WORLD METEOROLOGICAL ORGANIZATION

GLOBAL CRYOSPHERE WATCH (GCW)

IMPLEMENTATION PLAN

Version 1.0

(19 October 2012)

DOCUMENT VERSIONS

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1.0	J. Key, B. Goodison	19 Oct 2012	Incorporated comments from EC-PORS and partners

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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 for the next five years. The document provides background information on GCW, applications of cryosphere data, a conceptual framework, operational structure including working groups and task teams, near-term tasks, milestones and deliverables, management, indicators of success, partnerships, and a discussion of resources. This plan will be periodically updated as GCW evolves over the coming years.

2 INTRODUCTION

The cryosphere collectively describes elements of the Earth System containing water in its frozen state. It includes solid precipitation, snow cover, sea ice, lake and river ice, glaciers, ice caps, ice sheets, permafrost, and seasonally frozen ground. The cryosphere is global, existing not just in the Arctic, Antarctic and mountain regions, but at all latitudes and in approximately one hundred countries. The cryosphere provides some of the most useful indicators of climate 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 climate variability and change.

The cryosphere, its changes, and its impacts have received increased attention in recent years. Today, it receives constant coverage by the media, creating an unparalleled demand for authoritative information on the past, present and future state of the world's snow and ice resources on a multitude of time and space scales, reaching from polar ice to tropical glaciers. 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

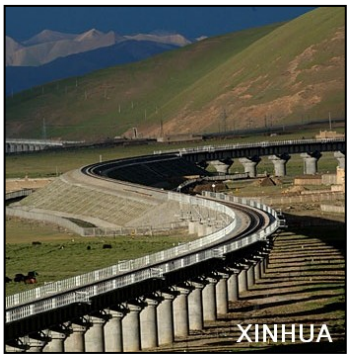
Changes in the cryosphere have major impacts on health, water supply, agriculture, transportation, freshwater ecosystems, hydropower production, and cryosphere-related hazards such as the floods, droughts, avalanches, and sea-level rise.

The amount of snow and the rate of snowmelt help to govern the timing and characteristics of runoff. For example, as much as 75% of water supplies in the western United States come from snowmelt, and most central Asian countries/regions rely on meltwater for agriculture and industry. Some countries rely on snowmelt forecasting to predict floods and snowmelt runoff and to provide flood alerts. Changes in the cryosphere affect hydropower operations.

Sea level rise is a major concern for heavily populated coastal areas and is critical for a number of small island nations. Although the volume equivalent of glaciers in terms of global sea level rise is small (0.5 m) compared to that of the ice sheets of Greenland (7 m) and Antarctica (about 70 m), their relative contribution to recent global sea level rise has been much larger. Melting of glaciers and ice caps in the second half of the 20th century led to about a 2.5 cm rise in sea level, in contrast to the loss of ice from the Greenland and Antarctic ice sheets, which added about 1 cm to sea level. Mountain glaciers are also an important water resource for many communities and they play a vital role in local hydrological cycles.

Wave-induced undercutting of permafrost leads to coastal erosion by the action of waves and currents. Reduction of the sea ice cover, and especially of the fast ice, corresponds to increased

fetch of waves allowing them to grow and become more destructive as they approach the coast. 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 100 feet per year have been observed in some locations in both Siberia and Canada.



Transportation is affected 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 represents a risk for marine ecosystems. Snowfall frequency and magnitude directly affect road and rail traffic and aircraft operations. River and lake-ice provide winter roads for access to remote areas. Thawing of permafrost may lead to the degradation of roads and railroads.

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 (e.g., skiing, snowmobiling, ice fishing), and tourism are significantly affected by short-term and long-term changes in snow and ice conditions. The insurance industry is becoming affected by increasing risks associated with a changing cryosphere. Cryosphere-related hazards include avalanches, catastrophic spring floods from the rapid melting of snow, the high variability of lake break-up and freeze-up dates that impact transportation, infrastructure damage from thawing permafrost, and icebergs in shipping lanes.

Changes in the cryosphere contribute to global climate change. Albedo changes from the loss of sea ice and snow cover, along with accelerating methane emissions from thawing permafrost, are heating the planet at a rate equivalent to approximately 3 billion metric tons of CO_2. This is comparable to about 42 percent of US global warming emissions. Heating from the melting Arctic will grow significantly over the coming decades, projected to more than double by 2100 when expressed in CO_2 equivalents.

Cryospheric observations contribute to a variety of societal benefit areas. They help reduce the risk of loss of life and property from natural and human-induced disasters, provide a better understanding of environmental factors affecting human health and well-being, improve the management of energy and water resources including flood forecasting, are required for infrastructure design in cold climates, help us understand, assess, predict, mitigate, and adapt to climate variability and change, improve weather forecasting and hazard warnings, improve the management and protection of terrestrial, coastal and marine ecosystems, help support sustainable agriculture, and improve our ability to monitor and conserve biodiversity.

