Global Cryosphere Watch (GCW): A Contribution to Arctic Products Validation and Evolution (APVE)

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(on behalf of GCW Steering Group, World Meteorological Organization)

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Sea level rise threatens vital infrastructure.

Changes in sea-ice affect access to the polar oceans and resources, tourism, and security. Declining summer sea-ice affects ocean circulation and weather patterns.

Natural hazards such as icebergs, avalanches and glacier outburst floods create risks.

Permafrost thawing impacts infrastructure and is potentially a major source of methane, a greenhouse gas.

Changes in the cryosphere impact water supply, food production, freshwater ecosystems, hydropower production, and the risk of floods and droughts.

Retreating sea ice results in a loss of habitat for mammals such as polar bears and seals.
WMO recognized that there was an urgent need for a sustained, robust, end-to-end cryosphere observing and monitoring system, not only for polar and alpine regions, but globally, and with its partners is now developing and implementing an operational Global Cryosphere Watch (GCW).

- **IPY 2007-2008** brought together existing initiatives:
  - WCRP/CliC, CRYSYS, ACIA, ICARPII, SWIPA, IASC, SCAR, etc.
  - Integrated Global Observing Strategy Report on Cryosphere (IGOS-CryOS): 100 recommendations, emphasizing that the cryosphere provides some of the most useful indicators of climate change, yet is one of the most under-sampled domains of the Earth System.

- **15th WMO Congress (2007)** - initial discussion.

- The **16th WMO Congress (2011)** agreed that “WMO needs to have a focus on global cryosphere issues” and decided to embark on the development of the Global Cryosphere Watch (GCW), as an IPY Legacy, with a view of an operational GCW based on the GCW Implementation Strategy.

- The **66th Session of WMO Executive Council (2014)** proposed new priority:
  - Implement operational polar weather, climate, and hydrological services focusing on operationalizing the GCW and advancing the Global Integrated Polar Prediction System (GIPPS).

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**WMO Executive Council Expert Panel on Polar Observations, Research, and Services (EC-PORS) oversees GCW**
**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**
Conceptual Framework for GCW Operations

WMO Executive Council

Steering Group

Task Teams

Coordination Office

Users and Applications
research, operational and service centres, security, impacts, adaptation

Outreach, Education, Capacity Building

GCW Portal and Website
integrating data and information

GCW Information and Analysis
anomaly tracking, hot-spots, variability and change, global and regional products

Observations
CryoNet, contributing networks, satellites

Cryosphere Products
operational products, reanalyses, research datasets

Partners
- met centres
- satellite agencies
- data centres
- specialized organizations

Data, Information, Services
Relevance to APVE: What is GCW doing?

• developing a **network of surface observations** called "CryoNet", which builds on existing networks;
• developing **measurement guidelines** and best practices;
• refining **observational requirements** for the WMO Rolling Review of Requirements;
• engaging in and supporting **intercomparisons of instruments and products**, e.g., the **GCW Snow Watch** project;
• contributing to WMO’s space-based capabilities database (with PSTG);
• creating **unique products**, e.g., the SWE Tracker, in collaboration with partners;
• engaging in **historical data rescue** (e.g., snow depth);
• building a **snow and ice glossary**;
• developing international training and outreach materials;
• providing **up-to-date information on the state of the cryosphere**;
• providing **access to data** through a portal;
• co-sponsoring workshops.
Portal and Website

End users

Web Browser User Interfaces

Data discovery

Retrieval of information

Metadata

Articles

Web portal

Data centres contributing to GCW

GCW scientific community

http://gcw.met.no
Portal and Website

- About GCW – impact, framework
- GCW News
- Cryosphere now - products
- CryoNet – site requirements, practices
- Activities – mtgs, projects
- Outreach – forum, video
- References – Glossary, acronyms, GCW documents

http://globalcryospherewatch.org
THE NEED FOR COMMON GCW CRYOSPHERE TERMINOLOGY

• 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 percent 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)
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:

<table>
<thead>
<tr>
<th>Cryosphere Element</th>
<th>Existing Documents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permafrost</td>
<td>Smith and Brown (2009)</td>
</tr>
</tbody>
</table>

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

- GCW Requirements are **being** formulated and documented on 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 theme** “GCW”.
• Operating in remote, data sparse regions
• CryoNet – baseline, reference, integrated – develop consortium of sustained, ground-based international multi-disciplinary observatories, strengthening collaboration
• Role for community-based monitoring

• Contributing to an optimized cryosphere observing system using in-situ and satellite systems
• Developing value added long-term standardized observational data and products to address systems science questions, initialize and validate model and satellite derived cryospheric outputs

• Comprehensive, coordinated cost-effective, sustainable system of observations & information
CryoNet – the core GCW Network

...an immediate priority in GCW development.

