data and interoperability of deployed systems.
- *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.

CryoNet, the core, standardized 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 the WMO Executive Council Panel of Experts on Polar Observations, Research and Services (EC-PORS). In 2011, Cg-XVI 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 Phase (2012-2015)

The Development Phase, undertaken between 2012 and 2015, will be led by the GCW Steering Group (GSG) under the responsibility of EC-PORS and coordinated with WMO constituent bodies and partners. It will focus on developing the internal GCW working structure of groups and teams charged with the development of agreed measurement practices and guidelines, the establishment of the core, standardized GCW Observing Network (CryoNet), the establishment of a system for documenting activities, practices and provision of products (GCW Website, regulatory materials) and reporting of data (GCW Data Portal).

2.3.3 GCW Implementation Phase (2016-2019)

The Implementation Phase, undertaken between 2016 and 2019, will be led by the GCW Steering Group (GSG) under the responsibility of either the EC or a technical commission and coordinated with WMO constituent bodies, partners and WMO and international Programmes. It will focus on implementing a newly defined GCW Programme in line with tasks and activities described in this GCW Implementation Plan (IP) and in GCW workshop reports, with a special emphasis on operating a standardized observing network (CryoNet), the sustainable provision of quality data to the WMO GTS/WIS through the GCW Data Portal, and the sustainable provision of authorized GCW products. The GCW IP is a living document that will be regularly reviewed and updated. Initial timelines and deliverables are given in the *Deliverables and Milestones* section.

2.3.4 GCW Operational Phase (2020 onward)

Once the framework is established, GCW enters its Operational Phase based on the agreed practices and objectives stated in the GCW Programme. It will continue to evolve to improve service delivery and support decision-making in response to the needs of users and technological opportunities. The implementation of the GCW programme will establish an improved scientific basis for national, regional and international efforts towards sustainable development. The programme will include assistance to Members and partners in the development and maintenance physical and human resources, and the knowledge needed to support the provision of services.

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 Working Groups (WG) 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 Working Groups. 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. Working Groups and their 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 Data Portal (http://gcw.met.no) is a web interface that contains information about datasets (metadata), but not necessarily 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 and will become a WIS Data Collection and Production Centre (DCPC) to allow for ingesting the available data into GTS/WIS. 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 programme 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.

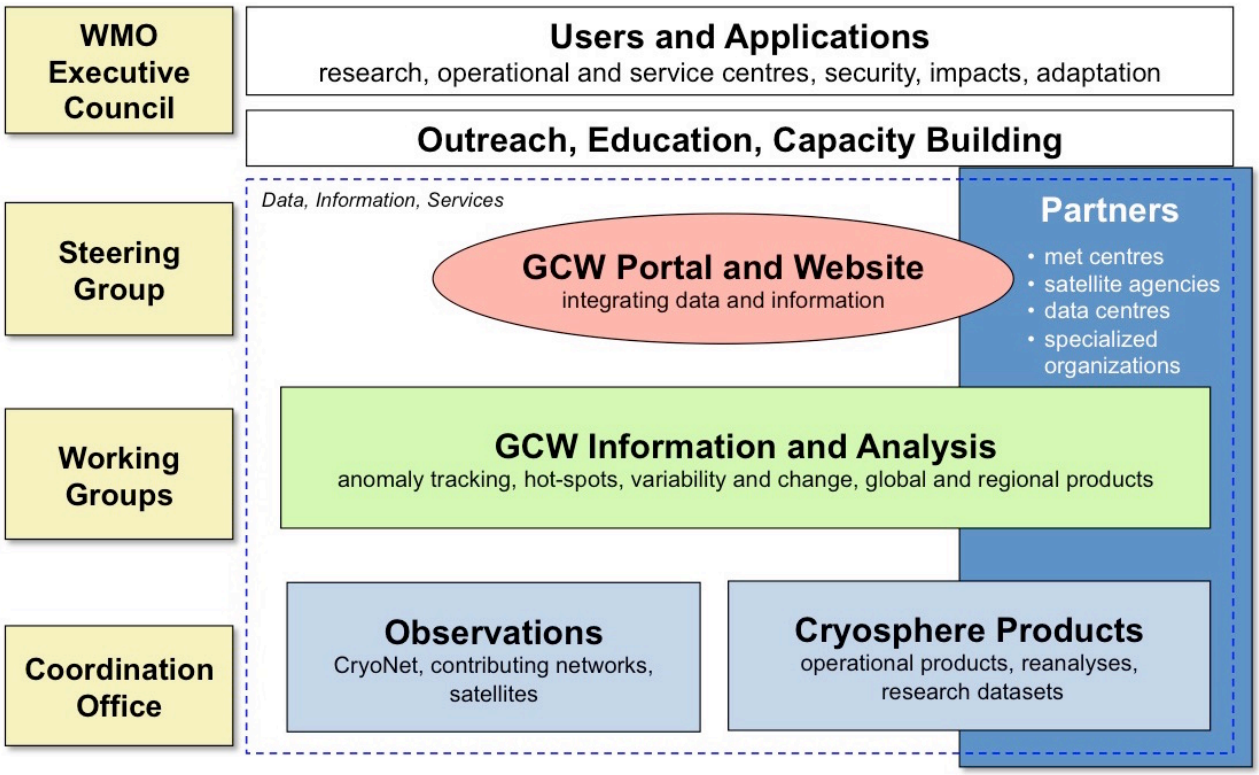


Figure 1: Conceptual Framework for GCW operation.

