



World Meteorological Organization

Weather • Climate • Water

# ***Global Cryosphere Watch (GCW)***

**Barry Goodison<sup>1</sup> and Jeff Key<sup>2</sup>**

**<sup>1</sup>Vice-Chair, GCW Steering Group (WMO, retired)**

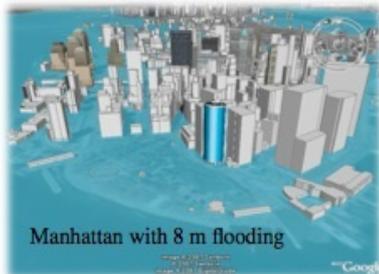
**<sup>2</sup>GCW Senior Scientist (US NOAA/NESDIS)**

**On behalf of GCW Steering Group**

**Scoping Workshop on Climate Services for Polar Regions:  
Establishing Polar regional Climate Centres Towards  
Implementing an Arctic PRCC-Network**

**Geneva , Switzerland, Nov 17-19, 2015**

Cg-16 (2011)...WMO needs to have a focus on global cryosphere issues to be able to provide authoritative information to meet Members' responsibilities on regional and global weather, climate, water and related environmental matters and seasonally frozen ground (\*GCOS ECV)



**Changes in the cryosphere can have significant impacts on....**

**The Global Earth System:**

**Cg-17 (2015) decided:**

- Sea level rise
- **to mainstream and implement GCW in WMO Programmes as a cross-cutting activity;**
- Climate
- Ocean circulation
- Atmospheric circulation

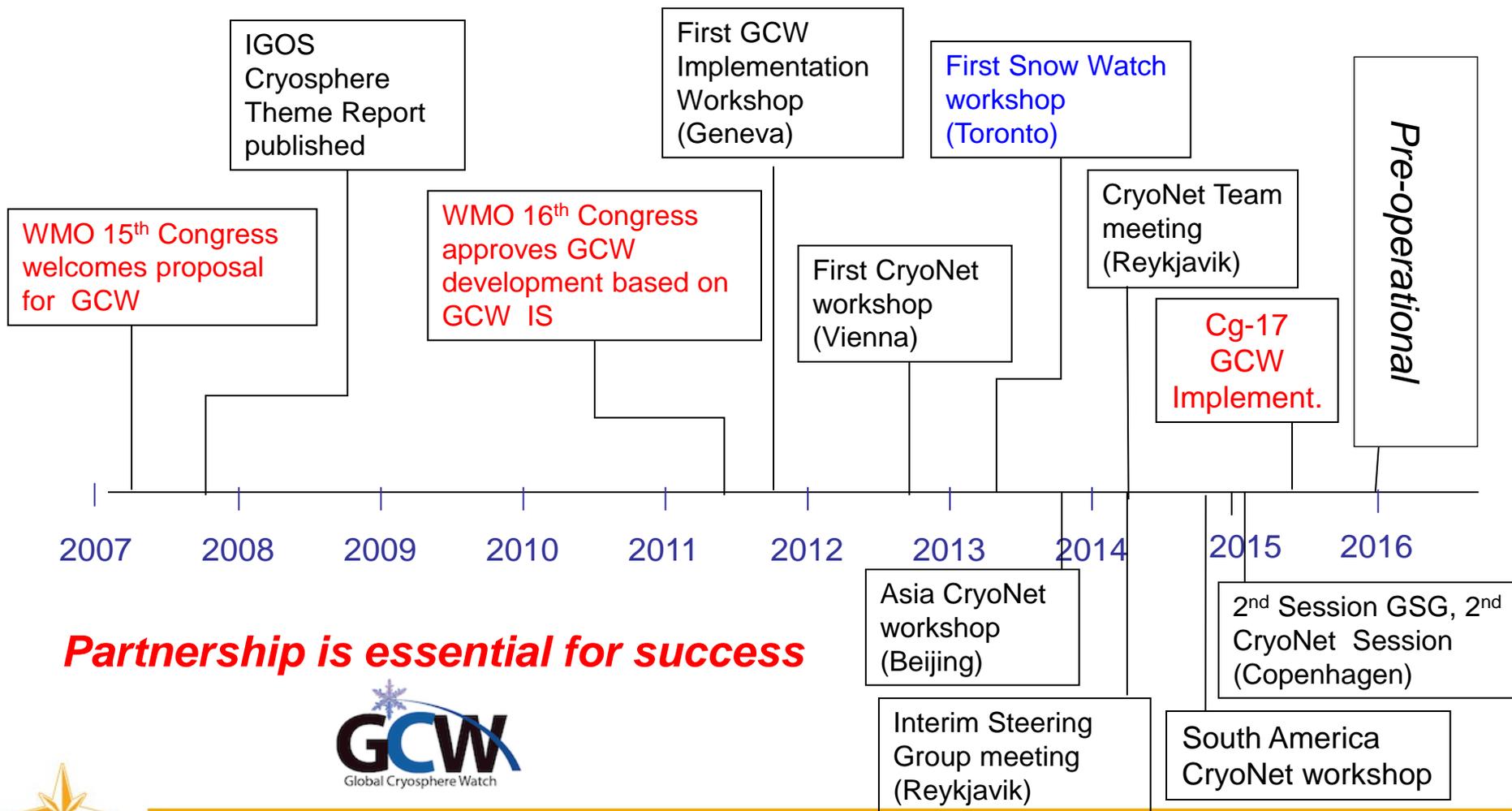
- that implementation activities will be undertaken during the next financial period as one of the major efforts of the Organization with the goal that

**Regional and local impacts:**

- Natural resources and hazards
- Ecosystems
- Food production and fisheries
- GCW should become operational;**
- Infrastructure
- Transportation
- Recreation
- GHG emissions



**GCW Mission:** GCW will provide authoritative, understandable, and useable data, information, and analyses on the past, current and future state of the cryosphere to meet the needs of WMO Members and partners in delivering services to users, the media, public, decision and policy makers.



**Partnership is essential for success**



## ***GCW Building on Past Accomplishments:***

### ***UNESCO - Climate Change and Arctic Sustainable Development: scientific, social, cultural and educational challenges – Monaco, 2009***

**Identified knowledge gaps and made more than 67 recommendations:** Education, communication and outreach (6+); Cultural heritage (7); Well-being and health (4); Economic development and resource management (11); Arctic Governance (14); ***Establishing, sustaining and strengthening research and monitoring systems (15+); Information access and data sharing (4+);*** Policy and decision Support(6)

- Given the limited number of ***observation networks*** in the Arctic, sustaining, strengthening and further developing long-term comprehensive multidisciplinary integrated pan-arctic observing systems is recommended
- recommended the ***cryosphere aspects*** of this pan-arctic system be linked to GCOS (GOOS, GTOS) in the Arctic, and GCW.
- promote implementation of research and monitoring activities into operational services, including establishment of a viable operational mechanism, such as the ***Polar Climate Outlook Forum*** (PCOF) to facilitate effective interactions between climate professionals and users/stakeholders (as an IPY legacy).
- ***WMO and UNESCO, as designated conveners by the UN*** for enhanced UN collaboration on climate knowledge: science, assessment, monitoring and early warning, invited to promote UN collaboration for establishing, sustaining and strengthening research and monitoring systems in the Arctic.



