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A Global Cryosphere Watch

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Executive Summary

There is now an unprecedented demand for authoritative information on past, present and future state of the world's snow and ice resources. The cryosphere, which includes solid precipitation, snow cover, sea ice, lake and river ice, glaciers, ice caps, ice sheets, permafrost, and seasonally frozen ground, exists in various forms at all latitudes and in about one hundred countries. It is one of the most useful indicators of climate change, yet is one of the most under-sampled domain in the climate system.

The International Polar Year (IPY) helped demonstrate the urgent need for a sustained, robust, end-to-end cryosphere observing and monitoring system not only for polar regions, but globally. The Sixteenth World Meteorological Congress (Geneva, 2011) decided to embark on the development of a Global Cryosphere Watch (GCW) as an IPY legacy with a view of an operational GCW. GCW is now being implemented for sustained cryosphere observing, monitoring and provision of data and information.

GCW will provide service-oriented information for informed decision-making and policy development related to climate, water and weather. It will ensure a comprehensive, coordinated and sustainable system of observations and information that will allow for a full understanding of the cryosphere and its changes. This includes initiating a surface-based cryosphere observing network called "CryoNet", which will lead in the effort to establish best practices, guidelines and standards for cryospheric measurement. A complementary task involves developing an inventory of candidate satellite products that are mature and generally accepted by the scientific community. GCW is establishing interoperability between data management systems, and the GCW data portal will make data and information available to users while providing the ability to exchange data and information among a distributed network of providers.

1. Background, Mission, and Objectives

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. It is not surprising, therefore, that the cryosphere, its changes, and its impacts have received increased attention in recent years. Today it receives constant coverage by the media, creating a demand for authoritative information on the state of the world's snow and ice resources from polar ice to tropical glaciers, based on data from the paleoclimate record, current observations, and future projections.

The World Meteorological Organization (WMO), with the cooperation 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). At its Sixteenth World Meteorological Congress (Cg-XVI) in 2011, WMO considered the GCW Implementation Strategy, which outlines the next steps for developing GCW, and decided to embark on GCW development as an IPY Legacy with a view of

an operational GCW. WMO's Executive Council Panel of Experts on Polar Observations, Research and Services (EC-PORS) guides the development of GCW. Support for GCW was expressed by representatives of countries from all of WMO's six Regions, with many developing countries specifically identifying the important impacts that glacier change is having on their country.

GCW is 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, and between scientists and practitioners. GCW implementation encompasses:

- *Requirements:* Update the requirements identified in the Integrated Global Observing Strategy (IGOS) Cryosphere Theme; contribute 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;
- *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).

The observing component of GCW is one of the four components of WIGOS. 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). 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). 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.

2. Framework

The conceptual framework for GCW is given in Figure 1. It illustrates the "why, what, and how" of GCW operation. 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.

GCW data include basic measurements and higher-level products. The GCW Portal is a web interface that contains information about datasets (metadata), but generally 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.