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. Solid precipitation, snow cover, snow water equivalent, snowstorms, icing, and river-, lake-, soil-, and sea ice freeze-up and break-up times are components of weather forecasting in cold climate regions. The performance of numerical weather forecasts strongly depends on the accuracy of initial conditions for predictive models. 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, directly or indirectly, data, information and products that will help Members and partners to provide services to the wider user community, thus helping to reduce the loss of life and property from natural and human-induced disasters, improve management and operation of energy and water resources, contribute to a better understanding of environmental factors affecting human health and well-being, understand, assess, predict, mitigate and adapt to climate variability and change, improve weather forecasts and hazard warnings, aid in management and protection of terrestrial, coastal and marine ecosystems, and support sustainable agriculture.

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

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

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

2.2 Mission and Objectives

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

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

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

GCW will organize analyses and assessments of the cryosphere to support science, decision-making and environmental policy through, inter alia, its foundational support to the Global

Integrated Polar Prediction System (GIPPS), 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 making CryOS a living document and 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, aimed at optimizing knowledge of environmental conditions and exploiting this information for predictive weather, climate and water products and services, thus contributing to the proposed WMO Global Integrated Polar Prediction System (GIPPS), Polar Regional Climate Centres (PRCCs), and Polar Climate Outlook Forums (PCOFs);
- *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 differences and inconsistencies in current practices, and by fully assessing error characteristics of in situ and satellite products;
- *Access:* Improve exchange of, access to, and utilization of observations and products from WMO observing systems and those of its partners;
- *Coordination:* Foster research and development activities and coherent planning for future observing systems and global observing network optimization, especially within the WMO Integrated Global Observing System (WIGOS), by working with all WMO Programmes, technical commissions (TCs), regional associations (RAs), partner organizations and the scientific community.

The observing component of GCW is a component of WIGOS. Implementation is directly linked to the WIGOS Implementation Plan (WIGOS-IP) and the evolution of the global observing systems. GCW will coordinate 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), enhancing GCOS support to the UNFCCC. GCW will provide essential data and products needed for services required by users from the Global Framework for Climate Services (GFCS). 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 Global Earth Observation System of Systems (GEOSS).

3 CONCEPTUAL FRAMEWORK

GCW's organizational, programmatic, procedural governance will be based on WMO structures and interfaced with those of partner organizations. An initial framework, or conceptual model, for GCW is given in Figure 1. It illustrates the "why, what, and how" of GCW operation.

An Advisory Group (AG), Management Board (MB), Working Groups (WG) and Task Teams (TT) will be established within the framework for GCW operations. The GCW Advisory Group and a Management Board will initially steer activities, tasks, and the establishment of teams within the available resources. Working Groups are responsible for implementing the GCW tasks through the various Task Teams.

Collaboration and cooperation through co-sponsorship and 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. WIS will play an important role in access, discovery and distribution of cryospheric data and products. GCW data include basic measurements and higher-level products. The GCW Portal is a web interface that contains information about datasets (metadata), but not the data itself. Instead, it links to data that are stored at partner data centres. It is WIS compatible. Information and analysis products will be derived from surface and satellite observations, operational products, reanalyses, and research datasets.

