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WORLD METEOROLOGICAL ORGANIZATION
GLOBAL CRYOSPHERE WATCH

FINAL REPORT OF THE SNOW WATCH TEAM MEETING, SECOND SESSION

COLUMBUS, OHIO, USA
13-14 June 2016

World Meteorological Organization
Weather • Climate • Water

Global Cryosphere Watch

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EXECUTIVE SUMMARY

The Second Session of the Global Cryosphere Watch Snow Watch Team was held at the Byrd Polar and Climate Research Center in Columbus Ohio, June 13-14, 2016. The meeting was attended by seven members of the Snow Watch Team and ten invited experts.

The objectives of the meeting were to:

- Update/review progress in the action items identified in the first GCW Snow Watch meeting in Toronto in 2013; confirm on-going initiatives.
- Develop a draft Terms of Reference for the Snow Watch Team.
- Provide an update on the current state of global snow cover monitoring activities and products; identify gaps and issues for further action.
- Identify contributions to other GCW activities e.g. CryoNet, terminology, guidelines/best practices
- Discuss potential products and information to support the proposed WMO Polar Regional Climate Centres
- Identify priority issues that can be moved forward through GCW Snow Watch initiatives; establish task teams and timelines
- To start the process to identify priorities for future space-based observing missions.

Barry Goodison, vice-chair of the GCW Steering Group, provided a summary of the current status of GCW noting that GCW activities and accomplishments have all been captured on the GCW web site at: http://globalcryospherewatch.org. Considerable progress was shown in the priority action items identified at the First Session in Toronto in January 2013. First, there has been considerable progress in the development and adoption of a new BUFR template for reporting snow depth, including zero snow depth reporting, that has resulted in significant increases in snow depth reports from Europe on the GTS/WIS. Yet, there is still a need for improved knowledge and understanding of manual vs. automatic station capability with respect to snow depth observing, including the measurement and reporting of patchy snow around a sensor/station. Discussion revealed that there were inconsistencies in the determination and reporting of patchy snow cover. It was also recognized that zero snow depth reporting is not required all-year round for every station, but the WMO regions could determine the reporting period applicable to their region. It was stressed that consistency is essential and that regional practices need to be harmonized.

The GCW Snow Dataset Directory, identified as a priority at the First Session, was implemented. The dataset can be queried online on the GCW website (http://globalcryospherewatch.org/reference/snow_inventory.php). It now contains 53 dataset entries subdivided by source: satellite derived (19 entries), analysis/reanalysis (19 entries), and in situ (15 entries). The latest addition is a 212 station historical snow depth dataset from China that only happened because of a formal request from GCW to the Chinese Permanent Representative for WMO. A GCW-initiated compilation of long-term in situ snow observations from different sources globally would be a useful contribution for cryospheric monitoring. A prototype snow course data archive established in 2016 by FMI is now available at: http://litdb.fmi.fi/eraclim2.php. It contains 30495 snow courses from Canada, Finland and Russia spanning 1935-2009 and has about 4.2 million observations of snow water equivalent (SWE), snow depth (SD) and snow density. It was indicated that the dataset could be shared through the GCW portal using the WMO information System (WIS). The Team continues to populate the GCW website with other snow information, including the ongoing development of its Snow Trackers, another outcome of the first meeting. Development of additional trackers on a global and regional basis was encouraged.

The meeting was updated on the major accomplishments of the ESA SnowPEx project which was initiated in response to a recommendation from the First GCW Snow Watch Meeting. This international satellite snow product intercomparison involving 30 organisations from 10 countries has developed standardized protocols and reference datasets for evaluating snow extent (SE) and snow water equivalent (SWE) products. Preliminary conclusions from SnowPEx are provided and a number of recommendations on next steps were presented and discussed. GCW Snow Watch recommended holding an International Satellite Snow Product Intercomparison, ISSPI-WS, every 2 to 3 years, as a continuation of ISSPI-1 and 2.