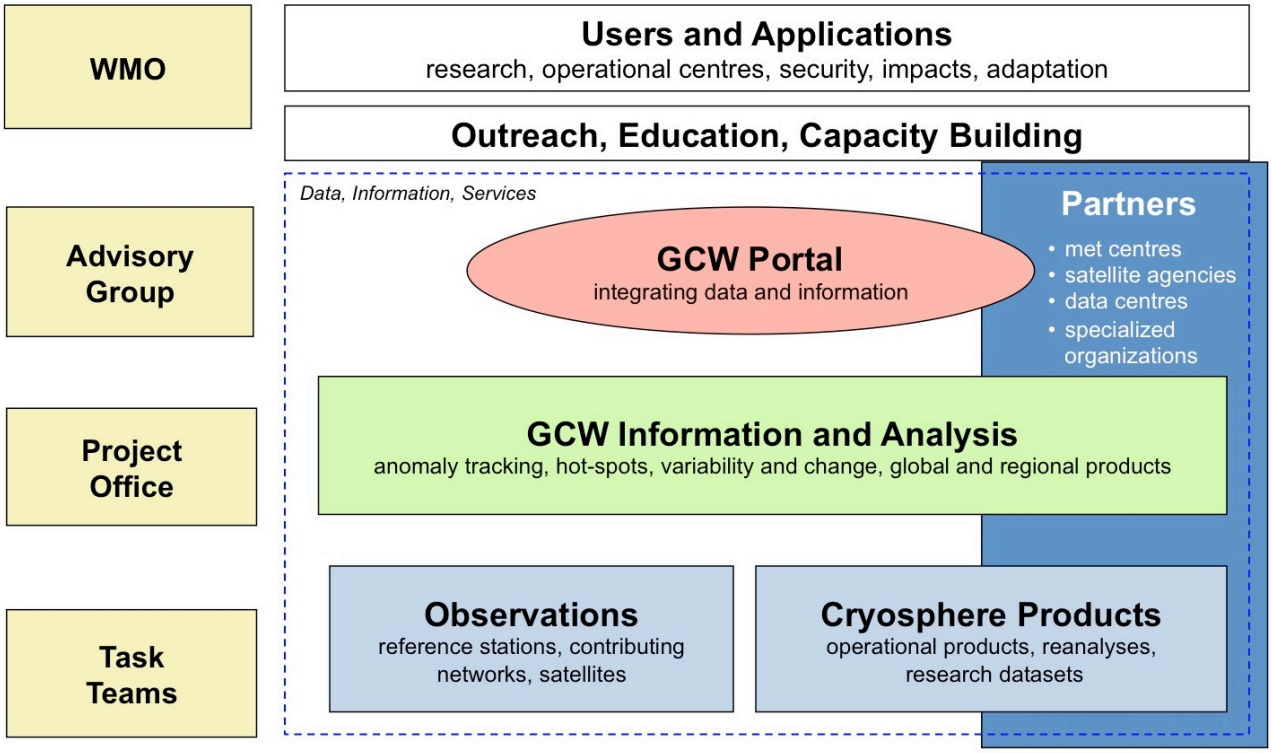

Figure 1. The conceptual framework for GCW operation.

The implementation of GCW will be done primarily by its task teams. The *CryoNet Team* establishes the surface-based observational network. It is currently defining 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 is developing formal procedures for establishing the GCW network, evaluate potential supersites, and determine data availability.

The *Requirements and Capabilities Team* assesses user needs, periodically reviews and updates observing system requirements and capabilities, contributes to the WMO Rolling Review of Requirements database, and links to the WMO Polar Space Task Group (PSTG).

The *Infrastructure and Practices Team* conducts an inventory of the current network, including infrastructure and practices, compiles best practices, guidelines, and standards, determines what should be measured, and facilitates interaction and collaboration between the scientific and operational communities.

The *Products Team* selects 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 *Portal Team* is developing the GCW web portal. It evaluates candidate products, including meteorological data, and plans further portal development including linking to data contributors, testing by partners, working with national focal points, and developing documentation for outside use. It works through interoperability issues with data centres and other programmes.

The *Outreach Team* is an authoritative voice on cryosphere issues, is available to speak to the media and policymakers, provides guidance for outreach products, facilitates training of students and early career scientists, works with social media, and issues newsletters.

Prioritization of tasks will be accomplished through meetings with the cryosphere community, guidance from the Advisory Group, and Task Team workshops. 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 where prioritized in the First CryoNet workshop (November 2012, Vienna) and the First Snow Watch Workshop (Toronto, January 2013). Future workshops such as these will provide valuable guidance on GCW implementation.

3. Measurements, Products, and Data

Achieving sustained observation and monitoring of the cryosphere and related environmental variables is a key task in the development of GCW. A comprehensive cryosphere observing system must be a combination of ground-based instrumentation, satellite remote sensing, aircraft measurements, modeling, and data management (Figure 2). Surface and airborne observations provide data that cannot currently be measured from space, more detailed information in critical areas, and observations with which to calibrate and validate satellite retrievals. Satellite instruments are essential for delivering sustained, consistent observations of the global cryosphere, and are a key to extending local in situ measurements. Surface-based measurements and satellite products are the two main components of the GCW observing framework.

National weather and ice services, space agencies, and research groups are critical to the implementation and success of GCW. They provide the basic observations for GCW, but also influence measurement practices, observational requirements, and product selection.