- Establish the core network of GCW surface measurement sites – CryoNet.
- CryoNet is one part of the whole GCW observing system, which is a component observing system of the WMO Integrated Global Observing System (WIGOS).
- CryoNet covers all components of the cryosphere (glaciers, ice shelves, ice sheets, 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.
CryoNet (subset of GCW observations) objectives

CryoNet will link with different cryospheric observational networks to achieve its comprehensive potential through:

- Extensive monitoring of the cryosphere through harmonized measurements
- Providing cryospheric data for improved process understanding and modelling
- Providing calibration and validation data for satellite products
- Linking cryospheric ground truth observations to cryospheric models
- Training for cryospheric observations
- Standardized guidelines for cryospheric observations
- Long-term, sustainable observing and monitoring.
CryoNet - Structure

To meet different user-needs and because of the spatially distributed nature of different components of the cryosphere the CryoNet network of in-situ observations is structured into three different classes of observational sites.

- **Baseline Sites**
  - Single sphere
  - Compliant with CryoNet agreed practices
  - Target of long-term continuous operation

- **Reference Sites**
  - Single sphere
  - Compliant with CryoNet practices
  - Calibration/Validation
  - Long-term financial commitment
  - Long-term, continuous measurements
  - Near real-time availability of data, where possible

- **Integrated Sites**
  - Multi sphere
  - Compliant with CryoNet practices
  - Calibration/Validation
  - Long-term financial commitment
  - Strong research focus
  - Training
  - Onsite staff

- Surface measurement sites. Over 150 have been “offered” so far;
- “Sphere” refers to the different components of the climate system, e.g., cryosphere, atmosphere, biosphere
SOME REQUIREMENTS FOR SITE INCLUSION IN CRYONET TO SUPPORT INTERCOMPARISONS AND CAL/VAL

- The site location is chosen such that, for the variables measured, it is partially/temporally representative for measuring one or several components of the cryosphere.

- User needs have been considered in the observation design process.

- CryoNet sites have to be active and perform sustained observations according to CryoNet agreed practices.

- For reference and integrated sites, there is intent by the responsible agencies to sustain long-term observations of at least one of the CryoNet variables. For baseline sites the responsible agencies intend to support a long-term observing program.

- The relevant CryoNet observations are of documented quality. The measurements are made and quality controlled according to CryoNet agreed practices.

- The data and metadata including changes in instrumentation, traceability, observation procedures are submitted to a data centre that is interoperable with the GCW portal in a timely manner.
CryoNet Initial Sites

The core network of GCW surface measurement sites is called CryoNet.
Take Home Thought:
Added value of GCW CryoNet for satellite community

GCW CryoNet will offer new quality for CAL/VAL tasks because of:

- Better **access** to cryospheric data on global scale
- High level of **standardization** of observations
- Improved **spatial coverage**
- **New parameters** of observation (e.g. physical properties of snow)
- Characterisation of **sensors** from intercomparison experiments (e.g. SPICE)

Range of cryospheric variables available from a reference site will depend on the existing observing program and further refined in cooperation between GCW-CryoNet and satellite community.
**ESA use of CryoNet sites for Cal/Val**

ESA already uses (or has previously) some of the CryoNet sites for Cal/Val:

- **Sodankyla:**
  - L-band validation for SMOS products - with permanent stationing of ELBARA L-band instrument under agreement with FMI.
  - Airborne campaign/measurement validation for CoReH2O with comparison of snow course, SWE and other measurements.
  - Was a key station for validation of atmospheric sensors on Envisat.

- **Dome C:** A CEOS Cal/Val reference site - documented by CEOS Cal/Val WG
  - L-band validation for SMOS products
  - Permanent tower-based radiometer measurements to provide independent L-band reference brightness temperatures for SMOS, as well as being used for Aquarius (and SMAP in future)
  - US investigators use it for snow grain size retrieval validation (optical)

- **PROMICE:**
  - The Greenland sites are very useful for validation of snow albedo products to be developed from Sentinel-3.

- **Davos:**
  - Operated SnowScat - in support of development of snow water equivalent retrievals for CoReH2O candidate mission.
  - Ad-hoc airborne microwave campaigns for snow tomography.

*PSTG input to J. Key on specific needs/requirements for CryoNet sites*
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.