# *GCW Building on Past Accomplishments: SWIPA recommendations are important considerations for GCW observing systems in the Arctic*

- There are numerous snow and ice measurement **sites across the Arctic** , but operations at existing sites are, **in general, not well coordinated**
- A need to **improve coordination of resources** provided by national and international agencies responsible for cryospheric observations, and to **facilitate transition of research-based products into sustained monitoring systems**
- Need to **standardize** the types and methods of measurements at surface stations
- Satellite observing system is robust, with a few potential gaps in long-term
- **Traditional knowledge** can provide **important** value-added content to data products and information and serves to make data more useful and relevant to northern users
- **Community based observing programs** provide a mechanism for two-way knowledge transfer
- **Existing cryospheric data are underutilized**; use of cryospheric data in weather and climate models needs to be extended



# GCW Building on Past Accomplishments: User Needs are Critical: CryoLand User Group

## **CRYOLAND USER GROUP:**

60 Organisations from 15 European countries + 3 EU organisations:

- Product & Service Requirements and Specs
- Product & Service Testing and Evaluation

- Hydropower companies
- Energy traders
- Hydrological services
- Meteorological services
- Climate monitoring institutions
- Avalanche warning centres
- Road, Railway and River Authorities
- Geotechnical & Construction companies
- Ecologists
- Reindeer herders
- Environmental agencies



# *GCW - Relevance to PRCC*

GCW will ensure a ***comprehensive, coordinated and sustainable system of observations and information*** to allow for a more complete understanding of the cryosphere (past, present and future) and to ***contribute to the improved observations, research and services that are essential*** to fully assess, predict, and adapt to the variability and change now witnessed in the Arctic

***Cryosphere is a defining characteristic of polar and high mountain regions***

***GCW addresses GCOS ECVs (more than T&P)***

***GCW and PRCC both have operational mandates***



## *GCW Activities Relevant to PRCC (what is GCW doing, or what's happening that wouldn't otherwise happen)*

- developing a **network of surface observations**, with "CryoNet" at the core, which builds on existing networks;
- establishing **measurement guidelines** and best practices;
- refining **observational requirements** for the WMO RRR;
- engaging in and supporting **intercomparisons of instruments and products**, e.g., the **GCW Snow Watch** project;
- **enhanced** near real-time snow depth observation on the GTS/WIS and **reporting** of zero snow depth (with modelling centres and CBS);
- contributing to WMO's space-based capabilities database (with PSTG);
- **evaluation/intercomparison** of satellite snow products initiated with ESA (SnowPEX);



## *GCW Activities Relevant to PRCC...2*

- producing ***unique hemispheric products***, e.g., “snow anomaly trackers” for SCE and SWE in collaboration with partners;
- engaging in ***historical data rescue*** (e.g., snow depth);
- building a ***glossary of cryospheric terms***;
- developing international training, outreach materials; co-sponsoring workshops
- providing ***up-to-date information on the state of the cryosphere***;
- providing ***access to data and metadata*** through a portal;



# ***THE NEED FOR COMMON GCW CRYOSPHERE TERMINOLOGY (in all WMO languages)....an issue for PRCC and PCOF?***

- **Snowfall:** (1) Snow falling. (2) Depth of fresh snow deposited on the ground during a specific period. (WMO)
- ❖ **Snow cover:** Covering of the ground, either completely or partially, by snow. (METEOTERM)
- ❖ **Snow cover:** Areal extent of snow-covered ground, usually expressed as per cent of total area in a given region.
- ❖ **Snow cover:** In general, the accumulation of snow on the ground surface, and in particular, the areal extent of snow-covered ground (NSIDC, 2008); term to be preferably used in conjunction with the climatologic relevance of snow on the ground. See also snowpack. (UNESCO Seasonal Snow on the Ground)
- ❖ **Snow cover:** (1) in general, the accumulation of snow on the ground surface (2) the areal extent of snow-covered ground, usually expressed as percent of total area in a given region. (NSIDC)
- **Snow coverage:** ratio of the snow covered area to the total area of a basin. (WMO/UNESCO, Int. Glossary Hydrology)
- **Inuktitut** - *qanik* snow falling; *aputi* snow on the ground; *pukak* crystalline snow on the ground.....



# GCW Surface Network – CryoNet, Contributing Stations

- *an immediate GCW priority* is to establish the core network of GCW surface measurement stations/sites – *CryoNet*, one part of the whole *GCW observing system*.
- GCW/CryoNet is a component observing system of the WMO Integrated Global Observing System (*WIGOS*).
- CryoNet stations/sites *must meet a minimum set of requirements*
- CryoNet covers *all components of the cryosphere* (glaciers, ice shelves, ice sheets, solid precipitation, snow, permafrost, sea ice, river/lake ice) through an extensive approach of *in-situ* observations.
- CryoNet is initially comprised of *existing stations/sites*, rather than creating new sites; some SEARCH and AON sites are already part of CryoNet.
- *GCW Contributing Stations* provide useful measurements of the cryosphere, but whose data *records may be shorter or with large gaps*, or do not provide the quality and consistency of data required of CryoNet stations; *may be* in remote, hard to access regions *where cryospheric observations are scarce*.





# CryoNet will support RCC functions

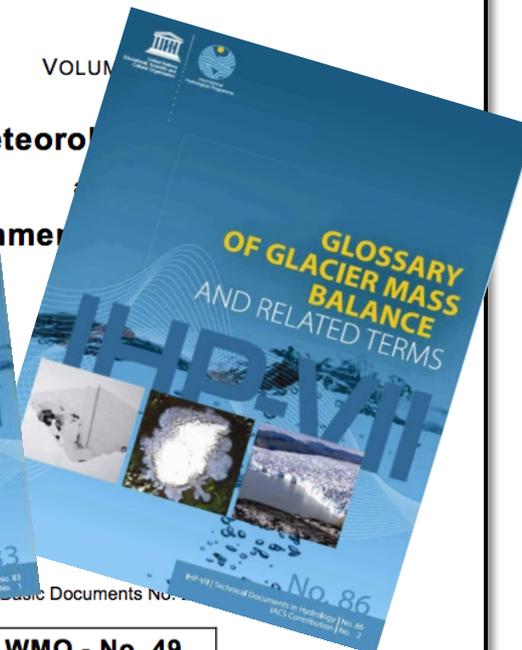
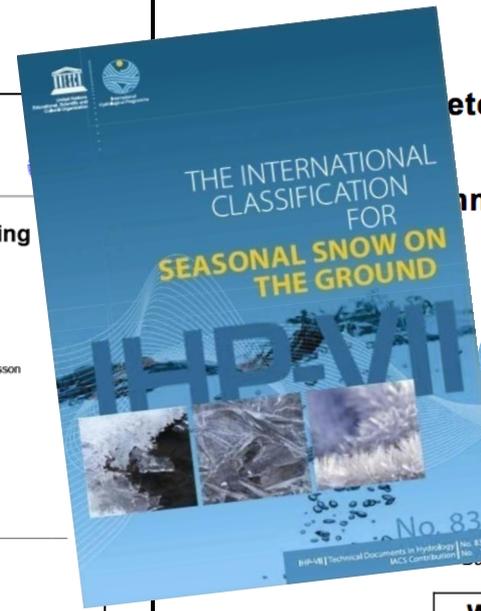
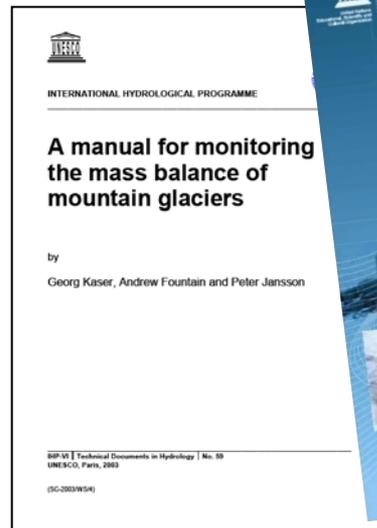
CryoNet will achieve its own comprehensive potential and contribute to RCC mandatory and recommended functions through