3.2 The GCW Steering Group (GSG) and Working Groups

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 Working Groups, provide oversight of the Groups 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 chairperson and vice-chairperson. The GSG currently 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 the GCW website and/or newsletter.

3.2.2 Working Groups

Three Working Groups have been established:

- the **Observations Working Group***,*
- the **Integrated Products Working Group***,* and
- the **Information and Services Working Group***.*

Working Groups will establish Teams, as needed, to address the priority tasks defined in the work plans of the Groups. Initially, the Observations Working Group includes the **CryoNet Team**, the **Best Practices Team,** and the **Solid Precipitation Team**. The Integrated Products Working Group includes the **Snow Watch Team,** the **Sea Ice Team**, and the **Glacier Team**. The Information and Services Working Group contains the **Portal Team**, the **Terminology Team,** and the **Website and Outreach Team**. All Working Groups and Teams will facilitate interaction between the operational and research communities.

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

The Observations Working Group will address capabilities and needs for surface-based and satellite observations. It will be responsible for the establishment and coordination of operations of the GCW surface-based observational network, including the core network called **CryoNet**. The group will develop a network strategy and procedures for becoming part of the GCW network, evaluate proposed sites, and will determine data availability. It will develop relevant material to be included in the WMO Technical Regulations and in the WIGOS Manual. To establish CryoNet, it will define the types of sites on land or sea, operating a sustained, standardized programme for observing and monitoring as many cryospheric components and variables as possible. An example of a robust snow measurement programme for a land site is given in Appendix 1. This Group will compile best practices, guidelines, and standards, facilitate instrument intercomparisons, and promote interaction and collaboration between the scientific and operational communities. It will conduct an inventory of measurement methods and infrastructure at sites that measure components of the cryosphere. The Observations Working Group 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 Integrated Products Working Group 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 operational and scientific community. The Group will facilitate the harmonization of products (e.g., multiple sea ice estimates), product intercomparisons, and oversee development of data policies for GCW including data exchange by WMO Members. The Group will consider data homogeneity, interoperability, and compatibility of GCW observing and monitoring systems and derived cryospheric products.

The Integrated Products Working Group and the Observations Working Group will engage users to help determine which cryospheric observations are most important, identify the spatial, temporal, and knowledge gaps, and address other aspects of data usability such as error assessments and data formats. Users will be engaged through dedicated workshops and comprehensive surveys. User needs may vary regionally.

The Information and Services Working Group will be responsible for the ongoing development and operation of the GCW Data Portal and its data catalogue, cryospheric metadata and terminology, the GCW Website, and outreach activities. The Group will manage linkages to data contributors, work with national focal points, and develop documentation for outside use. It will work through interoperability issues with data centres and other programmes. The Group will be available to speak to the media and policymakers, provide guidance for outreach products and work with social media. A variety of outreach materials will be developed to educate the public, Members, funding agencies, and policymakers on the cryosphere and its importance to society.

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).

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* (available on the GCW website). 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 Programmes

GCW is an initiative sponsored by WMO, in which WMO and its Members and partners individually and collectively contribute to GCW's Mission and objectives. Collaboration, cooperation and commitment are essential to successfully conduct 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, and with international bodies and services involved in cryospheric observations, services, or research. While there are formal GCW partners (see GCW Partnership Criteria), informal partnerships as participating organizations, agencies, institutions, programs, projects, and networks are critical to GCW's success.

3.4.1 Network Partners

There are many organizations that participate in GCW through its surface network. They are both partners and sponsors. Some established observing networks contribute to the GCW surface network, including the International Permafrost Association (IPA), the World Glacier Monitoring Service (WGMS, a service of the International Association of Cryospheric Sciences, IACS), and projects such as the European Space Agency (ESA) GlobPermafrost initiative. 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), is 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 from professional consortia like the International Ice Charting Working Group (IICWG).

Programmes such as the Global Climate, Ocean, and Terrestrial Observing Systems (GCOS, GOOS and GTOS) 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 works with the GCOS Secretariat, GCOS Panels and implementing bodies.

3.4.2 Data Partners

Data centres and providers that contribute through interoperability with the GCW Data Portal include the National Snow and Ice Data Center (NSIDC), GTN-P, CryoClim, the Arctic and Antarctic Research Institute (AARI, Russia), the National Institute of Polar Research (NIPR, Japan), the British Antarctic Survey (BAS), the Canadian Cryosphere Information Network (CCIN), the Data Publisher for Earth & Environmental Science (Pangea, Germany), the Norwegian Polar Institute (NPI), the Environment Climate Data Sweden, the World Glacier Monitoring Service (WGMS, the Global Precipitation Climatology Centre (GPCC). See the Data page for a diagram of centres with which the GCW Portal is currently interoperable.

3.4.3 Science Partners

Science programs that GCW engages with include the Scientific Committee for Antarctic Research (SCAR), the World Climate Research Programme (WCRP) Climate and Cryosphere (CliC) project, 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.
Lastly, the WMO Executive Council Expert Panel on Polar and High Mountain Observations, Research, and Services (EC-PHORS) has facilitated engagement of organizations with polar interests in the development of GCW. EC-PHORS has members from the Arctic Monitoring and Assessment Programme (AMAP), the International Arctic Science Committee (IASC), and SCAR. Through the EC-PHORS 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-PHORS, provides engagement of CEOS and major satellite operators like CSA, ESA, EUMETSAT, JAXA, NASA, and NOAA.