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

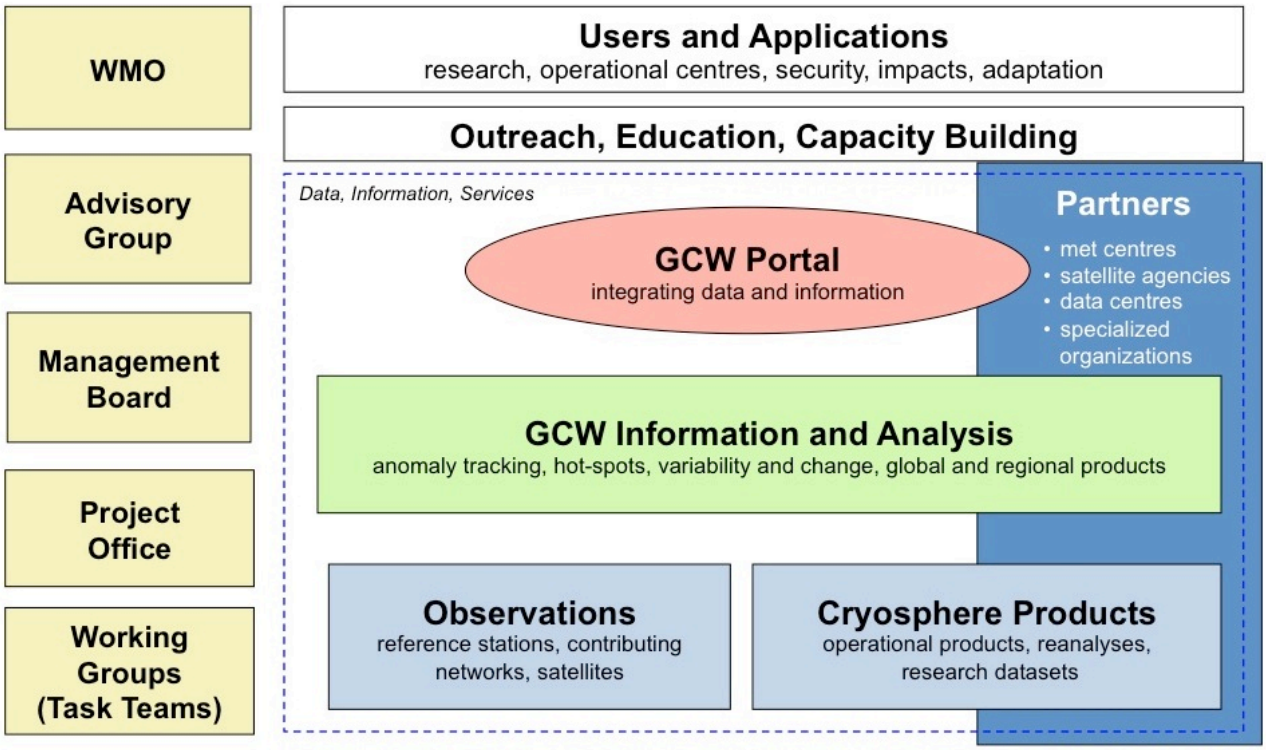


Figure 1: Conceptual Framework for GCW operation.

3.1 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 Management Board. They will serve as the national contact(s) for, and contribute to, the development and implementation of GCW and its activities locally, nationally, regionally and globally. They will liaise with national bodies that have responsibilities for information, products and services related to the cryosphere, engage national representatives of international organizations partnering with GCW, identify national and regional cryosphere-related issues, needs and gaps, engage their WMO Regional Association, identify needs and opportunities for capacity building and resource mobilization. More information on focal point responsibilities is given in the *GCW Focal Points Terms of Reference* (see http://www.wmo.int/pages/prog/www/OSY/Reports/GCW-IM-1_FinalReport_rev1.pdf). To date, over 30 countries from all WMO Regions identified contacts for the development of GCW.

GCW will engage WMO co-sponsored programmes, TCs, RAs, and other organizations that have cryospheric 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 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 is being discussed. Memorandum of understanding or agreements would be established between all sponsors.

3.2 Partnerships and Links with Other International Programs

GCW partnerships are being identified, including government agencies and institutions that measure, monitor, or archive cryosphere data and information from in-situ and satellite research and operational networks and model sources. International bodies and services, such as International Permafrost Association (IPA), the World Glacier Monitoring Service (WGMS), a service of the International Association of Cryospheric Sciences (IACS), the Global Precipitation Climatology Centre (GPCC), and national institutions, such as the US National Snow and Ice Data Center (NSIDC) have already indicated their willingness to support GCW. Additionally, major stakeholders such as the International Council for Science (ICSU) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO will be engaged in the implementation of GCW.

SCAR's expressed interest in GCW will ensure an appropriate linkage with its research programmes. The International Arctic Science Committee (IASC), which has been working with the wider Arctic community through the International Conference on Arctic Research Planning (ICARP) and the Arctic Council to develop a suite of plans for cryospheric observations and Arctic Observing Networks, is envisaged to be engaged in implementing GCW. Interest is also expected from the regional political bodies, the Arctic Council, and the Parties to the Antarctic Treaty. CEOS and major satellite operators like CSA, ESA, Eumetsat, JAXA, NASA, and NOAA are also expected to be involved.

Programmes such as GCOS, GOOS and GTOS (the Global Climate, Ocean, and Terrestrial Observing Systems) will contribute to GCW, as will the ocean and sea ice observations made under the aegis of the Joint WMO/IOC Technical Commission on Oceanography and Marine Meteorology (JCOMM), which includes an Expert Team on Sea Ice. JCOMM is the implementation arm for GOOS, and receives strategic advice from GOOS on what measurements need to be made. The main source of advice to GOOS on ocean measurements, including sea ice, comes from the Ocean Observations Panel for Climate (OOPC), which is co-sponsored by GOOS, GCOS and the WCRP. Other programmes such as the Global Geodetic Observing System (GGOS) may also contribute to GCW.

Advice on sea ice measurements needed in polar regions for climate purposes has been published by GCOS in its 2nd report for the UN Framework Convention on Climate Change (UNFCCC) on the adequacy of the observing systems for climate, in its GCOS Implementation Plan (GIP), and in its supplement to the GIP. GCW will seek reviews, approval and involvement of the CEOS Strategic Implementation Team and work with the GCOS Secretariat, GCOS Panels and implementing bodies.

The WMO-IOC JCOMM Observations Programme Area (OPA) is seen as one of the important mechanisms for GCW implementation, via GOOS and the Data Buoy Cooperation panel (DBCP) in connection with the existing International Programme for Antarctic Buoys and International Arctic Buoy Program. Additional advice on sea ice measurements and polar ocean observing systems will come from regional organizations such as the Arctic Ocean Science Board (AOSB), EuroGOOS, and the newly established Arctic GOOS Regional Alliance, and professional consortia like the International Ice Charting Working Group.

GCOS and GTOS will be major partners for GCW. GTOS and GCOS, currently through the Terrestrial Observations Panel for Climate (TOPC) guide the development of crucial networks as the Global Terrestrial Networks (GTNs) for permafrost, glaciers, hydrology, run-off, and lakes (GTN-P, GTN-G, GTN-H, GTN-R, GTN-L). GCW should work in close cooperation with the TOPC and these terrestrial networks.