- *Linkages* with cryospheric observational networks beyond the WMO family, *long-term, sustainable* observing and monitoring, *harmonized measurements and products*
- Providing cryospheric-data for *improved process understanding and modelling*
- Providing *calibration and validation* data for satellite and modelling products
- Linking cryospheric ground truth observations to cryospheric *models*
- *Training* for cryospheric observations
- *Standardized guidelines* for cryospheric observations

# Measurement standards and practices

*SEARCH and AON are discussing measurement methods. Collaboration with GCW is essential.*

GCW is part of the WMO Integrated Observing System (WIGOS) and contributes to technical regulations of WMO through WIGOS



"IUGG urges snow and ice scientists, practitioners, and scientists from related disciplines to adopt these new schemes as standards."

# Measurement Standards and Best Practices

GCW is drawing on **existing** measurement methods where possible and where a scientific **consensus** has been or can be reached.

Step 1: Inventory of existing guidelines:

Cryosphere Element	Existing Documents
Snow	CEN (2010), Fierz et al. (2009), Armstrong et al. (2009), MSC (2012, 2013), UNESCO, IASH and WMO (1970)
Glaciers, ice sheets, ice caps	Kaser et al. (2003), Östrem and Brugmann (1991), Paul et al. (2009), UNESCO (1970), UNESCO and IASH (1970), WGMS (2012), Zemp et al. (2009)
Sea ice	JCOMM (2004), MSC (2005), NOAA (2007), WMO (2004), Johnson and Timco (2008)
Solid precipitation	Goodison et al. (1998), MSC (2012, 2015), Nitu and Wong (2010), WMO (2012)
Permafrost	Smith and Brown (2009), GTN-P (2012)

Step 2: GCW works through these documents, engages the community, and reaches a consensus on best practices for each variable.





# Solid Precipitation Intercomparison (SPICE, CIMO)

## A GCW Demonstration Project

### A Critical Issue for PRCC

15 countries hosting a total of 20 field sites; *Australia, Chile, Canada, Finland, France, Italy (Nepal), Japan, Korea, Norway, New Zealand, Russia, Poland, Switzerland, Spain, USA.*

Investigating the in-situ measurement and reporting of **Precipitation amount**

- » *over various time periods (minutes, hours, days, seasons),*
- » *as a function of precipitation phase (liquid, solid, mixed);*

**Snow on the ground (snow depth)** - *Will include linkages between snow on the ground and snowfall*



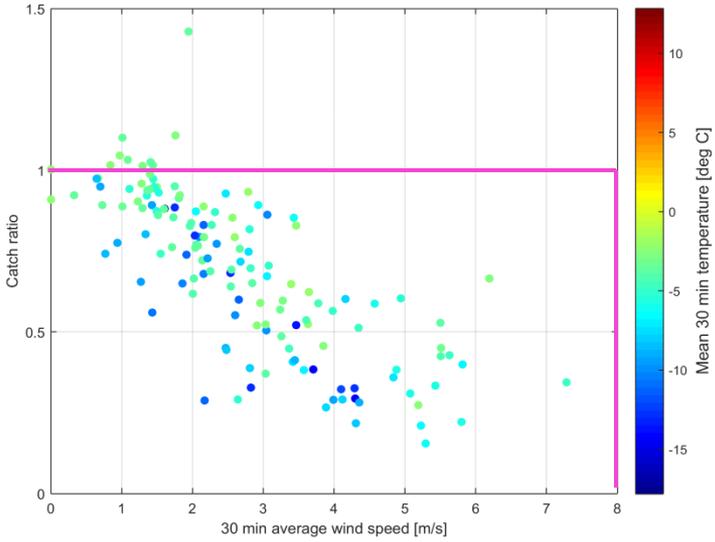
#### Legend

- |     |                                       |     |                                               |
|-----|---------------------------------------|-----|-----------------------------------------------|
| 1.  | Caribou Creek, Saskatchewan, Canada   | 11. | Haukelisetser, Norway                         |
| 2.  | Bratt's Lake, Saskatchewan, Canada    | 12. | FMI/Sodankylä Arctic Research Centre, Finland |
| 3.  | Marshall Site, Colorado, USA          | 13. | Valdai, State Hydrological Institute, Russia  |
| 4.  | CARE, Ontario, Canada                 | 14. | Volskaya Observatory, Gorodec, Russia         |
| 5.  | Tapado AWS, Región de Coquimbo, Chile | 15. | Pyramid Observatory, Nepal                    |
| 6.  | Formigal, Spain                       | 16. | Gochang, Korea                                |
| 7.  | Col de Porte, France                  | 17. | Joetsu, Japan                                 |
| 8.  | Weissfluhjoch, Davos, Switzerland     | 18. | Rikubetu, Hokkaido, Japan                     |
| 9.  | Forni Glacier, Italy                  | 19. | Guthega Dam, New South Wales, Australia       |
| 10. | Hala Gasienicowa Station, Poland      | 20. | Mueller Hut Weather Station, New Zealand      |