Examples of collaborative activities with these partners and programmes include:

- coordination of GCW development and implementation,
- coordinated observing, capacity building and training with their existing networks,
- compilation and development of manuals on best practices for cryospheric measurements and observation,
- development of satellite, in situ, and other product inventories relevant to GCW,
- joint intercomparison of products,
- development of community monitoring of the cryosphere,
- co-publication of glossaries of cryospheric vocabulary and terminology,
- 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 Surface Observation Network

The GCW surface observation network builds on existing cryosphere observing programmes and promotes the addition of standardized cryospheric observations to existing facilities in order to create more robust environmental observatories. The basic component of the GCW network, including its core network called *CryoNet*, is the *station*. A station measures one or more components of the cryosphere and one or more variables of each component, for example depth and density of the component snow. All types of GCW stations need to make their data, metadata, and observation procedures available in a timely manner, preferably to a data centre that is interoperable with the GCW portal. Observations are made and quality controlled according to CryoNet best practices.

A *CryoNet station* must meet the minimum set of requirements, which includes providing ancillary meteorological measurements. Potential attributes of CryoNet stations are given below. All stations will be either Primary or Reference, and may have one or more additional attributes.

- *Primary* - Have a target (intent) of long-term operation and have at least a 4-year initial commitment.

- *Reference* - Have a long-term operational commitment and long-term (more than 10 years) data records.
- *Cal/val* - In addition, the station is being used for calibration and/or validation of satellite products and/or (earth system) models, or it has been used for such purposes in the past and it still provides the needed facilities.
- *Research* - In addition, the station has a broader research focus related to the cryosphere.

The minimum requirements of CryoNet station are:

1. **Meeting Core CryoNet Measurement Requirements -** The station shall measure at least one of the variables of one of the cryosphere components (i.e. snow, solid precipitation, lake and river ice, sea ice, glaciers, frozen ground and permafrost). The station location is chosen such that cryospheric measurements are representative of the surrounding region, and such representativeness needs to be clearly described.
2. **Commitment of Operational Continuity -** The station must be active. The responsible agencies are committed, to the extent reasonable, to sustaining long-term observations of at least one cryosphere component. There must be a commitment to continue measurements for a minimum of four (4) years.
3. **Metadata Up to Date and Availability -** The station metadata, including all metadata describing the station characteristics and observational programme, are kept up-to-date and available in the GCW Portal as the interface to the WIGOS Information Resource (WIR).
4. **Compliance with Agreed Regulatory Practice -** The station observational procedures, the instruments and method of observations, quality control practices, etc., should follow GCW endorsed regulations, manuals, guides and, to the extent possible, the recommended best practices.
5. **Data and Ancillary Data Freely Available -** Data are made freely available, and whenever possible in near real-time. In situ ancillary meteorological observations, as required by CryoNet best practices, should also be available with documented quality.
6. **Competency of Staff -** Personnel must be trained in the operation and maintenance of the station.

A *CryoNet site* generally encompasses an area greater than a conventional observing station and is comprised of two or more active GCW stations with varying capabilities that are operated as a coordinated unit. At least one station has to be a CryoNet station. A site may encompass several micro-climatological regions or extend over larger altitudinal gradients. Thus, further ancillary meteorological stations are part of a site. Different partners may operate the stations, but they are co-ordinated through one agency or institute. Each CryoNet site has to provide a concept describing the research approach and the site management (e.g. cooperation between different partners).

Typically, sites have a broader research focus related to the cryosphere compared to stations. Whereas simple sites investigate the cryosphere only, integrated sites aim to provide a better understanding of the cryosphere and/or its linkages to other components of the earth system, for example, the atmosphere, the hydrosphere, the biosphere, the oceans, soil, vegetation, etc. Potential attributes of CryoNet sites are:

- *Basic* - Monitor single or multiple components of the cryosphere.
- *Integrated* - Monitor at least two components of cryosphere or at least one cryosphere component and one other component of the earth system. Integrated sites are particularly important for the study of feedbacks and complex interactions between these components.

Requirements for CryoNet sites are:

1. A site comprises at least one CryoNet station.
2. Integrated sites have technical supporting staff.
3. Integrated sites have training capability.

4. There is a long-term financial commitment.
5. Data are made freely available, and whenever possible in (near) real-time.

CryoNet station and site characteristics are summarized in Figure 2.

A *GCW contributing station* is required to measure at least one variable of at least one cryosphere component (e.g. snow, permafrost, sea ice, etc.). Contributing stations are those that provide useful measurements of the cryosphere but do not fulfill CryoNet minimum requirements, or in some other way do not provide the quality and/or consistency of data required by CryoNet stations; for example, where data records may be short or with large gaps. These stations may be in remote, hard to access regions where cryospheric observations are scarce or in regions where they complement other cryospheric measurements. Mobile platforms such as ships, drifting stations and buoys may also be contributing stations. Contributing stations may have this attribute:

- *Reference* - Have a long-term operational commitment and/or long-term (more than 10 years) data records.

Synoptic/climate stations of the NMHSs measuring cryospheric variables to WMO standards, and providing their metadata and data via WIS and WIGOS, could fulfill the necessary requirements in order to contribute to GCW and to be accepted as stations in the GCW surface network.