Examples of collaborative activities with these programmes and partners include:

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

4 IMPLEMENTATION

4.1 GCW Operating Structure and Key Implementation Tasks

4.1.1 The Advisory Group (AG) and Management Board (MB)

The Advisory Group (AG) will provide high-level guidance on how GCW should continue to develop. It will be concerned with process and general direction more than specific actions, the latter being the role of the Management Board (MB). The AG is expected to be comprised of the MB Chair, experts from EC-PORS, relevant WMO Programmes, TCs and co-sponsored programmes and from contributors, partners and co-sponsors. The MB will help plan and manage the specific tasks and activities of GCW. It will be comprised of the Working Group and Team chairs, a Polar Space Task Group liaison, the WMO Secretariat, and others that may be recommended by EC-PORS.

In the near-term, the Advisory Group will provide guidance on which IGOS Cryosphere Theme (“CryOS”) recommendations and which Pilot and Demonstration Projects GCW should pursue**.** Their implementation will be the responsibility of the Management Board, through the Working Groups and Task Teams.

CryOS provides a framework for developing and implementing GCW. Developed through widespread consultation and review 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. It describes arrangements to ensure that existing

cryospheric data and products are openly accessible to users in a timely and interoperable manner. It highlights the need for the identification and coordination of resources to continuously improve observations as requirements and technology evolve, and reiterates the need for commitment by observing system operators to sustain and augment cryospheric observations and products. GCW will build on these recommendations to ensure a comprehensive, coordinated and sustainable system of observations and information to allow for a full understanding of the cryosphere and its changes.

Not all CryOS recommendations will be implemented by GCW. Some have already been completed; some are beyond the scope of GCW (e.g., designing a new satellite system). Therefore, the first step is to compile a subset of the CryOS recommendations that are within the scope and resources of GCW. The IGOS Cryosphere Theme report and a separate document containing only the recommendations are available at http://igos-cryosphere.org.

Pilot projects will be used to demonstrate various components of the GCW framework:

(a) the types of data and information that GCW could provide for cryosphere components globally, regionally and nationally;
(b) how GCW could build on existing efforts by the cryospheric community;
(c) the time and resources required to create a integrated cryosphere information system;
(d) how to document standards and best practices for observing and product development; and
(e) challenges/gaps/needs that GCW could address.

Demonstration projects would focus on regional or national contributions to standardization, integration and interoperability. Projects will involve contributions of WMO Members, Programmes and TCs, and contributing partners. Potential projects which can 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) The 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.

GCW will build on existing programmes and projects, but additional pilot and demonstration projects need to be established in different regions, including alpine areas, central Asia (notably the "Third Pole"), the tropics, and Antarctica. For example, a demonstration project on data assimilation of snow cover for various regions has been suggested.

4.1.2 The Observing Systems Working Group

The Observing Systems WG will address capabilities and needs for surface-based and satellite observations. It will perform its tasks through the CryoNet Team, the Requirements and Capabilities Team, and the Infrastructure and Practices Team.

4.1.2.1 The CryoNet Team

The *CryoNet Team* will establish the surface-based observational network. It will define the types of sites, e.g., "supersites", reference sites, and/or tiered sites in cold climate regions, on land or sea, operating a sustained, standardized programme for observing and monitoring as many cryospheric variables as possible. It will develop formal procedures for establishing the GCW network, evaluate potential supersites, and determine data availability.

The GCOS implementation strategy envisaged five observation network types for climate:

(a) Comprehensive global observing networks, including regional and national in situ sites as well as satellites;
(b) Baseline global observing networks, a limited number of observations at selected locations that are globally distributed and provide long-term, high-quality data records of key variables;
(c) Reference networks that provide highly detailed and accurate observations at a few locations for calibration purposes;
(d) Research networks that can provide estimates of the local variability of key variables; and
(e) Ecosystem networks, where a number of different variables are measured at several locations within a specific ecosystem.

Like the GCOS network types, CryoNet will be comprised of sites with varying capabilities. CryoNet will build on existing cryosphere observing programmes and promote the addition of standardized cryospheric observations to existing facilities in order to create more robust environmental observatories. It will be a tiered network of "supersites" (tier 1), "reference sites" (tier 2), and "observation sites" (tier 3). The CryoNet Team will determine the required capabilities for each type of site. Supersites are, in the context of GCW, generally single sites that measure a robust set of cryosphere, atmosphere, and ocean characteristics, depending on the location. They may, however, be comprised of multiple sites in a homogenous region. They are particularly important for the study of feedbacks and complex interactions between the atmosphere, cryosphere, and ocean.

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

Members, through their GCW focal points, are being asked to recommend suitable sites. Many Members have proposed contributing to GCW through their sites in China, Finland, the US, Austria, and elsewhere. For example, China has established supersites in the "Third Pole" region where the High Asian cryosphere (HAC) serves as the Asian "water tower" for over a billion people. Finland has the Sodankylä-Pallas site in the boreal forest. Its infrastructure is designed for integrated monitoring of soil-snow-vegetation-atmosphere interaction and provides reference measurements for satellite sensors on a continuous basis. Some of the atmospheric observatory sites operated by the International Arctic Systems for Observing the Atmosphere (IASOA) program are being expanded to include measurements of surface properties, including permafrost, making them ideal for inclusion in CryoNet. Current IASOA member observatories include Barrow-U.S.,

Eureka and Alert-Canada, Summit-Greenland, Ny-Alesund-Norway, Abisko-Sweden, Pallas and Sodankylä-Finland, Tiksi and Cherski-Russia, and the Arctic Drifting Station-Russia.