There was a very informative session on the development and validation of snow cover products. It included presentations and discussions on: GlobSnow SWE and SE products; MODIS and S-NPP VIIRS NASA Snow Products; the NOAA Climate Data Record; the Norwegian CryoClim Global Snow Cover Extent product; and work with AMSR by JAXA and NASA. A very lively and constructive discussion ensued after Chris Derksen's update on proposed satellite missions for snow monitoring and Bojan Bojkov's presentation on EUMETSAT snow-related activities and the link to GCW needs and expectations. The need for independent "in situ" data for validation and intercomparison of satellite datasets was raised as well as the need for "ancillary datasets". In addition, the importance in defining the "base" or "minimum" measurements for GCW CryoNet sites was emphasized and it was noted that the satellite agencies require continued activities on "standardization" through GCW. Derksen emphatically made the important point that new mission concepts should be pitched to cover multiple cryospheric and non-cryospheric variables to address as wide a range of user needs as possible (not just terrestrial snow). This is a critical issue and there is a strong rational for satellite sensors to serve multiple purposes. Given this, how do we move from inter-connected, but independent, activities to jointly funded proposals with international partnerships. The discussion led to strong agreement that GCW must be engaged in the co-ordination of satellite snow mission planning activities, particularly for a ~1 km daily global SWE product (EUMETSAT, CSA, NASA SnowEx, ESA, etc) to fill a fundamental gap in the observing system.

A very productive session provided an update on snow analysis products including in situ, satellite data assimilation and associated observing and archiving issues. The need for quality controlled, homogeneous, long-term (1950?-) continuous daily snow depth observations for a global assessment of in situ snow cover change was identified. An update on in situ snow cover datasets at the US NCEI, the sources of snow data, the stations reporting snow depth in the US and globally and associated Quality Assurance procedures was provided. The issue of metadata for snow observing practices at stations was raised, and it was recommended that GCW should assess the availability and access of metadata for snow measurements in the GCW observation network, including CryoNet sites. Sean Helfrich updated the group on several snow products produced by the National Ice Center (NIC) and NOAA NESDIS. It was noted that these activities are being driven by user needs for higher resolution snow cover information for NWP and hydrometeorological applications. Very useful updates on snow data assimilation were provided for ECMWF and the UK Met Office, resulting in several recommendations/actions. The requirements for NWP in planning in situ and satellite sensing of snow were emphasized. Finally, an important update on NSIDC products was presented. . It was pointed out that there are significant resource implications for datasets archived in the NSIDC collection, and product updates and additions are limited by the available funding. This means that hard decisions must be made on what can be supported, and is something that users need to understand. This is an important issue for all archives of snow data, and especially those which will hold GCW data and products.

The group was briefed on several new initiatives relevant to GCW Snow Watch. Dorothy Hall updated Snow Watch on SnowEx, a NASA a multi-year airborne snow campaign designed to collect multi-sensor aircraft data and ground truth measurements to enable algorithm development and design of a future satellite mission. Discussion noted the benefits of linking with the efforts of the Canadian mission planning and those of other international satellite agencies. Snow Watch was updated on the current status and plans of the Best Practices Task

Team which was established to compile best practices, guidelines and standards for observing/measuring cryosphere variables, building on what has been compiled to date and available on the GCW Website. As well, information on HarmoSnow, a European COST Action was provided. Both of these efforts would benefit tremendously from the contributions from Snow Watch and the associated snow community. Similarly, the benefits of GCW and Snow watch working closely with the Polar Space Task Group on matters of mutual interest was emphasized. Ross Brown then led a lively discussion on real-time reporting of SWE on the GTS which concluded that reporting of SWE should be a GCW priority. The question remains whether the BUFR code could be used, and if not, what alternative methods could be implemented effectively. FMI would be willing to host the data and produce a bi-weekly product which in turn would be useful as a building block for other related activities such as QA testing. A global snow course archive could be built, including US SNOTEL data.

An important new initiative of WMO and the Global Framework for Climate Services is the development and implementation of an Arctic Polar Regional Climate Centre (Arctic-PRCC). It has now been accepted by WMO Executive Council as a trans-regional RCC (RAII, IV and VI). A GCW priority is providing support to the development and implementation of an Arctic-PRCC. Several actions were discussed, one being that Snow Watch is requested to identify potential products (regional or pan-Arctic) which could be offered as contributions to the Arctic PRCC. The Team's experience in developing hemispheric snow products would be extremely useful to the countries engaged in developing the Arctic-PRCC.