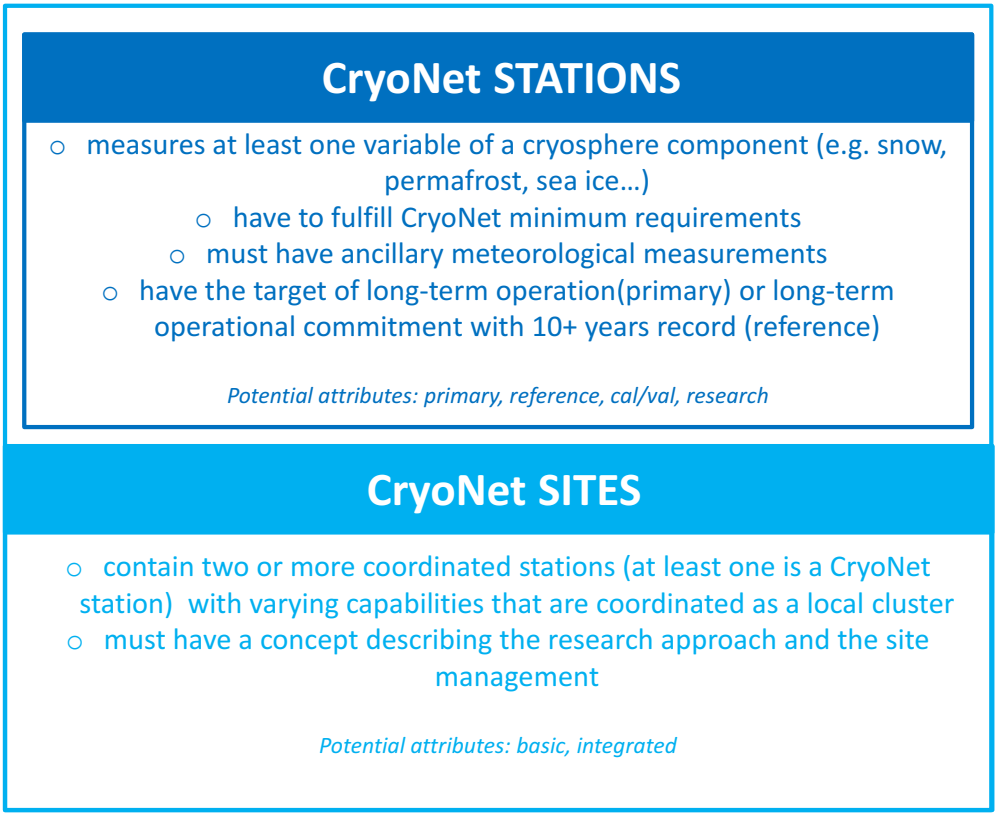


Figure 2: Properties of GCW and CryoNet Stations as well as CryoNet Sites.

As encouraged by GCOS, GCW will facilitate the establishment of high-latitude stations 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. In addition, aerosol contamination of surface snow (dust, black carbon, heavy metals, etc.) will also be monitored to link with existing atmospheric measurements from the GAW network. 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 stations and sites. Many Members have proposed contributing to GCW through their sites in Europe, Asia, North America, and South America. For example, China has established sites 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-USA, 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. Various countries in South America have proposed glacier stations.

GCW will drive performance and provide motivation for high quality observations. Being a GCW station or 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.

The process of selecting initial CryoNet stations and sites for the GCW network is in its "pre-operational" phase (see http://globalcryospherewatch.org/cryonet/stations.php). It will be completed in 2016.

Space 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 Integrated Products Working Group 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.

High-level monitoring products will complement the more basic observational datasets provided by GCW and its partners. The Snow Watch Team 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.

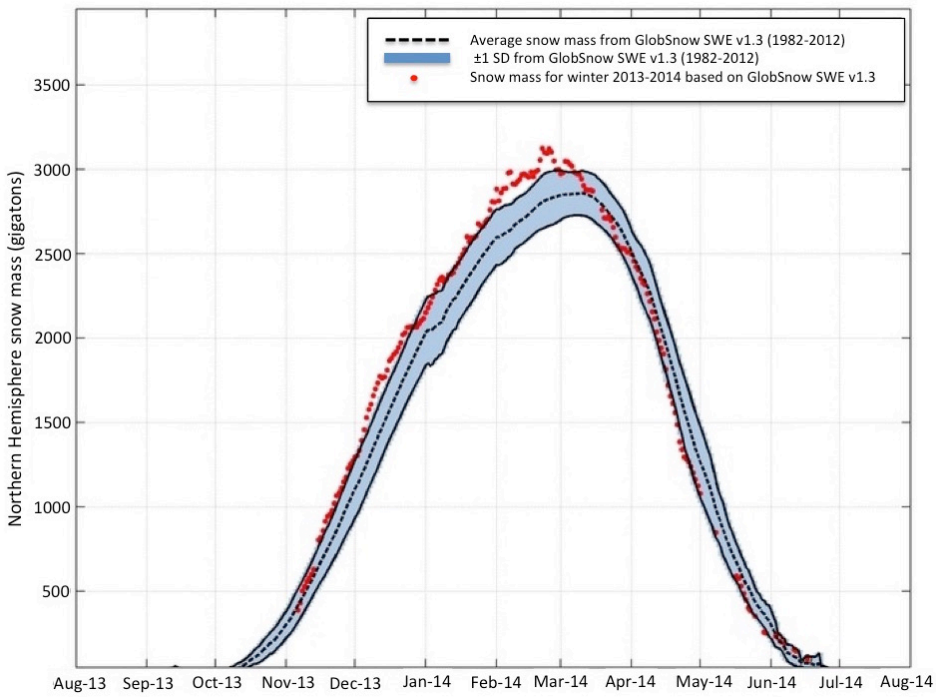


Figure 3: Example of a product for monitoring snow water equivalent. (GCW/FMI)