The *CryoNet Team* will specify a core set of measurements for each site type. An example for sites where snow is the primary parameter is given in Appendix 1. The team will also develop a network strategy and formal procedures for becoming part of the GCW network, evaluate selected sites, and determine data availability.

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

4.1.2.2 The Requirements and Capabilities Team

The *Requirements and Capabilities Team* will assess user needs, periodically review and update observing system requirements and capabilities and contribute to the WMO Rolling Review of Requirements database, link to the WMO Polar Space Task Group (PSTG).

The team will engage with the user community to help determine which cryospheric data types are most important, to identify the spatial, temporal, and knowledge gaps, and to address other aspects of data usability such as error assessments and data formats. Users will be engaged through dedicated workshops and comprehensive surveys. Requirements may vary regionally.

Observational requirements and capabilities will be periodically updated based on evolving user needs, instrumentation, and error analyses. 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.

Periodic review and update of observing system requirements and capabilities is necessary and will contribute to the WMO Rolling Review of Requirements database. A new cryosphere application area should be considered for 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.

4.1.2.3 The Infrastructure and Practices Team

The *Infrastructure and Practices Team* will conduct an inventory of the current network, including infrastructure and practices, compile best practices, guidelines, and standards, determine what should be measured, and facilitate interaction and collaboration between the scientific and operational communities.

A critical component in the development of CryoNet is the effort to establish best practices, guidelines and standards for cryospheric measurements. This will include consideration of data homogeneity, interoperability, and compatibility of observations from all GCW observing and monitoring systems and derived cryospheric products.

The *Infrastructure and Practices Team* will review existing instrument and observing methods and practices for the cryosphere in the Guide to Meteorological Instruments and Methods of Observation (CIMO Guide), and consider whether the CIMO Guide should be expanded to include instruments for the cryosphere. A "GCW Manual" could provide input to the WIGOS Manual and the CIMO Guide. All standard practices will be documented in the WMO Technical Regulations. GCW should establish small task groups to initiate the compilation of current guidelines, standards and best practice in use in the cryosphere community.

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 (including snowfall & snow depth) is of direct relevance to GCW, and is considered as a contribution to GCW. GCW reference sites might be suitable sites for inclusion in this intercomparison.

4.1.3 The Products and Services Working Group

The Products and Services WG will decide, in consultation with the Advisory Group, the Management Board, and all Teams, which products and services GCW will provide and develop the "clearinghouse" for products and services. It will facilitate the harmonization of products (e.g., multiple sea ice estimates), facilitate product intercomparisons, develop data policies for GCW, including data exchange by WMO Members, and work with the Observing Systems WG to facilitate interaction between the operational and research communities. The Products and Services WG will perform its tasks through the Products Team, the Portal Team, and the Outreach Team.

4.1.3.1 The Products Team

The *Products Team* will select a set of key GCW datasets. It starts with developing an inventory of candidate in situ and satellite products for GCW that are mature and generally accepted by the scientific community. It includes an intercomparison of products to assess quality and to ensure an authoritative basis. It will facilitate the harmonization of products (e.g., multiple sea ice estimates), facilitate product intercomparisons, and develop data policies for GCW.

The *Products Team* will encourage, and support where possible, workshops for intercomparisons of similar products. For example, the WCRP/SCAR/IASC Climate and Cryosphere Project (CliC) recently 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 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 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. As a first step, plots of cryospheric elements will be generated using currently available operational products. For example, Figure 2 is a plot of NH near real-time snow cover extent (SCE) from two operational snow analyses: the Canadian Meteorological Centre (CMC) daily snow depth analysis and the NOAA/National Ice Center Interactive Multi-Sensor Snow and Ice Mapping System (IMS) 24 km daily snow cover analysis. The "normal" range for SCE was determined from the NOAA monthly CDR product maintained at Rutgers University.

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.

The *Products Team* will have a *Terminology Sub-Group* which will also identify current cryosphere glossaries, and develop/evaluate terminologies, vocabularies, and ontologies. It will have focus areas for snow, sea ice, ice sheets, glaciers, permafrost, and climate modelling.