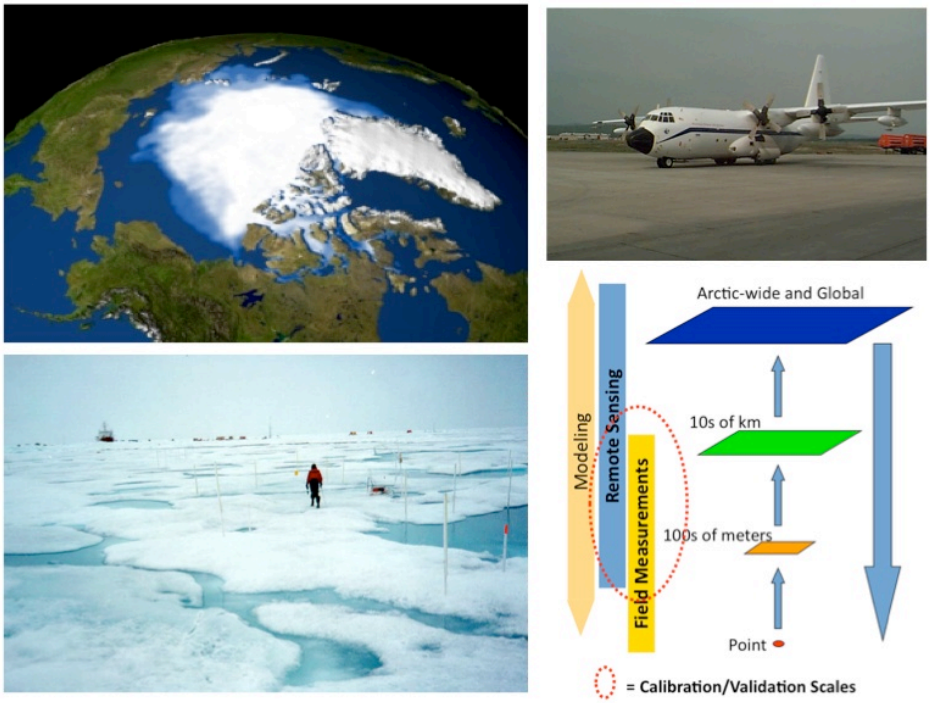

Figure 2. The various observational system types, satellite, aircraft, and in situ, and the scales of operation. Sources clockwise from upper left: NASA, J. Key (NOAA), B. Goodison (WMO), W. Abdalati (NASA).

3.1 CryoNet

GCW will initiate a comprehensive cryosphere observing network called "CryoNet", a network of reference sites or "supersites" in cold climate regions, on land or sea, operating a sustained, standardized programme for observing and monitoring as many cryospheric components as possible. Initially, it will build on existing cryosphere observing programmes or add standardized cryospheric observations to existing facilities to create supersite environmental observatories.

CryoNet covers all components of the cryosphere: glaciers, ice shelves, ice sheets, snow, permafrost, sea ice, river/lake ice, and solid precipitation. Whereas some of these cryospheric components are already measured by existing networks (e.g. GTN-P for permafrost or GTN-G for glaciers), other components are not integrated into equivalent networks (e.g. sea ice). In order to meet different user needs and because of the spatially distributed nature of different components of the cryosphere, CryoNet will be structured into three different classes of observational sites: Baseline sites, Reference sites, and Integrated sites[1] (Figure 3).