The meeting identified over 50 actions and recommendations for GCW and Snow Watch which were collated and summarized (ANNEX 11). All will be considered by the Team. Key issues are requiring the attention of the Snow Watch Team are summarized below. A work plan will be developed for discussion and approval at the next GSG meeting.

Observation and exchange of snow data:

- continue efforts to implement the observation and exchange of snow depth and reporting of zero snow depth in real-time on the GTS through the WMO regulatory process (CBS and Regional Associations) and through members' individual efforts with GCW partners and regional activities (e.g. COST Action HarmoSnow); fill national gaps
- work with WIS to exchange SWE and snow course data to the global snow course archive at FMI; this will serve as a prototype test to exchange non standard cryosphere data in real and non-real time using WIS
- review and advise on snow measurement procedures and requirements for GCW Observation Network, including CryoNet;
- Contribute to GCW Guide and Manual on Best Practices

Satellite missions: planning, products, assessment:

- Coordinate satellite snow mission planning activities for ~1 km daily global SWE product (EUMETSAT, CSA, NASA SnowEx, ESA, etc) to fill a fundamental gap in the observing system
- SnowPEx follow-on activities: publication of results, ISSPI-3, define objectives for next phase
- Discuss how to expand initial regional user surveys for snow products and information, such as done by CryoLand, to other regions as a GCW contribution to WMO OSCAR and for satellite mission planning.
- investigate and test the concept proposed by SnowPEx for ongoing evaluation of NH snow products using high resolution satellite data
- investigate the causes for SE differences in snow maps retrieved by different Landsat snow mapping algorithms, including assessment of uncertainty in different environments

Snow products:

- Development of multi-dataset SWE tracking and regional snow trackers, particularly for use by the Arctic-PRCC
- Develop a GCW dataset of climate stations with quality controlled, homogeneous, long-term (1950?-) continuous daily snow depth observations for a global assessment of in situ snow cover change; establish clear guidelines for evaluating the QC and homogeneity of historical daily snow depth observations.
- Review the user needs identified in the initial survey by the PHORS/PRCC SG and identify snow products and information needed to meet user needs, including satellite and in-situ observations required for producing/developing products and services.
- Continue development of the snow products dataset inventory on the GCW website and assess the need and modality for an associated evaluation page.

Data and Analysis:

- expand the historical SWE database at FMI and ensure its inter-operability through the GCW Portal;
- Produce a paper on NH in situ SWE trends for AR6. Ditto for long-term snow depth stations.
- Identify national contacts for contributing to and updating the historical snow depth and SWE archive at FMI; update Canadian historical SWE dataset from 2003
- Assess availability and access of metadata for snow measurements in the GCW observation network, including CryoNet sites.

Communication and Outreach:

- Ensure Snow Watch Team has required expertise to execute Snow Watch activities from regional to global scales
- Identify potential contributions and experts to strengthen the snow content and the Snow Watch page on the GCW website**.**
- Strengthen linkages with the hydrological community (observation, applications, modelling), particularly in high alpine areas
- Contribute expertise to development and refinement of snow terminology
- invite representatives from the Observations Working Group and Information and Services Working Group to actively participate with Snow Watch on issues of mutual interest/need and participate in telecons and meetings, as necessary

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1. ORGANIZATION OF THE MEETING

1.1. **Welcome and opening:** Dr. Ellen Mosley-Thompson, Director, Byrd Polar and Climate Research Center (BPCRC), welcomed participants to the Center, noting that the Center was founded in 1960 and its early work stemmed from the International Geophysical Year (IGY) Antarctic research. Its research endeavours have since extended globally; for example, scientists at the Byrd Center are reconstructing past climate by studying chemical records preserved in ice cores collected from glaciers in Greenland, Asia, North and South America, and Antarctica. The Center, in co-operation with the Ohio State University, began an archival programme when, in 1986, it received the Byrd papers. The archives now also hold the Wilkins, Cook and other papers. In 2014, the Center's name was changed to include Climate.