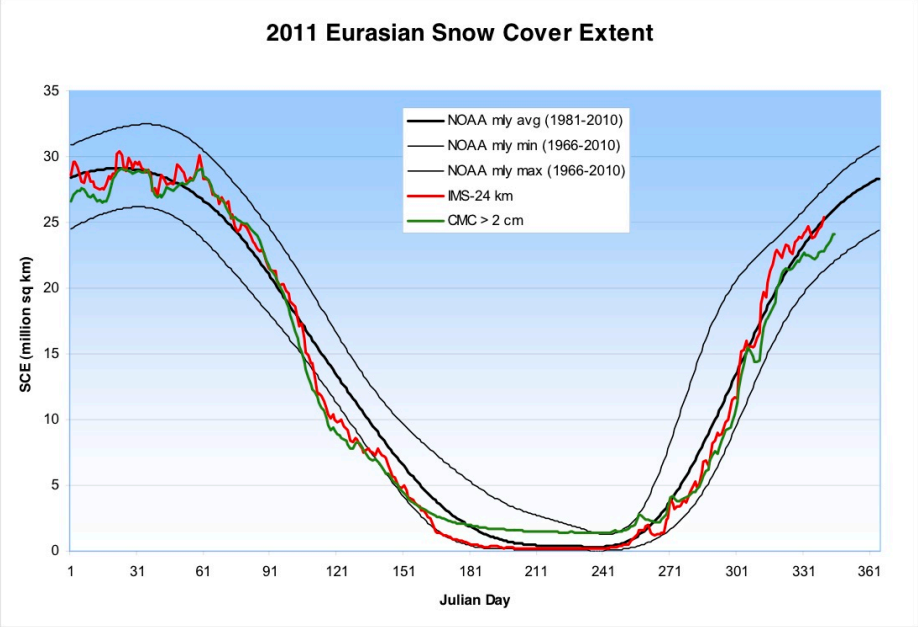


Figure 2: Example of a product for monitoring snow cover. (Courtesy of R. Brown)

4.1.3.2 The Portal Team

The *Portal Team* will develop the GCW web portal. It will evaluate candidate products, including meteorological data, and prepare an initial plan for development including linking to data contributors, testing by partners, working with national focal points, and developing documentation for outside use. It will work through interoperability issues with data centres and other programmes.

The GCW web portal will make GCW data and information available to WMO Members, their partners, and users while providing the ability to exchange data and information among a distributed network of providers of data and products (Figure 3). The portal will be WIS-compliant, will allow for rapid exchange of data, metadata, information, and analyses.

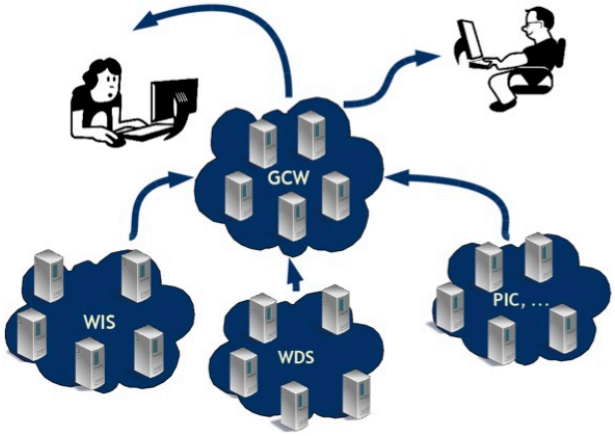


Figure 3: A web portal that links existing catalogues and portals is sustainable. Data resides in its original location while metadata are exchanged. (Courtesy of Ø. Godøy)

The portal and associated data and information will be capable of including all elements of the cryosphere at national, regional and global scales. It will provide access to data and information on past, present and future cryospheric conditions, and be able to draw on operational and research-based observation and monitoring and modelling. GCW will ensure access to real time, near-real time and historical cryospheric data and products. GCW will respect partnership, ownership and data-sharing policies of partners. It will allow new types of information to be widely distributed, such as real-time cryospheric "hot news" (e.g. extremes, physical or socio-economic impacts, new research results).

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

A prototype GCW web portal has been developed by the Norwegian Meteorological Institute (METNO), building on their web-based tool for searching data. IPY data centres/portals, such as METNO, Canadian Cryosphere Information Network (CCIN), British Antarctic Survey (BAS), and US National Snow and Ice Data Centre (NSIDC) are already interoperable. This approach will facilitate seamless access with NMHSs and external data centres holding relevant cryospheric data and information at the national or global scale. After further development of the demonstration portal, tasks include testing by partners, working with national focal points, and developing documentation for outside use.

A GCW website is also being developed (http://globalcryospherewatch.org). 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 materia, a description of the contributing observing networks and their capabilities, information on standards and best practices, and data policies. It will link to the METNO data portal. The website is an information resource; the portal is a metadata resource.

The types of data and products that GCW will make available through its web portal and website are dictated by user needs. User needs can be summarized as:

(a) *Long-term, sustained, high quality observation and monitoring of cryospheric parameters at key sites/networks* to meet specific national needs (e.g. building snow loads, agriculture, water security, transport, tourism, public security, natural hazards).
(b) *Real-time information for operational forecasting,* including estimates of uncertainty.
(c) *Research datasets for process and climate model validation*.
(d) *Public and media*. The main issues are credibility (accuracy, accountability), up-to-date information, quick access, and the ability to monitor and respond to cryosphere anomalies.
(e) *Future scenarios for long-term planning strategies, policy development*.

4.1.3.3 The Outreach Team

The *Outreach Team* will be an authoritative voice on cryosphere issues, be available to speak to the media and policymakers, provide guidance for outreach products, facilitate training of students and early career scientists, work with social media (blogs, Facebook, Twitter), and issue semi-annual or annual newsletters.