# One instrument (weighing gauge): three sites, three climate regimes

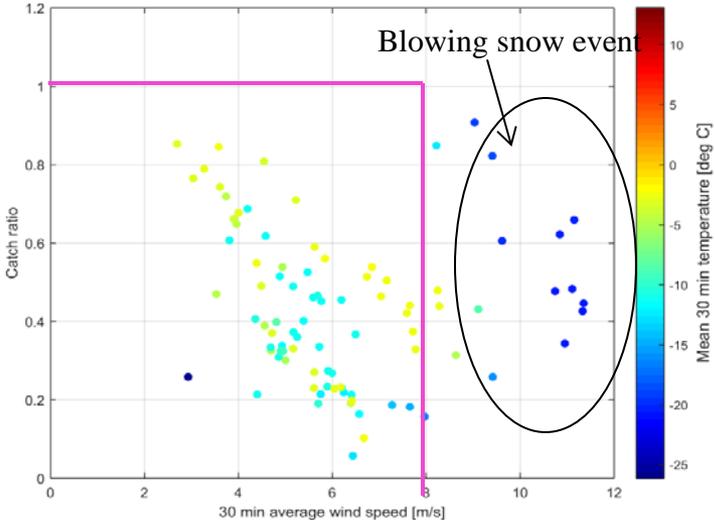
## Continental climate

Site 1



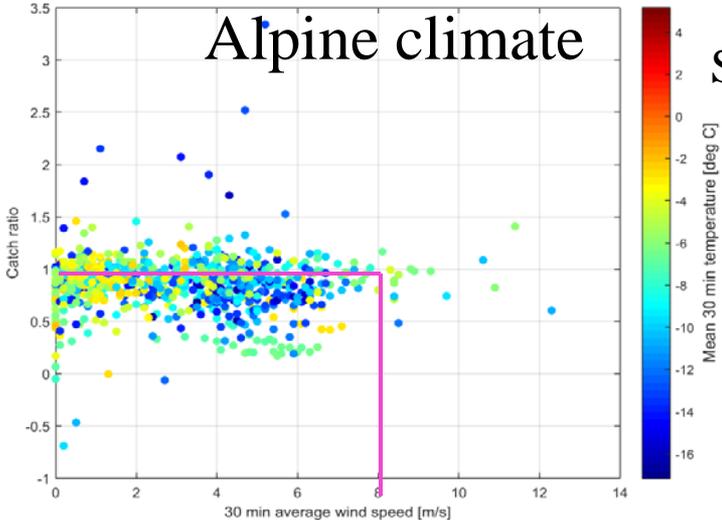
- Catch ratios of 30 minute accumulation (ratio of sensor under test/reference) for events as a function of mean wind speed (season 2014/2015), with:
  - reference accumulation > 0.25 mm
  - mean temperature < -2 °C,.
- The mean temperature for each event is indicated by colour (colour bar).
- *Catch ratio < 1, wind speeds < 8 m/s (inside the magenta line rectangulars)*

Site 2

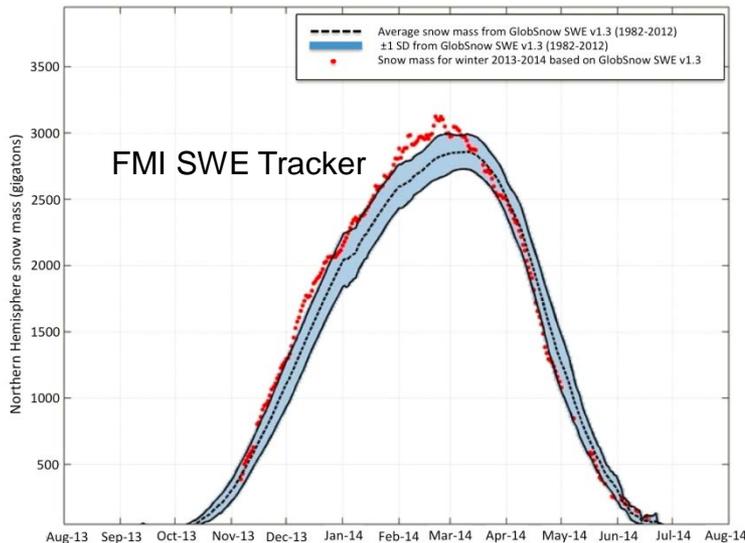


## Alpine climate

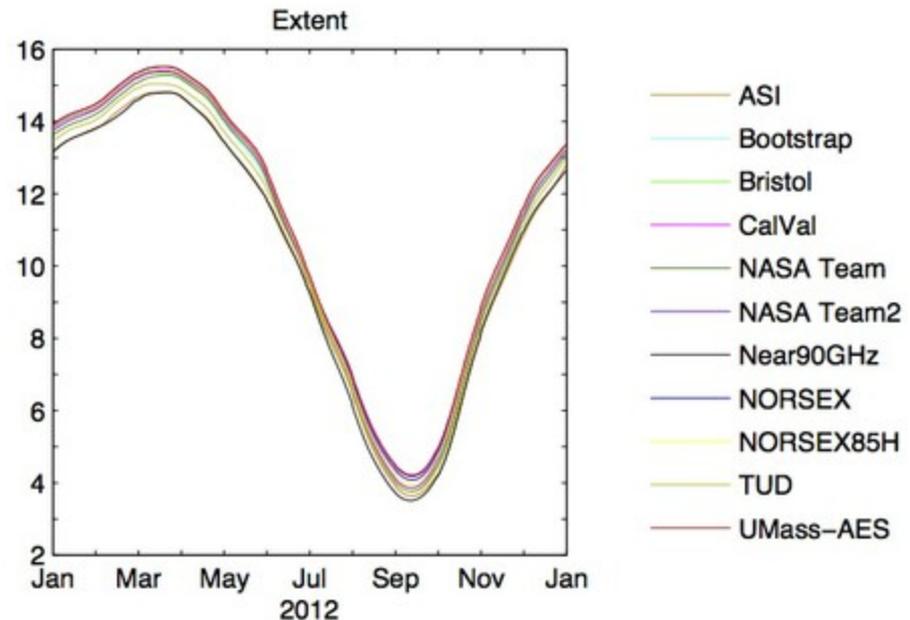
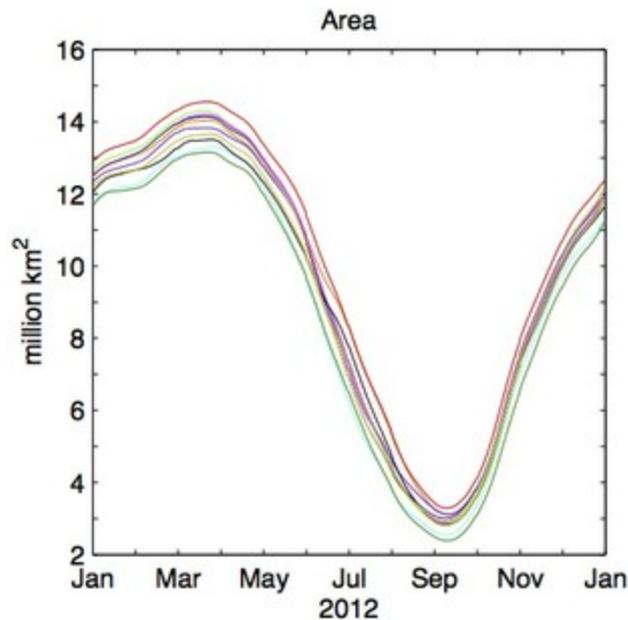
Site 3