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 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 GCW 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), and (c) to connect GCW with the WMO Information System (WIS) and WMO Global Telecommunication System (GTS) when real time exchange of data is requested by the GCW community. The intention is to establish the GCW Data Portal as a WIS Data Collection and Production Centre (DCPC) and to rely on WIS and WIGOS efforts for standardising the metadata that are submitted to WMO. GCW data management follows a metadata-driven approach where datasets are described through metadata exchanged between contributing data centres and the GCW catalogue.

The GCW Data Portal, and its data catalogue, is 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 efforts in 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 (e.g. WMO GTS or a robust Internet exchange) 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.

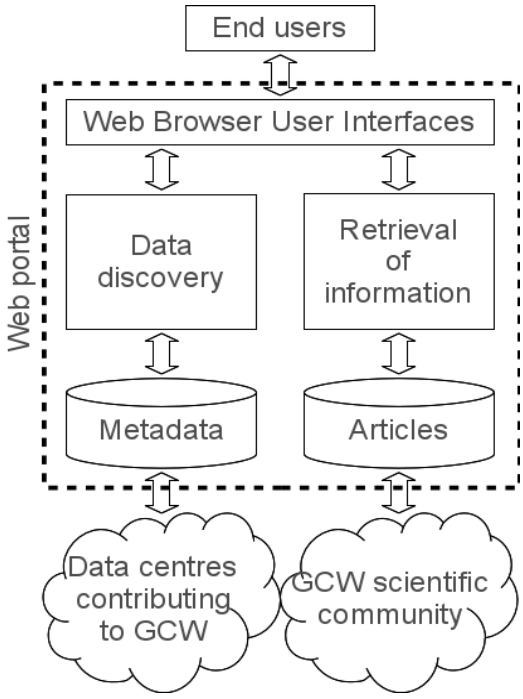


Figure 4: The GCW Data Portal has two components. One addresses editorial information (right) and the other addresses datasets (left).

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 Centres (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 following a request from the user community.

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 Data 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.

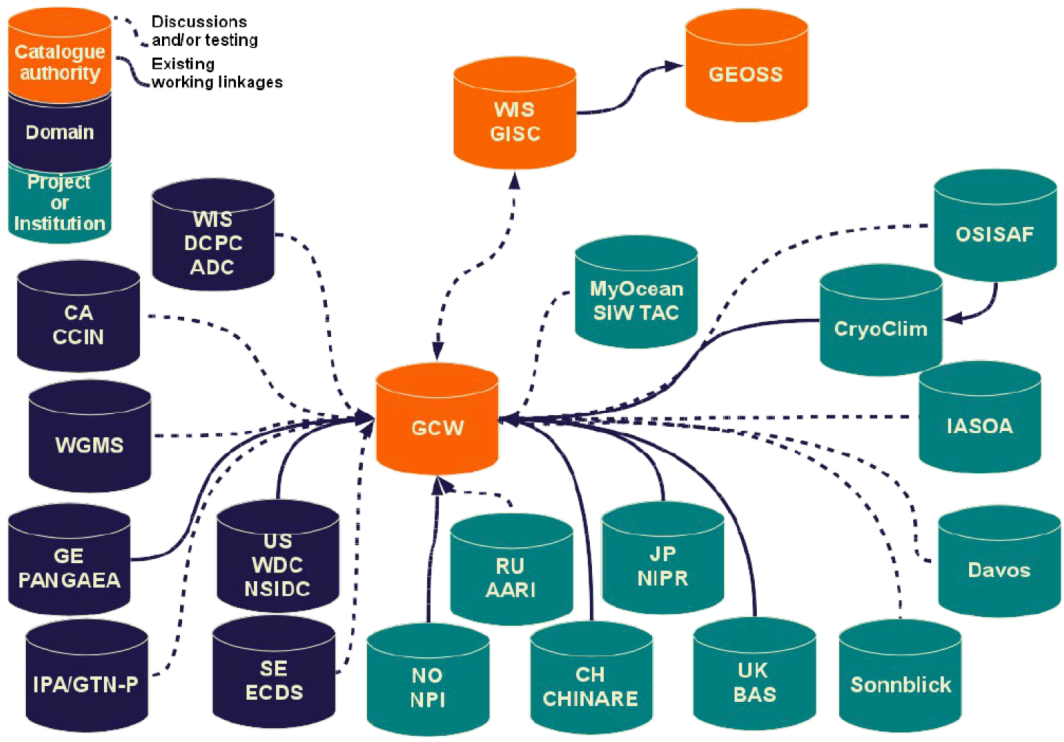


Figure 5: Data centres being addressed within GCW data management currently or in the short term. Solid lines indicate existing linkages; dashed lines indicate ongoing discussions and/or testing.