On behalf of the Secretary General of the World Meteorological Organization, Dr Petteri Taalas, Dr Barry Goodison (Vice Chair of the Steering Group for the Global Cryosphere Watch (GCW)) welcomed participants and thanked Dr Mosely-Thompson and the BPCRC for hosting the meeting of the Snow Watch Team, noting also that the Eastern Snow Conference was being hosted at the Center on 15-16 June. Dr Goodison noted that this session was an excellent opportunity to liaise with the BPCRC and its scientists and students, and to build synergies with the WMO Global Cryosphere Watch.

1.2 Participant introductions: Introductions were performed amongst the participants (see the full list in **ANNEX 2**). Marco Tedesco (USA) was unable to participate.

1.3 Local arrangements: Dr. M. Durand, local host, outlined arrangements for the meeting. R. Brown and K. Luojus, Snow Watch Team co-leads thanked Mike for his support in facilitating the meeting at the BPCRC, in conjunction with the 73rd annual meeting of the Eastern Snow Conference.

1.4 Adoption of the agenda, assignment of rapporteurs: The programme **(ANNEX 1)** for the meeting was adopted with minor amendments. Item 4.6, Update of NASA AMSR work which was to have been presented by M. Tedesco, was not presented nor discussed. As requested, participants/presenters presented their thoughts on Issues, Gaps, GCW priorities and contributions at the end of their agenda item. Rapporteurs were assigned to monitor and collect input on key points raised in presentations and discussions, and on any recommendations and action items developed. The rapporteurs were Ross Brown (Monday AM), Sean Helfrich (Monday PM), Chris Derksen (Tuesday AM) and Samantha Pullen (Tuesday PM). The rapporteurs reported under agenda item 7.1. The final document plan and all of the presentations and background documents and information notes can be accessed at https://drive.google.com/drive/folders/0B0DFbV705pJMQnloRi1HQ0EzbVU

2. SNOW WATCH BACKGROUND

2.1 Meeting Objectives: The objectives of the meeting were considered, namely:

- Update/review progress in the action items identified in the first GCW Snow Watch meeting in Toronto in 2013; confirm on-going initiatives.
- Develop a draft Terms of Reference for the Snow Watch Team.
- Provide an update on the current state of global snow cover monitoring activities and products; identify gaps and issues for further action.
- Identify contributions to other GCW activities e.g. CryoNet, terminology, guidelines/best practices
- Discuss potential products and information to support the proposed WMO Polar Regional Climate Centres

- Identify priority issues that can be moved forward through GCW Snow Watch initiatives; establish task teams and timelines

In discussion, Dr Bojkov noted an additional objective would be to start the process for identification of priorities for future space-based observing missions. The Team agreed that this was an important topic to be discussed.

The Snow Watch workplan for 2015-2016 submitted to the GCW Steering Group in December 2015 is given in **ANNEX 3** and will be updated based on outcomes of this meeting.

ACTION: Update Snow Watch workplan for 2016-2018 (co-leads, Secretariat)

2.2 GCW update: Dr Goodison noted that the GCW activities and accomplishments were all captured on the GCW web site at: http://globalcryospherewatch.org. A summary of the status of GCW is given in **ANNEX 4.** He briefly reviewed the establishment of the concept of GCW, and its evolution into a partnership-based and cross-cutting programme within the WMO, noting that GCW is (since the seventeenth World Meteorological Congress in 2015) one of WMO's seven priorities. GCW is guided by the WMO Executive Council (EC), through the EC Panel of Experts on Polar and High Mountain Observations, Research and Services (EC-PHORS). The current Implementation Plan is available at: http://globalcryospherewatch.org/reference/documents/.

Building on past and current initiatives such as those organized through, inter alia, National Meteorological and Hydrological Services, UNESCO, the Arctic Council and its AMAP, and the European Union CryoLand project, GCW is working on strengthening observations, developing Best Practices guidance, identifying observational requirements, participating in intercomparisons, enhancing data exchange and reporting, contributing to WMO's space-based capabilities database, conducting data rescue, developing a terminology, developing hemispheric products, conducting outreach and training, assessing the state of the cryosphere, and fostering access to data and metadata through a portal. The GCW Best Practices Team is developing the Guide and Manual on GCW that will become a source for updating WMO Technical Regulations, Manual on WIGOS and Guide on WIGOS, thus establishing standards and regulations to coordinate and make consistent the tools and practices used for cryosphere observing, exchange, analysis and product development.