Will investigate 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
**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
GCW Products and Services

- Identification and development of initial products
- Development of Hemispheric snow "anomaly" trackers for SE & SWE
- An inventory of snow datasets
- Product intercomparison:
  - Snow intercomparison project
  - ESA SnowPEX
- Improve real time flow and access to *in-situ* snow measurements
The Need for Intercomparisons?

NSIDC Sea Ice Extent Product
Sea Ice Area and Extent obtained by passive microwave sea ice algorithms: ASI, Bootstrap, Bristol, CalVal, NASA Team, NASA Team2, Near 90 GHz, NORSEX, NORSEX-85H, TUD, and UMass-AES
Recommendations from Sea Ice Thickness Intercomparison

- **Intercomparison**: A formal, robust, international intercomparison project should be undertaken to clearly identify strengths and weaknesses of each product, and to better characterize errors.

- **Blending**: Evaluate the feasibility of blending multiple data products to provide a single picture of sea ice thickness over time.

- **Assimilation**: There is very little use of ice thickness observations in models. Model impact studies should be undertaken. How often do we need thickness estimates? At what spatial scale?

- **Synergy**: Continue to explore the combination of laser and radar altimeters to solve the problem of unknown snow depth on ice. Are there other space-based solutions?

- **Validation**: In situ observations of ice thickness and snow depth should be expanded, standardized, and freely available.
Product Intercomparison and Assessment

• Intercomparison required to assess product quality (uncertainty, bias, error correlation), and to isolate algorithm/methodological weaknesses

• Intercomparison of satellite products with independent external reference measurements (in-situ, airborne, etc)
  – validation, characterisation of errors, estimate of absolute biases, sources of uncertainty etc.

• Intercomparisons amongst different satellite products
  – to establish relative biases and range of uncertainty

• Intercomparison must be a continuous process
  – to evaluate spectral content of errors
  – Evaluate rate of change of product uncertainties (e.g. contributed by instrument ageing, orbit degradation, switch to redundant instrument chains, etc.)
A Recipe for Intercomparison

- Generate Level playing field (agreed best practices/intercomparison standards or guidelines)
- Establish Temporal/Spatial coincidence of different products
- Select key Areas for Intercomparison, based on locations of GCW Reference Sites, or other independent validation datasets (e.g. airborne data)
- Assemble knowledge on spatial resolution limitations (e.g. impact of product gridding)
- Assemble knowledge on spectral content of time-series of temporally averaged products (e.g. impact of temporal averaging, impact of illumination geometry from successive orbits)
- Assemble necessary ancillary data for common use by all participants (e.g. DEMs, land cover maps; and common land/snow/ice masks);
The current generation has built the foundation. To go forward, we need young cryosphere scientists with their knowledge, energy, passion, networking and fresh ideas to be engaged not just in research, but also in development of service-oriented information – from Knowledge to Action.

Strengthen interdisciplinary research and engagement of users and northern peoples from the beginning; develop community-based monitoring as part of our networks; continue to incorporate traditional knowledge.

Need international funding mechanism for collaborative international network projects – as the EU does with its Framework Programme – open to consortiums of government, university, industry scientists; funders could be government, business, foundations. Also applies nationally and regionally.
GCW Website: http://globalcryospherewatch.org/
GCW Portal: http://gcw.met.no/
## Cryosphere Satellite Missions

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<tr>
<th>Year</th>
<th>Mission</th>
<th>Status</th>
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<tbody>
<tr>
<td>02</td>
<td>RA, SAR &amp; Wind Scat/ERS-2</td>
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<tr>
<td>03</td>
<td>RADARSAT-1 C-band</td>
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<td>RADARSAT-2 C-band</td>
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<td>06</td>
<td>Seawinds/QuikSCAT Ku-band</td>
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<td>07</td>
<td>ICESAT</td>
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<td>08</td>
<td>GRACE</td>
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<tr>
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<td>WindSat</td>
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</tr>
<tr>
<td>10</td>
<td>OLS &amp; SSMI/DMSP—AVHRR &amp; AMSU/NOAA</td>
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</tr>
<tr>
<td>11</td>
<td>MODIS &amp; AMSR-E/EOS-Aqua</td>
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<tr>
<td>12</td>
<td>Aster/MODIS/EOS-Terra</td>
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<td>13</td>
<td>COCTS/HY-1A</td>
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<tr>
<td></td>
<td>PCW 1 &amp; 2</td>
<td>In Orbit</td>
</tr>
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</table>

### Key:
- **In Orbit**
- **Approved**
- **Planned/Pending approval**

*Solid = R & D; Hatched = operational mission*

*Courtesy: M. Drinkwater*