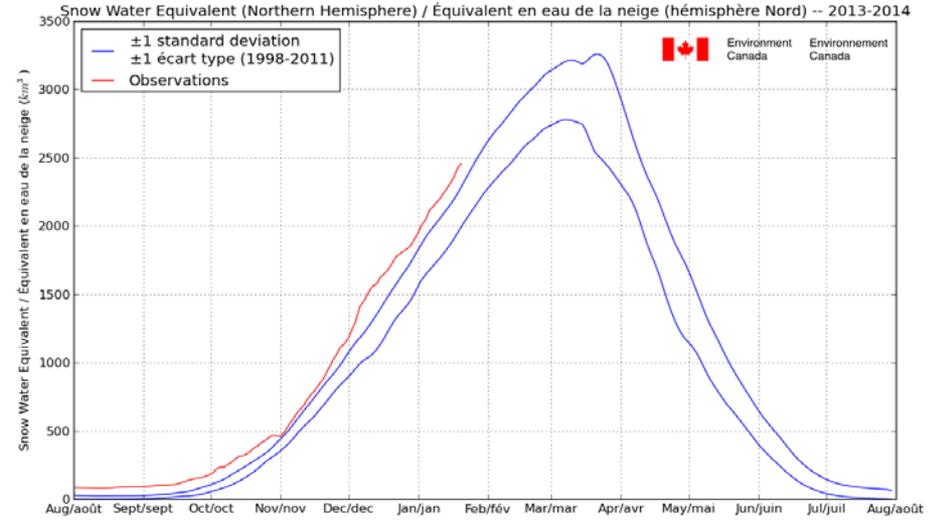
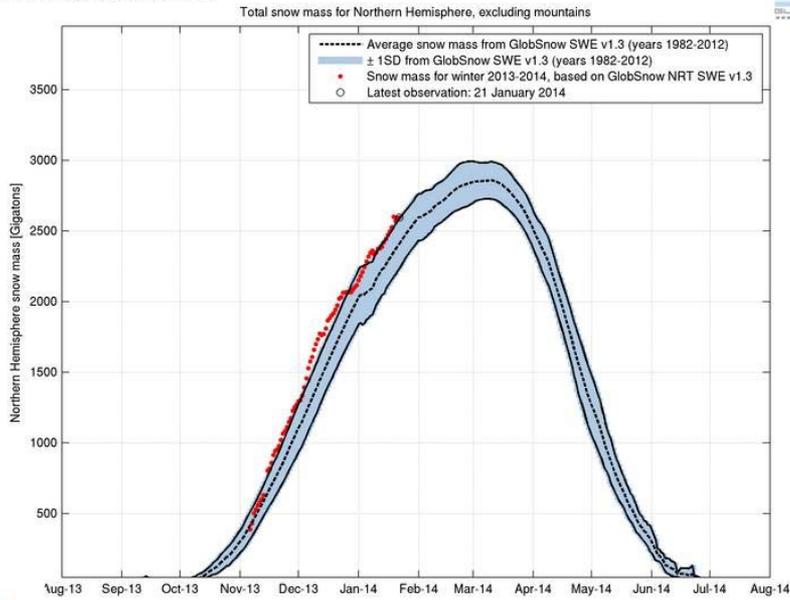
# GCW: Authoritative Products



- Routine evaluation of products
- Product intercomparisons
- Self-assessments of maturity, etc.
- Products meet user needs
- Sustainable product development and production
- Transfer from research to operations



*Sea Ice Area and Extent obtained by passive microwave sea ice algorithms*



2014-01-21

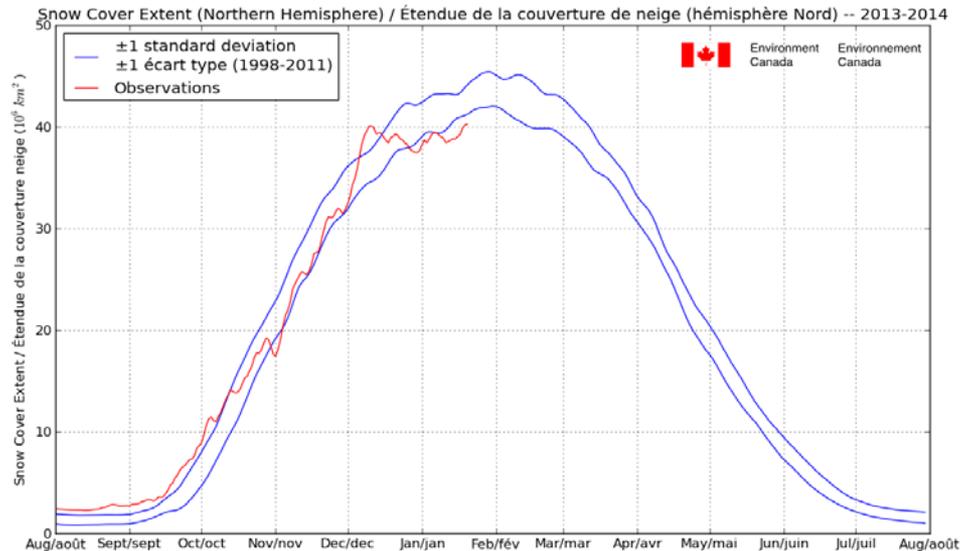


FMI - SWE

CMC - SWE

These 3 trackers are currently on-line.

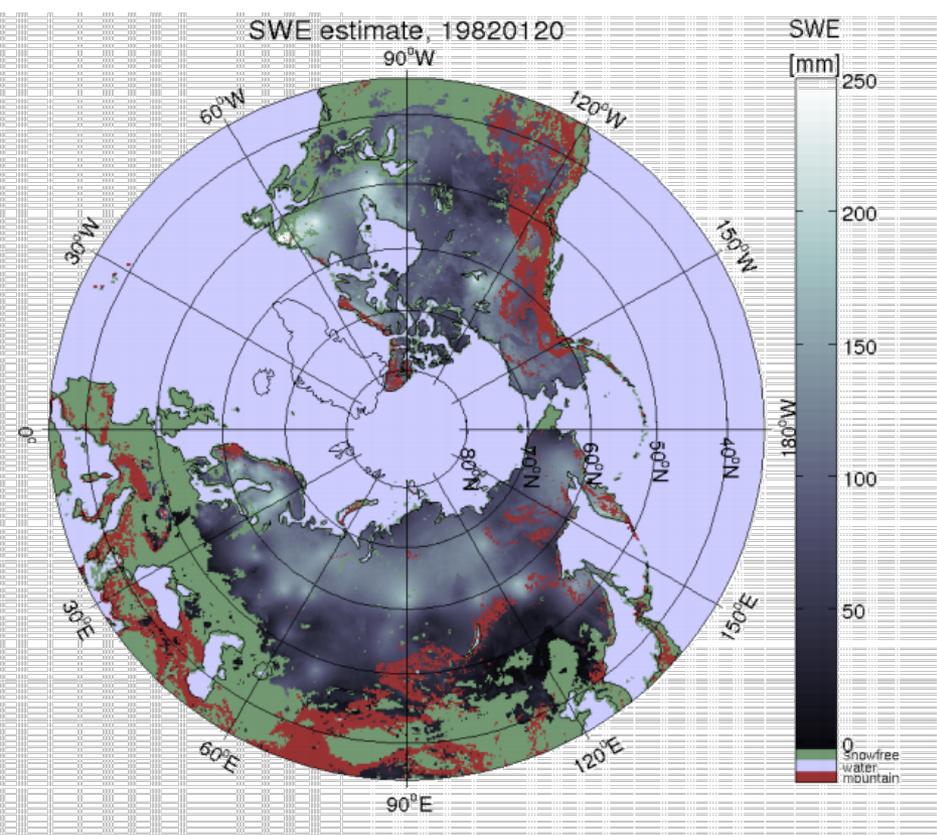
Daily graphs distributed via GCW-website