The development of official cryosphere terminology by GCW will require cooperation across all cryosphere domains, and it is recognized that each science community has developed specific language that may not be entirely consistent with terms in use in other communities – for example the numerous ways in which disciplines, organizations and countries discuss various aspects of 'snow'. The Snow Watch team is stronglyencouraged to take part in development of the snow components of the terminology (see **ANNEX 5** for current information on the Terminology Team plans).

ACTION: Snow Watch members and experts were invited to join or contribute to the GCW Terminology Task Team to ensure all snow related terms are properly defined.

In addition, the Snow Watch Team was asked to consider whether GCW should develop an activity to continue the work on solid precipitation measurement and analysis, including snow on the ground, launched under CIMO. SPICE (the Solid Precipitation Intercomparison Experiment) is coming to an end soon, and there may be a need for GCW to provide follow-on coordination of such activities. The Snow Watch Team would be the appropriate body to address aspects related to snow on the ground and snowfall data processing, analyses and products.

In discussion, it was noted that there is no set target for the number of stations in CryoNet, but that it is important that each approved site meet all the set requirements. In the early stages of CryoNet, site selection is not being limited by considerations of geographic coverage, but there is a clear goal to improve coverage in data sparse areas. Some sites included in CryoNet are still in research mode and efforts are being made to get data in near-real time from such sites to forecast centres such as ECMWF. As to ensuring that a (new) site is included in CryoNet, it was reiterated that the site proponents need to fill out the questionnaire, ensure that the site meets the criteria, and share the data.

With respect to university or project sites that may have, or will generate useful data but may not be sustainable into the future, it was noted that the data needs to be retained for study purposes, but wherever possible, long term sustainability should be factored in so the data will contribute to the broadest set of uses including prediction models. There is no funding from WMO, but National Meteorological and Hydrological Services should be urged to consider valuable sites for uptake into their networks. Being approved by WMO as a CryoNet site could help in leveraging funds for long term sustained support.

ACTION: Snow Watch Team members and experts were asked to identify potential CryoNet sites, particularly those in remote regions and those which include snow observations suitable for model and/or satellite validation/evaluation, and to encourage the site operators (agencies or researchers) to have the site considered for inclusion in the GCW observing network.

2.3 Snow Watch Team – Terms of Reference, Current Membership, Working Methods: The membership of the GCW Team prior to the 2nd session of the Snow Watch Team included: co-leads - Ross Brown (Canada) and Kari Luojus (Finland); members: Chris Derksen (Canada), Samantha Pullen (UK), Patricia deRosnay (ECMWF), Dave Robinson (USA), Sean Helfrich (USA). Thomas Nagler (Austria; SnowPEx) was added to the team and membership will continue to be updated as required.

The meeting discussed the draft terms of reference, including membership, accountability and working methods. It was noted that the team should also engage the GCW national Focal Points to enhance regional input. As well members and experts are encouraged to remind their Permanent Representative with WMO (and their associated staff) to think beyond their NMHSs when establishing FPs, and in communicating GCW information to relevant communities in their countries. Expertise on snow related matters exists in other agencies and academic institutes outside of the NMHS domain.

The final terms of reference are given in **ANNEX 6 b**ased on discussion at the meeting and input from the GCW Secretariat.

ACTION: The final terms of reference will be submitted through the Integrated Products WG to the GCW Steering Group for approval at its next meeting.

ACTION: Membership is to be updated by September 2016 and submitted to the GSG for approval.

2.4 Overview of action items from 2013 Toronto Snow Watch meeting: Environment Canada hosted the first workshop on implementing a Snow Watch component of GCW at Downsview from January 28-30, 2013. Twenty-eight scientists from nine countries (Austria, Canada, Finland, Italy, France, Norway, Switzerland, United Kingdom and USA) participated in this initial workshop to determine the current state of global snow monitoring, to identify critical issues affecting the ability to provide authoritative information on the current state of snow cover, and to initiate GCW Snow Watch projects to address priority areas. The workshop presentations, list of participants, participant questionnaire responses and rapporteur summaries are provided online at http://www.wmo.int/pages/prog/www/OSY/Meetings/GCW-PS1/DocPlan.html. Five priority action items were identified and assigned:

1. Improve real time flow and access to in situ snow measurements (e.g. non-reporting of snow depths by some countries)
2. Initiate a satellite snow products evaluation/intercomparison activity
3. Develop hemispheric "snow anomaly trackers" for SCE and SWE for GCW website
4. Develop an inventory of existing snow datasets and products
5. Initiate activities to standardize snow-related nomenclature, and promote standards and best practices as a contribution to CryoNet

Progress on these activities will be presented and discussed during the meeting.