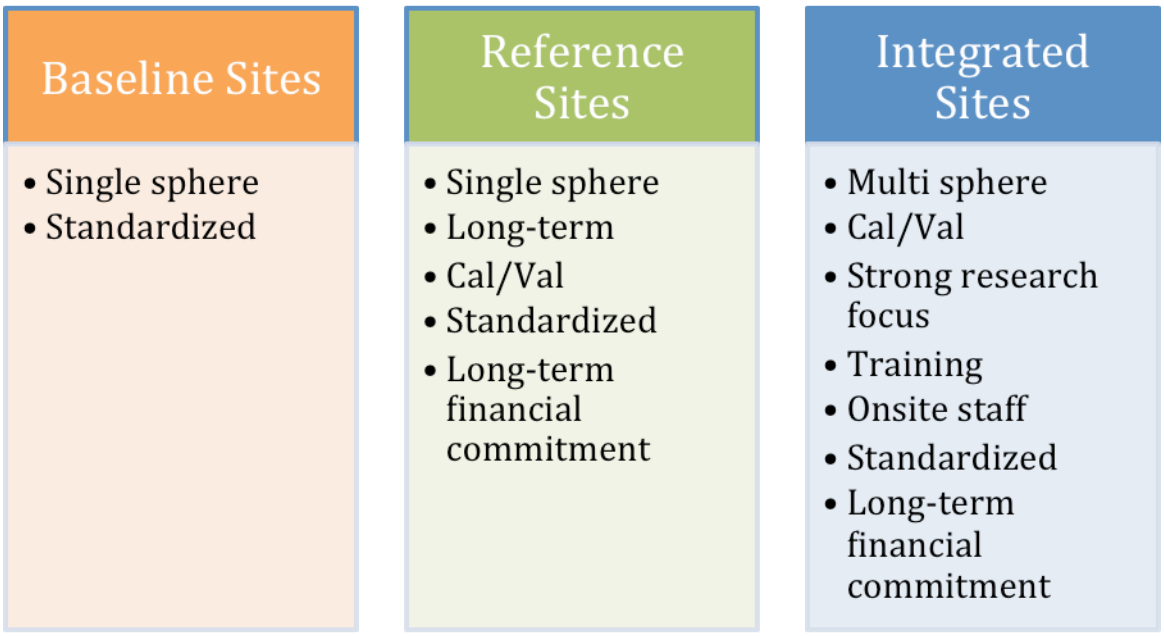

Figure 3: Proposed CryoNet site types and characteristics[1]. "Sphere" refers to the different components of the climate system, e.g., cryosphere, atmosphere, biosphere.

WMO Members, through their GCW focal points, have been 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. Participation in CryoNet workshops by groups such as IASOA and the Global Atmosphere Watch (GAW) is essential.

Similarly, the GCOS/GTOS Networks for Permafrost (GTN-P), Glaciers (-G) and Hydrology (-H) may offer potential reference sites while providing key observations from their global networks.

[1]The structure, terminology, and characteristics for the different site types are currently being developed and may change in the near future.

The World Glacier Monitoring Service (WGMS), for example, has expressed its willingness to support GCW with data, information and expertise from within the Global Terrestrial Network for Glaciers (GTN-G).

3.2 Satellite Products

For satellite products, the Polar Space Task Group of EC-PORS, with its direct connection to space agencies, will work with GCW to help identify new products to support GCW services. The satellite observing system for the cryosphere is robust, and missions planned for the next 10-20 years will provide even greater capabilities (Figure 4). Many satellite-based snow and ice products exist, and many new products are planned.

However, because there are often multiple satellite products for the same geophysical variable (e.g., snow cover), intercomparison efforts are needed in order to evaluate the strenghs and weaknesses, error characteristics, and overall maturity of each. GCW will encourage and support workshops for the intercomparison of satellite products.