There are technological considerations for catalogue interoperability, involving harvesting/exporting metadata using standard interoperability interfaces and documentation standards (e.g. Open Archives Initiative - Protocol for Metadata Harvesting (OAI-PMH), Open Geospatial Consortium (OGC) Catalogue Service for the Web (CSW), ISO23950, ISO19115, Global Change Master Directory (GCMD) Data Interchange Format (DIF)). OAI-PMH is the preferred solution for exposure of metadata due to its low cost of implementation. Implementations of OAI-PMH should support at least GCMD DIF or ISO19115 among which ISO19115 following the WMO profile is the preferred solution in the long term. To simplify data brokering, data streams established through Open-source Project for a Network Data Access Protocol (OPeNDAP) interfaces are the preferred solution as these map to the generic data model UNIDATA Common Data Model. There are relevant frameworks for catalogue interoperability including WMO Information System (WIS), ICSU World Data System (WDS), Group on Earth Observation (GEO).

The GCW Data 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 Center (NSIDC) are already interoperable. This approach will facilitate seamless access with NMHSs (primarily utilizing WIS) and external data centres holding relevant cryospheric data and information at the national or global scale.

The GCW 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.

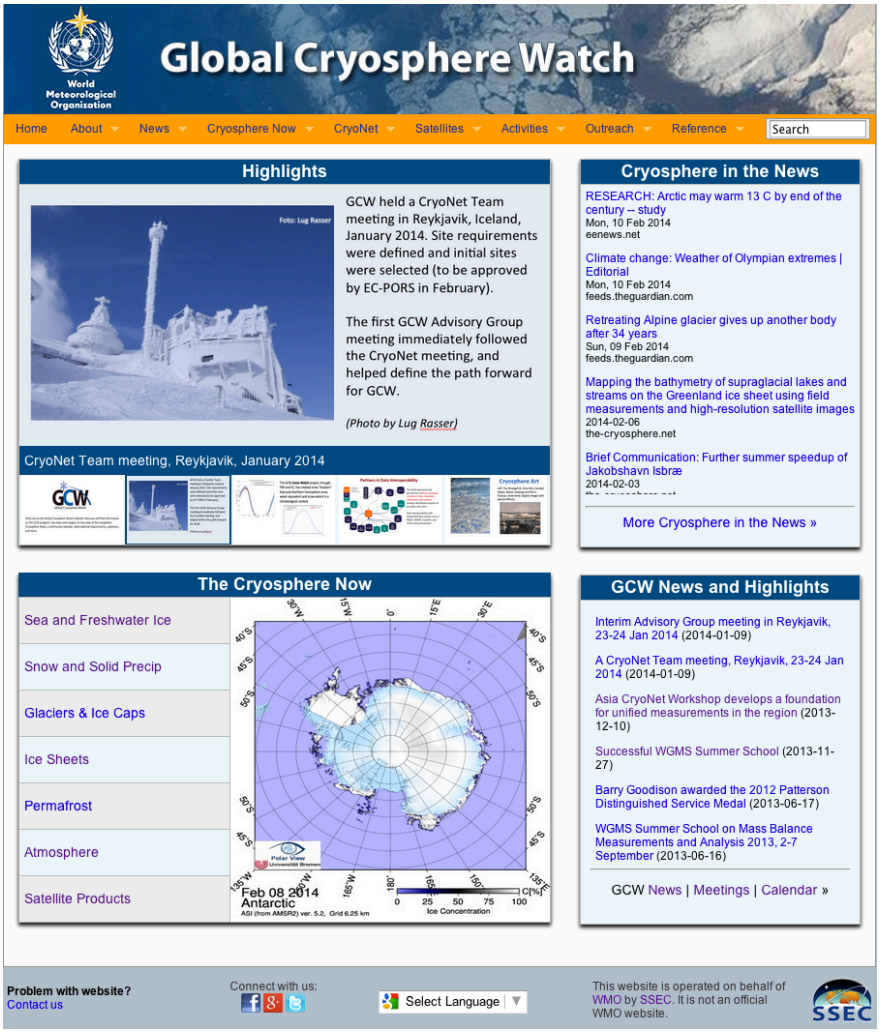


Figure 6: GCW Website home page.

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 Best 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 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 Terminology Team will identify current cryosphere glossaries and develop and evaluate terminologies and vocabularies. 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 programme. GCW will continue to explore ways to entrain new expertise into the programme 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.