GCW will have numerous, diverse stakeholders both within WMO and with its partners. GCW will establish an effective communication, outreach and education strategy in collaboration with WMO Members, Programmes, RAs, TCs, co-sponsors and partners. It will take advantage of outreach programmes developed and effectively deployed through IPY and with organizations such as

Association of Polar Early Career Scientists (APECS) and the Global Learning and Observations to Benefit the Environment program (GLOBE) program. The GCW website will provide relevant information on communication, outreach and capacity building, aimed at complementing, not duplicating, others' efforts. Given the importance of terminology in communication and outreach, this team will work with the Terminology Sub-Group to identify current cryosphere glossaries, and to develop or evaluate terminologies, vocabularies, and ontologies.

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

4.2 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, including tropical, glaciers, and improved understanding of the impact of cryospheric changes in the Antarctic on extreme weather and climate in tropical and sub-tropical regions has been identified by Members as a need to which GCW can contribute.

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

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

4.3 Project Phases

4.3.1 GCW Definition Phase (2007-2011)

Following a review of the feasibility study for developing and implementing GCW within WMO, EC-LXI endorsed the next steps for developing GCW with the guidance of its EC Panel of Experts on Polar Observations, Research and Services (EC-PORS). 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.

4.3.2 GCW Implementation phase (2012-2019)

The Implementation phase, undertaken between 2012 and 2019, will be coordinated by WMO and its partners. It will focus on developing and implementing GCW through tasks and activities that will form this GCW Implementation Plan. Initial timelines, and deliverables are given in the *Deliverables and Milestones* section.

4.3.3 GCW Operational Phase (2020 onward)

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

5 DELIVERABLES AND MILESTONES

Upon approval and within available resources, GCW will address tasks associated with the key deliverables and milestones. Figure 4 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.

Key implementation activities are given in Table 2. Some of these were described earlier in the Plan. The responsible GCW Task Teams and relevant outside groups that are expected to contribute (data centres, national agencies, etc.) are listed. The approximate implementation timeframe for each activity is also given.