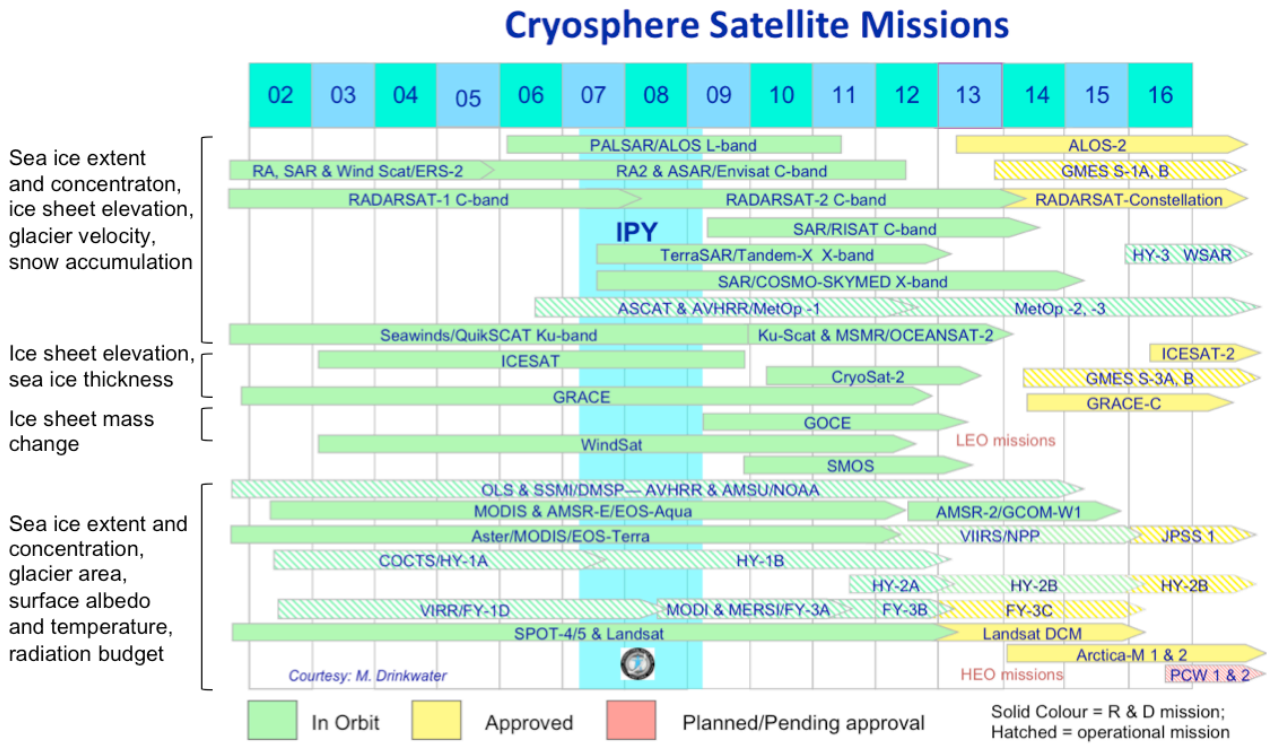

Figure 4. Timeline of satellites used for measuring and monitoring the cryosphere, as of October 2012. Source: adopted from a figure by M. Drinkwater, European Space Agency.

It is anticipated that satellite agencies, particularly through the PSTG, will provide guidance in the development of the surface observing network, given the importance of in situ observations for the validation of satellite products.

3.3 The GCW Data Catalogue and Information Website

The GCW web data catalogue, or “portal”, will make GCW data 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 5). The portal will be WIS-compliant

and will allow for rapid exchange of data, metadata, information, and analyses.

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).

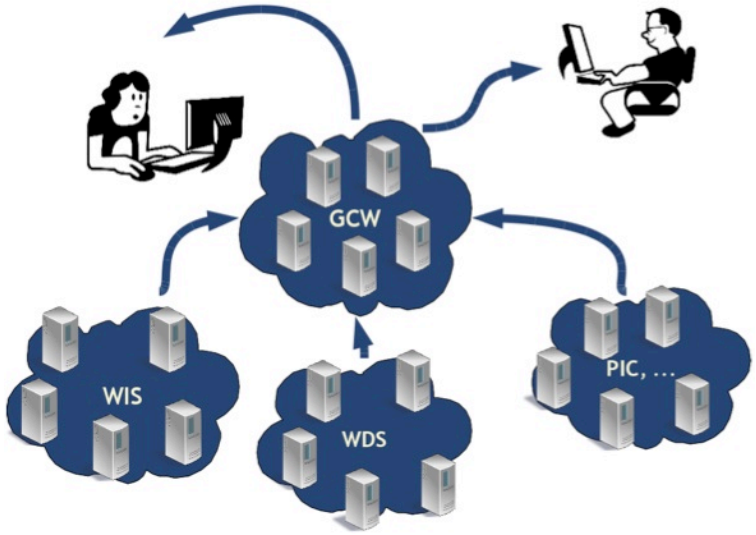

Figure 5. A web portal that links existing catalogues and portals is sustainable. Data resides in its original location while metadata are exchanged.

A GCW information website has been 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 material, a description of the contributing observing networks and their capabilities, information on standards and best practices, and data policies. It will link to the data portal. The website is an information resource; the portal is a metadata resource.

4. Status and Contributions

GCW implementation has begun. The first GCW implementation meeting was held in late 2011. The first CryoNet development meeting was held in late 2012. CryoNet site types and requirements are being defined. Existing measurement standards are being identified and evaluated.

Recent satellite product intercomparison workshops for sea ice and for essential climate variables sponsored by the World Climate Research Programme (WCRP) have provided a framework for future GCW intercomparison workshops. A GCW “Snow Watch” workshop along these lines took place in January 2013. The WMO Polar Space Task Group is helping identify satellite products relevant to GCW.

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.

Partnerships are a key element in the design and development of GCW. GCW partnerships have been, and continue to be, established, 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) are examples of bodies which have been engaged in the development of GCW. Participation in GCW is strongly encouraged. Collaboration, both on individual and institutional levels, can take many forms, such as

- coordination of GCW implementation,
- coordinated observing, capacity building and training with existing networks,
- compilation and development of manuals on best practices for cryospheric measurements and observation,
- co-publication of glossaries of cryospheric vocabulary and terminology,
- 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
- development of outreach materials and methods.

The current GCW Implementation Plan is available online at http://globalcryospherewatch.org. Comments are welcome.

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