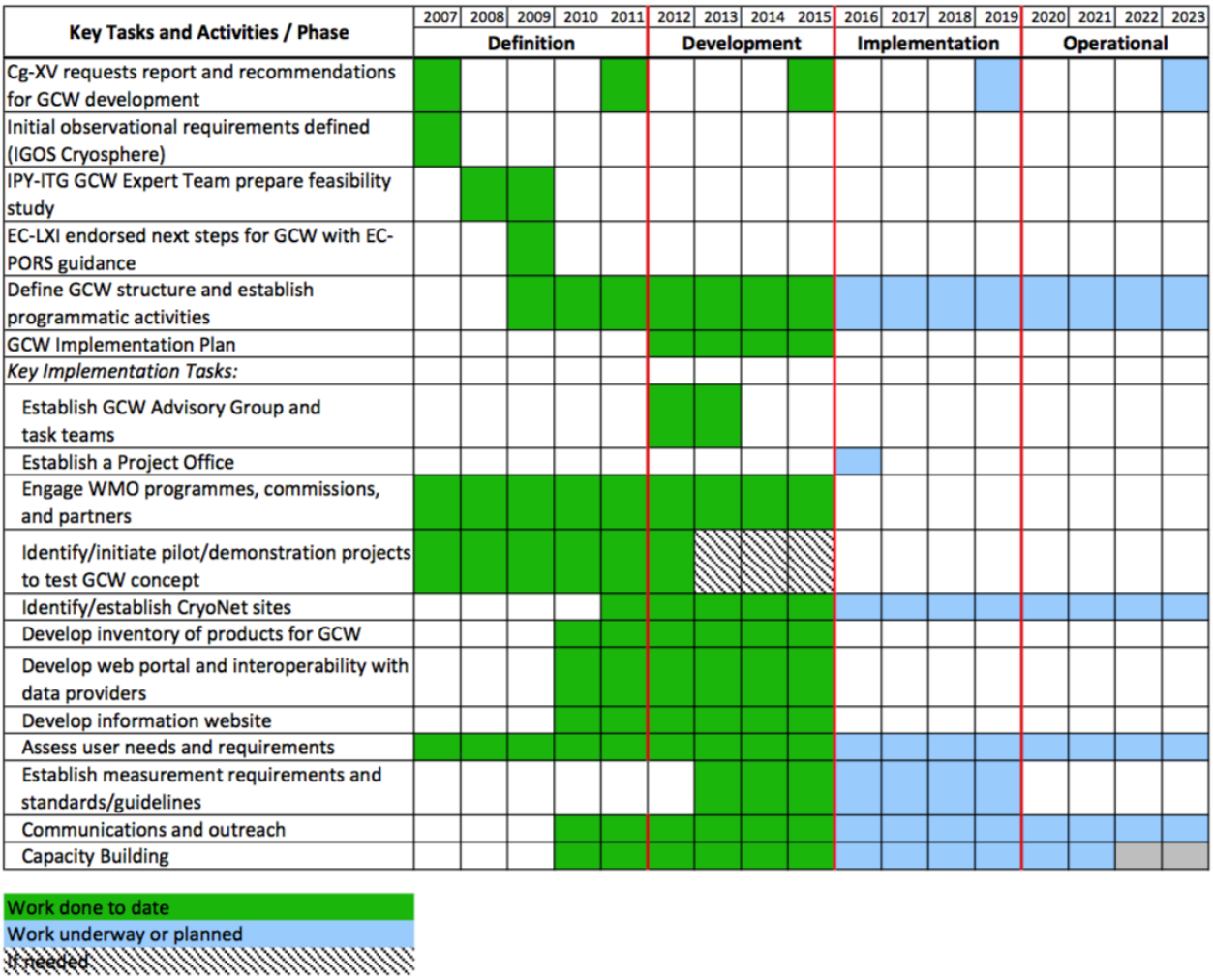


Figure 7: GCW Milestones and Deliverables as agreed by Cg-XVI. The timeline has been updated to show progress since Cg-XVI.

Key implementation activities are given in Table 1. Some of these were described earlier in this Plan. The responsible GCW Working Groups 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 working groups	GSG	-	2013-2015
1.3	Establish national GCW groups	Members	-	2014-2015
1.4	Establish regional CryoNet collaborations, particularly in Asia and South America	CryoNet Team, Members	NMHSs, research partners	2013-2016
1.5	Define a GCW WMO Programme	EC-PORS, GSG	-	Before Cg-XVII
1.6	Annual assessment of progress (indicators of success)	GSG	Task Teams	Annually
1.7	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, all teams	-	2012
2.2	Initiate pilot and demonstration projects	Teams	Members	2012-2016
2.3	Create an inventory of the current network and measurement practices	Best Practices Team	NMHSs, research partners	2012-2018
2.4	Identify and select stations for the core GCW network of surface sites (CryoNet)	CryoNet Team	NMHSs, research institutions	2012 onward
2.4	Establish CryoNet	CryoNet Team	NMHSs, research institutions	2015
2.5	Select candidate products for GCW	Integrated Products WG	Focal Points	2012-onward
2.5.1	Perform satellite and in situ product intercomparisons	Integrated Products WG	PSTG, Focal Points, NMHSs	2014-onward
2.5.2	Historical data sets (data rescue; e.g., snow depth)	Integrated Products WG	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	Observations WG	NMHSs	2012-2015
2.8	Establish best practices and measurement standards	Observations WG	NMHSs	2012-onward
2.9	Evaluate existing terminologies or glossaries; create or update as necessary	Products WG	Members, UNESCO, research partners	2013-onward
2.10	Annual State of the Cryosphere assessments	Outreach Team	-	Annually
3. Capacity Building				
3.1	Provide assistance to Members to introduce and implement GCW nationally	GSG		Ongoing
3.2	Develop GCW guidelines, training materials, and other relevant documentation	GSG		Ongoing
3.3	Develop partnerships with NMHs and international bodies.	GSG	NMHSs, international bodies such as IPA, GCOS, IASC, etc.	Ongoing
4. Outreach				
4.1	Develop information website	Website and Outreach Team	-	2012-2014
4.2	Create outreach materials (handouts, brochure, newsletter, etc.)	Website and 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

Initially, the WMO Executive Council, through its Expert Panel on Polar and High Mountain Observations, Research, and Services (EC-PHORS, formerly 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 programmes and groups. The Office 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 Office shall also pursue active linkages with WMO Programmes and with relevant international organizations. Some suggested tasks that the Office could oversee, depending on available human resources are:

- Provide support to the GCW Steering Group, Working Groups, and Task Teams
- Make available all relevant information to the GCW Steering Group, Working Groups, 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 Office 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 the 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 programme 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 GCW Data 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 Project Office and operational budget require a core allocation from the WMO regular 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 CHF 2.4M 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 43 of Cg-XVII, 2015 – Global Cryosphere Watch
2. Resolution 60 of Cg-XVI, 2011 – Global Cryosphere Watch
3. 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 a CryoNet 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 kilometres)
- Aerosol contamination in snow

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 CryoNet Basic 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 kilometres)
- Aerosol contamination in snow

APPENDIX 2: LIST OF ACRONYMS

AARI	Arctic and Antarctic Research Institute, Russia
APC	Arctic Data Centre, Finland
APECS	Association of Polar Early Career Scientists
Arctic-HYDRA	Arctic Hydrological Cycle Monitoring, Modelling and Assessment Programme
BAS	British Antarctic Survey
CAS	WMO Commission for Atmospheric Sciences
CBS	WMO Commission for Basic Systems
CCIN	Canadian Cryospheric Information Network
CEOP	Coordinated Energy and Water Cycle Observations Project
Cg	WMO Congress
CHINARE	Data sharing platform, China
CHy	WMO Commission for Hydrology
CliC	Climate and Cryosphere Project
CryOS	Cryosphere Observing System, generally referring to the IGOS Cryosphere Theme
DCPC	WIS Data Collection and Production Centre
DIF	Data Interchange Format
EC	WMO Executive Council
ECDS	Environment Climate Data Sweden
EC-PHORS	WMO Executive Council Expert Panel on Polar and High Mountain Observations, Research, and Services (formerly EC-PORS)
ECV	Essential Climate Variable
ESA	European Space Agency
GCOS	Global Climate Observing System
GAW	Global Atmosphere Watch
GCW	Global Cryosphere Watch
GCMD	Global Change Master Directory
GEOSS	Global Earth Observation System of Systems
GFCS	Global Framework for Climate Services
GIPPS	Global Integrated Polar Prediction System
GISC	Global Information System Centres
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
IASOA	International Arctic Systems for Observing the Atmosphere
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
NIPR	National Institute of Polar Research, Japan
NOAA	National Oceanic and Atmospheric Administration (USA)
NMHS	National Meteorological and Hydrological Service

NPI	Norwegian Polar Institute
NSIDC	National Snow and Ice Data Center (USA)
OAI-PMH	Open Archives Initiative - Protocol for Metadata Harvesting
OCG CSW	Open Geospatial Consortium Catalogue Service for the Web
OPeNDAP	Open-source Project for a Network Data Access Protocol
OSI SAF	Ocean and Sea Ice Satellite Application Facility (EUMETSAT)
OSI-TAC	MyOcean Ocean and Sea Ice Thematic Assembly Center
Pangea	Data Publisher for Earth & Environmental Science, Germany
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
WDC	World Data Center
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.

The 17th World Meteorological Congress (2015) decided to mainstream and implement GCW in WMO Programmes as a cross-cutting activity and requested that the Secretary-General ensure, to the extent possible within available resources, management of, and provide support to, the implementation of GCW and to establish a GCW Project Office. Congress agreed that the GCW Implementation Plan should be the guiding document for the implementation of the GCW. Congress also agreed that an immediate priority for GCW is to establish CryoNet, which is one of the four WIGOS component observing systems and agreed on 36 CryoNet sites that will be used for the pre-operational testing phase.

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.

The WMO Executive Council, at its Sixty-sixth session (June 2014), decided to recommend to the WMO Congress further improvements to the draft WMO Strategic Plan 2016-2019, including a new priority related to operational polar weather, climate, and hydrological services focusing on operationalizing the Global Cryosphere Watch and advancing the Global Integrated Polar Prediction System (GIPPS).

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 coverage is sparse and incomplete
Sea ice concentration	coastal and ship manual observations	passive microwave (O, L), SAR (O, C), optical and IR (O, L)	Potentially large uncertainties in satellite retrievals in certain conditions (melt, freeze-up); SAR coverage remains incomplete
Sea ice thickness	Coastal and ship manual observations, ice-profiling	optical (R), altimeters (R), SAR (R)	Satellite methods are still developing; snow depth on

	sonar on moorings (O); mass balance buoys (C), electromagnetic sleds (R)		ice is an unknown
Sea ice stage of development	Coastal and ship manual observations	SAR (O, C, R), optical and IR (O, L)	SAR coverage remains incomplete
Sea ice motion	drifting buoys (O, L); coastal radar (R)	passive microwave (O, L); optical (R); SAR (O, R)	In situ measurements are sparse
Sea ice topography	ship manual observations	altimeters (R), SAR (O, R)	retrieval possible only on a basis of high-resolution information
Icebergs	Air manual and radar reconnaissance Ship manual observations	radar (O, C), optical (O, L), altimeter (R)	satellite methods of automatic identification and tracking are still developing; coverage of high-resolution information remains incomplete
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); passive microwave (O)	Satellite optical 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 website, 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 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 GCW.
7. A Partner may at any time withdraw from the Partner status by giving notice to that effect to the 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.

Global Cryosphere Watch