CMC - SE

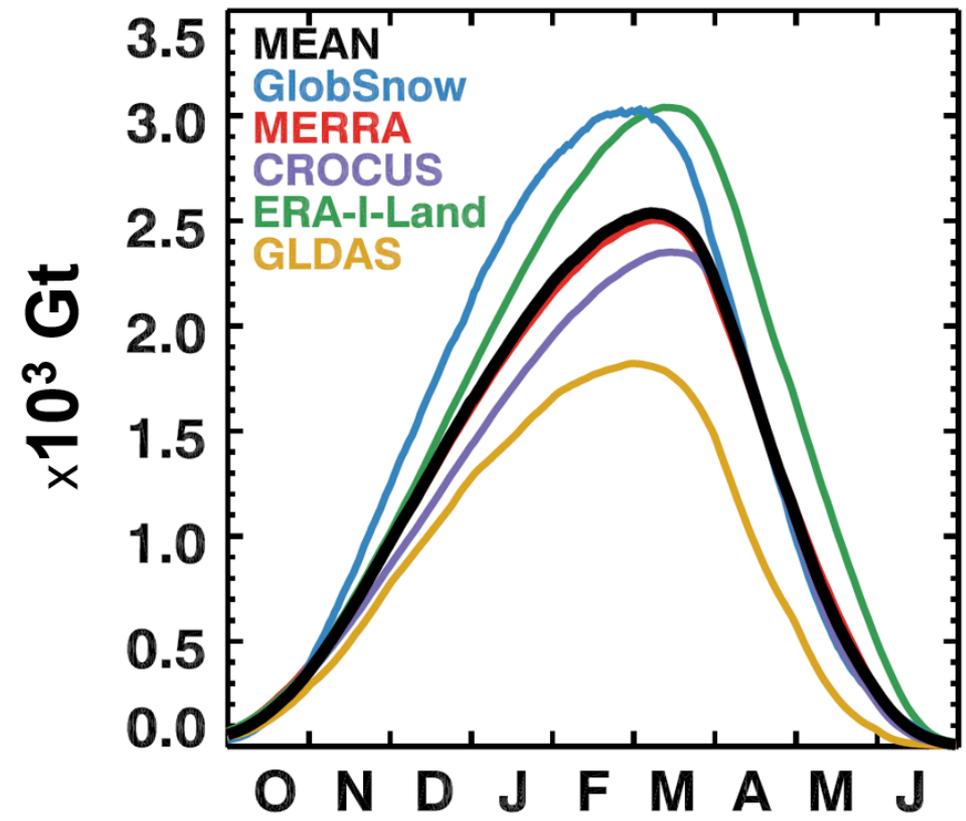
# Uncertainty in Mass of Seasonal Snow

Observation of SWE by means of Passive MW (GlobSnow, NASA Std/Prototype, AMSR-E, CMA, etc.)



GlobSnow SWE estimate

## NH Snow Mass



# *Product Intercomparisons*

## *Desired Outcomes of SnowPEX*

### *(GCW perspective)*

1. Compile list of products and reference datasets.
2. Determine availability of datasets. Ideally in GCW Data Portal.
3. Establish validation/intercomparison protocol.
4. Evaluate product maturity.
5. Quantify differences (and overall spread) in products for pre-selected cases and interpret the differences.
6. Standardize geophysical parameters relevant to users, including definitions, units, and quality flags.
7. Make the intercomparison case study data available (reproducibility leads to “authoritative”).
8. Convey results to end users, including the modeling community.

Colors: Done, In progress, Not started or just started

# Snow Dataset Inventory – February 2015

## Current draft Includes 60 dataset entries:

18 Satellite-derived snow products and datasets

20 Analyses, reanalyses and reanalysis-driven snow products and datasets

22 In-situ snow products and datasets

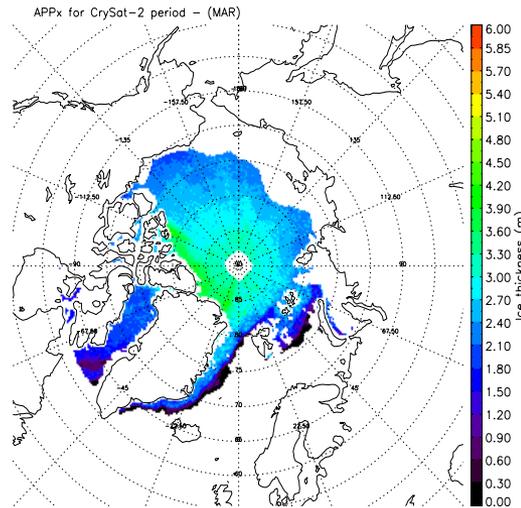
Product(s)	Type	Organization	Description	Period	Areal Coverage	Resolution	Variables	Frequent
GlobSnow SWE	Satellite	ESA, Finnish Meteorological Institute (FMI)	Combination of climate station snow depth observations and forward microwave emission model simulations with SMMR and SSM/I satellite passive microwave data	1979-	Non-alpine Northern Hemisphere	25 km	SWE	Daily; week monthly
GlobSnow Snow Extent	Satellite	ESA, Finnish Meteorological Institute (FMI)	Estimation of fractional snow covered area from SCAMod algorithm	1995-	Northern Hemisphere	0.01 deg	Fractional Snow Cover	Daily; week monthly
NASA Standard AMSR-E	Satellite	NASA	19 and 37 GHz Tb difference; enhancements for vegetation and grain size evolution; distinction between shallow and deep snow	2002-2011	Northern Hemisphere	25 km	SWE	Daily; penta monthly
NASA Prototype AMSR-E	Satellite	NASA	Combination of numerical techniques, snow emission modeling and climatology	2002-2011	Northern Hemisphere	25 km	SWE	Daily; mont
NOAA AMSR2 Snow Products	Satellite	NOAA	Variation of NASA AMSR-E methodology	2014-	Global	25 km	Snow Cover, Depth, SWE	Daily



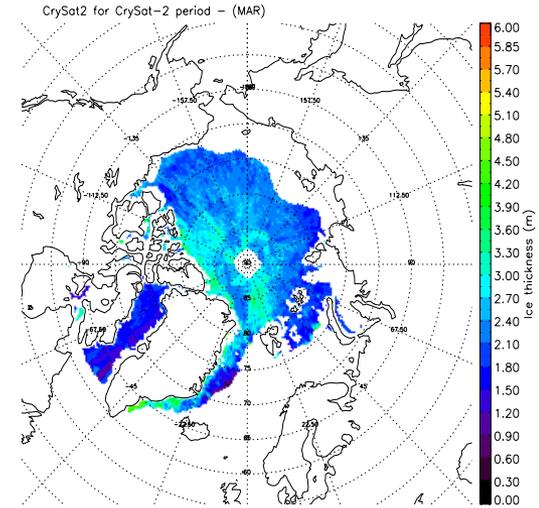
# Product Intercomparisons for Cryospheric Variables