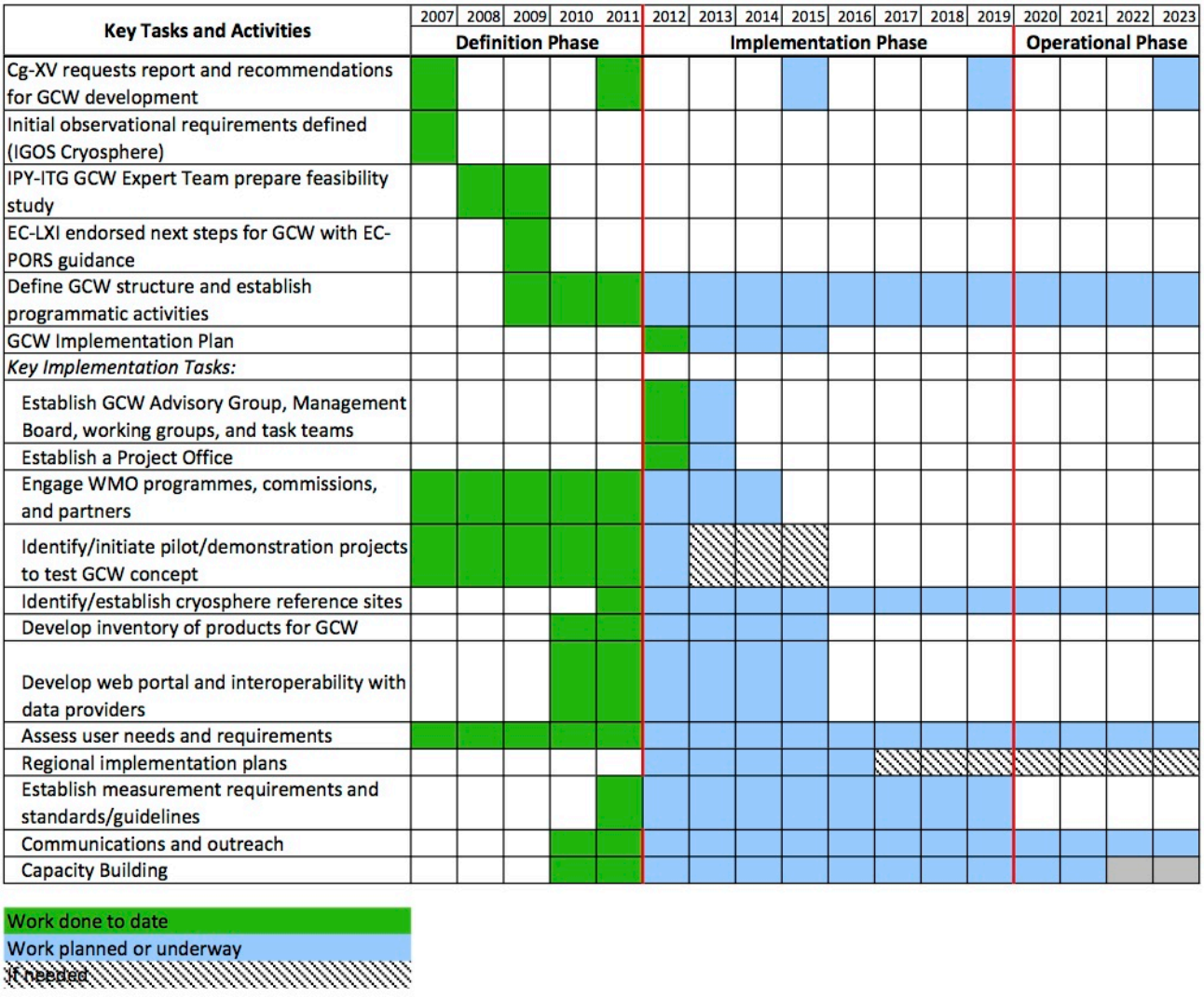


Figure 4: GCW Milestones and Deliverables as agreed by Cg-XVI.

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

6 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.

6.1 Oversight

The WMO Executive Council, through its EC-PORS, will oversee GCW's development and implementation, recognizing that the structure of the Secretariat will have to adapt, as and when appropriate, to ensure optimal management of, and support to, the initiative.. The Advisory Group will provide high-level guidance. A Management Board will be more directly involved in GCW implementation and operations.

6.2 GCW Secretariat

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

- Finalize the terms of reference for Focal points
- Make available all relevant information to the AG, MB, WGs, TTs, 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 teams, as needed
- Seek funding opportunities
- Maintain the Implementation Plan (with assistance from teams)
- Provide financial guidance and co-ordination
- Seek WMO and other support for GCW meetings, as appropriate
- Provide travel arrangements and support for GCW meetings, as needed

The Secretariat shall report to EC-PORS annually on GCW activities.

The Secretariat requires staffing of at least one position, and shall be reviewed on a bi-annually by EC-PORS. An IPO would provide a viable arrangement for the Secretariat. Based on the proposals from WGs and TTs, it will coordinate the production of relevant bulletins and outreach materials for the scientific community, the general public, funding agencies, and policy-makers.

6.3 Meetings and Reporting

The GCW Management Board will report to EC-PORS at its annual meetings. EC-PORS will provide guidance on GCW structure, tasks, and progress. Reports will be provided to Congress every four years, as required. In addition to reports given to EC-PORS and Congress, GCW will report on progress in its semi-annual or annual newsletters.

Implementation meetings will be held every 2-4 years. The implementation meetings will include participants from a broad cross-section of the cryosphere community as well as national, institutional, and program focal points. All aspects of GCW implementation will be evaluated.

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

6.4 Indicators of Success

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

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 satellite products by cryospheric element
5. Satellite product inventory (percent complete)

Portal

6. Interoperability (percent complete)
7. Number of products accessed
8. Number of users

Outreach and communication

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

Other

12. Number of CryOS recommendations that have been implemented

7 RESOURCES

7.1 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 would be needed in the WMO Secretariat for GCW implementation activities and should be funded jointly by the WMO regular budget and other sources, including:

- GCW and EC-PORS Trust Funds to supplement the WMO regular budget;

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

A GCW International Programme Office (IPO) hosted by a Member(s) is also seen as a viable option.

8 REFERENCES

1. Sixteenth WMO Congress Resolution on GCW (Cg-XVI Res. 11.9/6)
2. List of Member Focal Points
3. GCW Focal Points Terms of Reference

APPENDIX 1: SAMPLE LIST OF PARAMETERS TO BE MEASURED AT SURFACE LAND SITES

A potential list of parameters to be measured at sites where snow is the primary cryospheric element is given below. The list will be further developed by the CryoNet Team. Glacial, ice sheet, permafrost, and sea ice sites will have different measurement requirements.

Parameters to be monitored at supersites

Continuous automatic data (distributed observations covering different land cover types)

- Soil moisture profiles (distributed)
- Soil temperature/soil frost profiles (distributed)
- Snow depth and/or SWE (distributed)
- Snow temperature profiles (distributed)
- 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)
- Disdrometer observations on precipitation
- Atmospheric soundings (troposphere and stratosphere)
- CO2 and/or methane fluxes between the atmosphere and soil-vegetation system (preferably for different ecosystems)
- Water table depth on wetlands

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/photography and/or specific surface area (SSA) measurements)
- Soil frost depth
- Snow surveys (snow courses with a preferable length of some kilometers)

Optionally

- Specific reference measurements for cryosphere monitoring satellite instruments
- Aerosol optical depth
- Energy fluxes (sensible, latent and soil heat), evaporation/transpiration and soil respiration.

Parameters to be monitored at reference sites

Continuous automatic data

- Soil moisture profiles
- Soil temperature/soil frost profiles
- Snow depth and SWE
- Snow temperature profiles
- Automatic synoptic weather station observations
- Radiation observations (incoming and reflected)

Regular manual observations

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

APPENDIX 2: LIST OF ACRONYMS

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

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

ANNEX 1: WMO DECISIONS ON GCW

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

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

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

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

GCW and the WMO Strategic Plan

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

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

ANNEX 2: CRYOSPHERE OBSERVING SYSTEM GAPS

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

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

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

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

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

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