3. REVIEW OF PROGESS

3.1 Snow depth reporting: real time data exchange and reports of zero snow reporting. Patricia deRosnay and Samantha Pullen provided valuable updates on the issue of real time data exchange of snow depth and zero snow depth reporting (Doc 3.1.1 and 2.1.2). Significant progress has been made on these issues. It is very important to understand that suggested improvements in procedures for reporting do require changes in WMO Regulations, which require approval from the Commission for Basic Systems and the WMO Regions.

The Snow Watch Team has made considerable progress on increasing the exchange of snow depth data on the GTS. ECMWF and the UK MetOffice have demonstrated that Snow Data Assimilation (DA) is crucial for NWP. In the absence of a dedicated satellite mission, in situ snow depth is by far the most relevant information for snow DA. It was noted that there are fewer SD observations on the GTS now than in 1985. Areas with sparse reports exist regionally (e.g. Finland, Iceland, Bulgaria) and over larger areas (e.g. Southern Hemisphere) and zero-depth reporting is still not being carried out in some countries in Europe. USA and China observations are not available in real time, although in the case of the US this is because the data is not yet reported in the correct BUFR format. Some countries only report seasonally when there is snow cover present. In these countries, snow depth data do exist, and generally are available nationally, but are not exchanged on the GTS. Snow Watch efforts have shown that the new ECMWF BUFR template can be used to exchange snow depth data, but recognizes that agency or national data policy, resources and even awareness may be limitations to implementation. Addressing these issues would improve the availability of snow depth reports on the GTS. ECMWF is helping NMHSs with the implementation of the dedicated BUFR template (e.g. Bulgaria). Collaboration and coordination of efforts by COST action HarmoSnow, NAEDEX (North America Europe Data Exchange), and Snow Watch are needed to ensure the more global acceptance of this recommended action. It was noted that the new OSCAR data base now allows for information on in situ observations, but that snow depth was not yet included; OSCAR could be a very useful tool for monitoring the availability of snow depth reports.

A key problem for snow depth reporting is that snow depth is generally reported only when snow is present; hence there are few zero snow depth reports. Consequently, missing data could mean no snow, a technical problem, or the station is out of service. This ambiguity means missing data cannot be inferred to be zero snow depth. For assimilation, observations of zero snow are as important as observations of snow, for informing model snow extent. Actively reporting zero snow depth would provide the data user community with a huge amount of valuable additional data, providing positive observations of snow-free conditions.

Observing network reporting practice is governed by WMO CBS guidelines that encourage zero SD reporting. However, FM 12 SYNOP regional guidelines still contain instructions that SD “shall be included only if snow or ice cover is observed on the ground”. It was also noted that regional snow reporting guidelines differ and the reporting of snow depth is not consistent from region to region. Therefore, there is a need to harmonize observing practices across all WMO Regions. It is proposed that CBS-16 (Nov. 2016) will request Regions to address this issue with the help of the respective CBS OPAG-ISS Team. This is to ensure that all practices require the reporting of snow depth on a regular basis regardless of the state of ground. Transition to use of BUFR encoding enables the use of a distinct code for zero cm snow, as opposed to a missing report. **ANNEX 7** provides more technical information on the issues and the need for zero snow depth reporting, as presented to the CBS Expert Team responsible for such matters and **ANNEX 8** provides the current status on snow observations reporting.

There is nothing to stop individual nations adopting the new practice before it is mandated by WMO. It was noted that it takes some work to adapt the observing system to use the BUFR code. The UK is incorporating the change in zero snow depth reporting in the rollout of a new observing system software planned for Nov 2016. It was also noted that the COST Action "HarmoSnow" has offered the opportunity to promote awareness of the issue and gain the support of other European nations.