*For example:  
A robust, international,  
ice thickness  
intercomparison  
project along the lines  
of GCW's Snow Watch  
or the GEWEX CREW  
series of workshops  
would be beneficial*

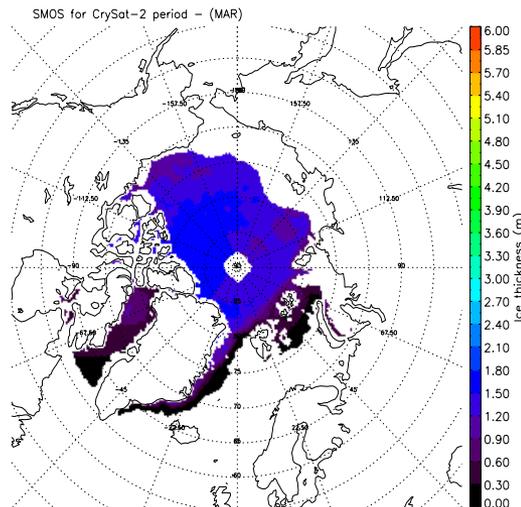
APP-x



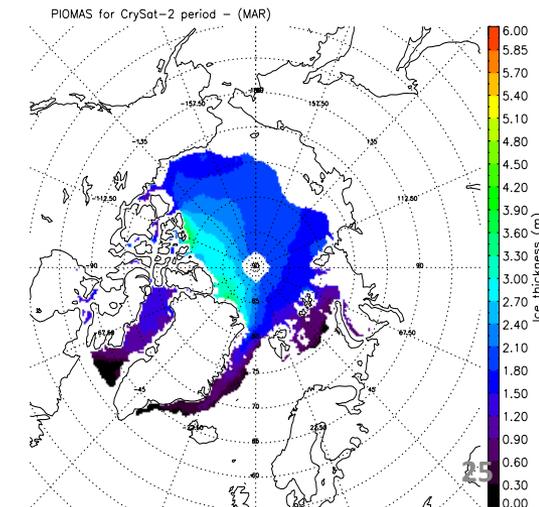
CryoSat-2



SMOS



PIOMAS



# Requirements and Capability for observations (in progress)

- GCW Requirements are **being** formulated and documented on the GCW website;
- They will **draw** from various sets of existing user requirements and will be vetted by the scientific community;
- Those requirements will become part of the WMO **Rolling Review of Requirements (RRR)**;
- Will be accessible through the Observing Systems Capability Analysis and Review Tool (**OSCAR**), the official source for WMO requirements, which has a cryosphere theme;
- Need for a new application area "GCW"**.



## Observational Requirements

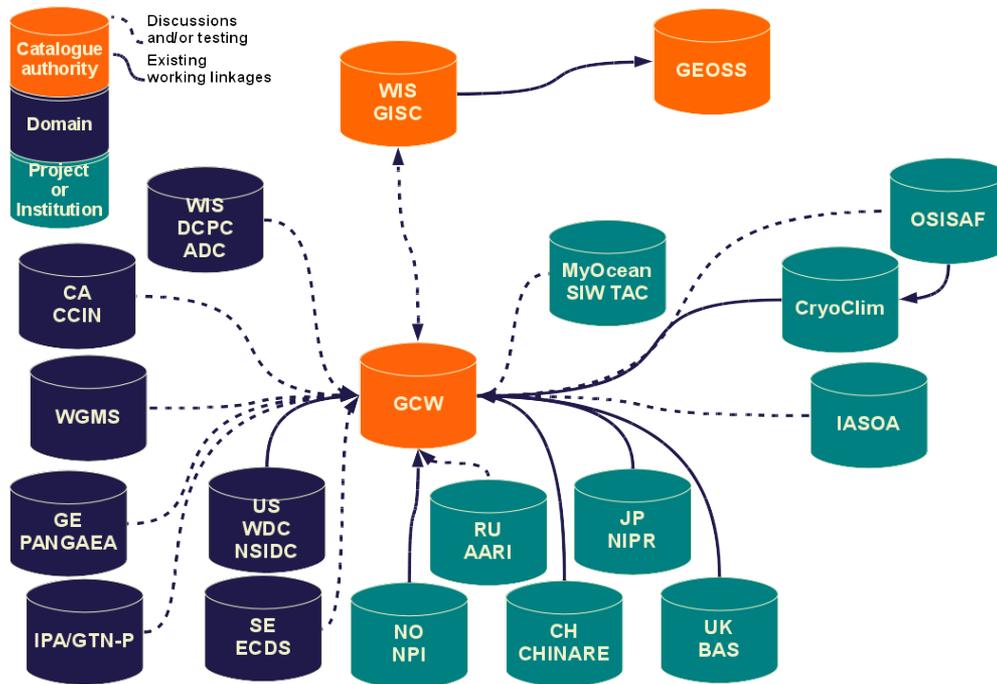
GCW observational requirements are being formulated. They will draw from various sets of existing user requirements and will be vetted by the scientific community. They will become part of the WMO Rolling Review of Requirements (RRR) and will be accessible through the Observing Systems Capability Analysis and Review Tool (OSCAR), which has a cryosphere theme. **OSCAR is the official source for WMO requirements.** The IGOS Cryosphere Theme Report (see Documents) contains the most comprehensive set of observational capabilities and requirements for the cryosphere. It is the starting point for GCW. The IGOS and OSCAR cryosphere requirements are given below. Click the **Filter Options** button to filter the results. Each entry in the table gives the **current measurement capability in green**, the **threshold requirement (minimum necessary) in blue**, and the **objective requirement (target) in orange**, if available.

Filter Options

Variable	Element	Application Area	Special Conditions	Measurement Range, Low	Measurement Range, High	Uncertainty	Spatial Res	Temporal Res	Timeliness	Source
Ice thickness	Sea ice	CLIC		-	-	-	500 km	30 day	90 day	WCRP (OSCAR)
				-	-	200 cm	200 km	7 day	30 day	
				-	-	100 cm				
Ice thickness	Sea ice	IGOS	Climate	0 m	10 m	0.5 m	0.5 km	0.5 year	-	IGOS 200
				0 m	10 m	-	-	-	-	
				0 m	10 m	0.1 m	25 km	1 month	-	
Ice thickness	Sea ice	IGOS	Operational	0 m	10 m	10%	0.5 km	1 week	-	IGOS 200
				0 m	10 m	-	-	-	-	
				0 m	10 m	10%	0.5 km	1 day	-	
Ice thickness	Sea ice	Global NWP		-	-	-	-	-	-	John Eyrn (OSCAR)
				-	-	100 cm	250 km	30 day	30 day	
				-	-	20 cm	15 km	1 day	24 hour	
Ice thickness	Sea ice	High Res NWP		-	-	-	-	-	-	T Montmerl (OSCAR)
				-	-	100 cm	40 km	2 day	3 day	
				-	-	20 cm	2 km	12 hour	12 hour	
Ice thickness	Sea ice	Climate-OOPC		-	-	-	-	-	-	OOPC (OSCAR)
				-	-	1 cm	500 km	7 day	24 day	
				-	-	0.1 cm	100 km	1 day	24 hour	
Ice motion	Sea ice	IGOS	Climate	0 km day <sup>-1</sup>	100 km day <sup>-1</sup>	5 km day <sup>-1</sup>	25 km	1 day	-	IGOS 200
				0 km day <sup>-1</sup>	100 km day <sup>-1</sup>	3 km day <sup>-1</sup>	25 km	1 day	-	
				0 km day <sup>-1</sup>	100 km day <sup>-1</sup>	1 km day <sup>-1</sup>	1 km	1 day	-	
Ice motion	Sea ice	IGOS	Operational	0 km day <sup>-1</sup>	100 km day <sup>-1</sup>	0.5 km day <sup>-1</sup>	1 km	3 day	-	IGOS 200
				0 km day <sup>-1</sup>	100 km day <sup>-1</sup>	3 km day <sup>-1</sup>	25 km	1 day	-	
				0 km day <sup>-1</sup>	100 km day <sup>-1</sup>	0.5 km day <sup>-1</sup>	0.1 km	1 day	-	

# BRINGING USERS AND PROVIDERS TOGETHER: ROLE of GCW DATA PORTAL

The GCW Data Portal will exchange cryosphere data, metadata, information and analyses among a distributed network of providers and users in support of informed decision-making. The **GCW Data Portal is part of WIS**, a Data Collection and Production Centre (under development), and is interoperable with data centres.



## Data quality, sharing and access are fundamental principles

- improve access to, and utilization of observations and products from WMO and other observing systems and national and international data centres, built using the principles developed for IPY2007-2008.
- facilitates the interaction between users and providers of the products
- **YOPP data management builds on GCW data management (both principles and solution)**



# Information Website

The website differs from the METNO GCW Data Portal in that it contains more dynamic information (news, state of the cryosphere plots, highlights, calendar), as well as background, higher-level information, GCW documents, and outreach material. It links to the METNO data portal.

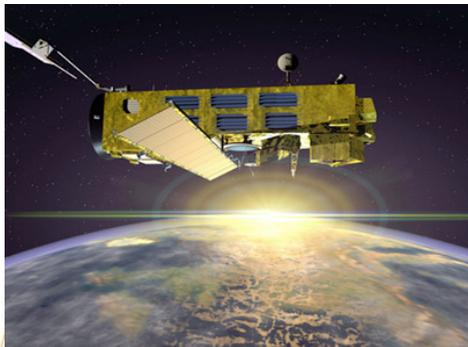
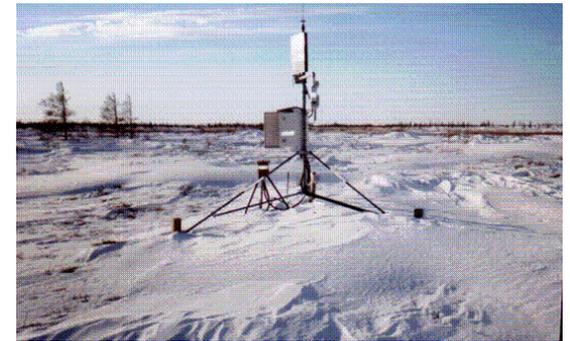
The screenshot shows the homepage of the Global Cryosphere Watch website. At the top left is the WMO logo. The main header is "Global Cryosphere Watch" in large white text on a blue background. Below the header is a navigation bar with links: Home, About, News, Cryosphere Now, CryoNet, Data, Activities, Outreach, Reference, and a search box. The main content area is divided into several sections:

- Highlights:** Features the GCW logo and a welcome message: "Welcome to the Global Cryosphere Watch website! GCW is evolving, so please check back periodically for additional information on GCW projects, CryoNet stations, and the *Cryosphere Now*." Below this is a banner for "GCW website is now live!" with several small thumbnail images.
- The Cryosphere Now:** A vertical menu on the left lists categories: Sea and Freshwater Ice, Snow and Solid Precip, Glaciers & Ice Caps, Ice Sheets, Permafrost, Atmosphere, and Satellite Products. To the right is a polar projection map of Antarctica showing ice concentration. The map is dated "Aug 25 2013 Antarctic" and includes a scale bar from 0 to 100 km. The legend indicates "Ice Concentration" from 0 to 100%.
- Cryosphere in the News:** A list of recent news items with dates and sources, such as "Study finds earlier peak for Spain's glaciers" (Mon, 26 Aug) from phys.org and "Earlier peak for Spain's glaciers" (Mon, 26 Aug) from feeds.sciencedaily.com.
- GCW News and Highlights:** A list of news items, including "Barry Goodison awarded the 2012 Patterson Distinguished Service Medal" and "WGMS Summer School on Mass Balance Measurements and Analysis 2013, 2-7 September".

At the bottom of the page, there is a footer with contact information: "Problem with website? Contact the webmaster", social media icons for Facebook and Twitter, and a statement: "This website is operated on behalf of WMO by SSEC. It is not an official WMO website." The SSEC logo is in the bottom right corner.

<http://globalcryospherewatch.org>

# Moving Forward...



# ***Moving Forward...***

The following are some suggestions for discussion which are important for GCW and for Arctic PRCC-network designation:

- Defining the highly recommended functions in addition to mandatory functions for an Arctic PRCC
- Determining elements to be produced (T&P is not enough); identifying cryospheric elements to be included; role for satellite or merged/blended products
- Defining the spatial domain of an Arctic PRCC – hemispheric? pan-Arctic (how far south?), RA II, IV, VI could subdivide? Evaluation/validation in data sparse regions.
- Defining suitable temporal scale especially for climate monitoring (minimum update frequency is monthly – strive for weekly, daily as well?)
- Data policy; access to data; timely exchange of data observed to meet user needs (forecasting, monitoring, data services); interoperability among data centres; role of GCW data portal/DCPC
- Determining user needs beyond NMSs (NMHSs?), e.g. those of Indigenous Peoples
- Engaging organizations outside WMO in developing Arctic-PRCC
- Identifying key gaps that would hinder development of operational LRF products, climate monitoring and data services of an Arctic PRCC (incl. review of outcomes of relevant workshops, conferences, meetings)



# GCW

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Extreme Events

***What can the GCW do for the PRCC?  
What can the PRCC do for the GCW?***

# GCW Upcoming Meetings and Workshops

- GCW CryoNet Team Meeting Fifth Session; Boulder, USA, 7-8 December 2015
- GCW Steering Group meeting Third Session; Boulder, USA, 9-11 December 2015
- 2nd GCW CryoNet Asia Workshop; Salekhard, Russian Federation, 2-5 February 2016
- GCW Snow Watch Team Meeting Second Session; Columbus, Ohio, USA, 13-14 June 2015





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*GCW.....Authoritative information for the past,  
present and future state of the cryosphere*

**GCW Website:**

**<http://globalcryospherewatch.org/>**

**GCW Portal: <http://gcw.met.no/>**