In summary, consistency is essential. Regional practices need to be harmonized. There needs to be improved knowledge and understanding of manual vs. automatic station capability with respect to snow depth observing, including the measurement and reporting of patchy snow around a sensor/station. Discussion on this topic revealed that there were inconsistencies in the determination and reporting of patchy snow cover. It is recognized that zero snow depth reporting is not required all-year round for every station, but the WMO regions could determine the reporting period applicable to their region.

ACTION: The Snow Watch Team shall continue its efforts to improve the exchange of snow depth and the reporting of zero snow depth on the GTS through the WMO regulatory process and through members' individual efforts with GCW partners and regional activities (e.g. COST Action HarmoSnow)

ACTION: All Snow Watch Team members and experts are requested to talk to observing system colleagues to encourage other NMHSs to adopt these changed reporting practices.

ACTION: CBS and WMO Regional Associations are requested to support the GCW Observing System by implementing changes in the WMO Technical Regulations to implement the exchange of snow depth on the GTS in real-time and for the reporting of zero snow depth. (Secretariat assistance required).

ACTION: There needs to be clarification on the measurement and reporting of patchy snow cover, particularly in the context of automation. The GCW Best Practices Team is asked to include this topic in the snow section of the GCW Guide and Manual. (Secretariat)

3.2 Dataset directory/Historical snow depth archive: Ross Brown gave an update on the GCW Snow Dataset Directory (http://globalcryospherewatch.org/reference/snow_inventory.php). The online dataset which can be queried now contains with 53 dataset entries subdivided by source: Satellite derived (19 entries), Analysis/Reanalysis (19 entries), In Situ (15 entries). The latest addition is a 212 station historical snow depth dataset from China that only happened because of a formal request from GCW to the China permanent representative to WMO. Contributors were asked to keep Ross informed of updates/additions. The need for such a dataset was identified in the 2011 SWIPA report and was one of the priority activities identified at the first Snow Watch meeting. In 2014 ECMWF organized an experts meeting under the Core-Climax programme to explore the development of a global archive of Historical in Situ Snow Data and the review of available datasets conducted at that meeting contributed 20 to the GCW Snow Dataset Inventory (see INF.4 for more information).

The following issues were offered for continuing discussion:

- Whose responsibility is it to provide information on known issues/problems in the dataset directory for particular datasets? With respect to “PI self evaluation” the PI has a conflict of interest by definition.
- SnowPEx will provide some guidance but we need to make sure that results are incorporated into the directory.
- Do we want/need a dataset evaluation page like the NCAR Climate Data Guide pages for reanalyses? This includes the views of a number of recognized experts and an associated blog where users can post questions/comments on datasets.

ACTION: SnowPEx is requested to provide guidance on issues/problems in datasets based on the experience of their intercomparisons.

ACTION: The Snow Watch shall continue the development of the dataset inventory and will assess the need and modality for an associated evaluation page.

3.3 FMI Arctic historical in situ snow data archive: Kari Luojus (Doc 3.3) provided an update on the compilation of long-term in situ snow observations from different sources (up to ~100 years if possible and where possible). It includes distributed snow course observations from Eurasia and North America on Snow Water Equivalent (SWE), including from Russia/Former Soviet Union, Finland and Canada. The prototype snow course data archive was established in 2016 by FMI as recommended by the EU FP7 Core-Climax coordination meeting. The data set is now available at: http://litdb.fmi.fi/eraclim2.php. It contains 30495 snow courses spanning 1935-2009 and has about 4.2 million observations of Snow Water Equivalent (SWE), Snow Depth (SD) and Snow Density.

Currently, the USA is not included, but this could be done. It was indicated that the dataset could be shared through the GCW portal using the WMO information System (WIS). There is some work in progress to extend beyond 2009. Ross Brown suggested that ideally you could have a coordinator for each contributing country to do updates and QC, to which Kari agreed. In Canada there are 10 different databases, but no single coordinator. Is there a role that the national focal points could play in supporting this initiative?

ACTION: FMI is urged to work with Oystein Godoy, who oversees the GCW Portal, to make this dataset interoperable and accessible through the portal.

ACTION: The Snow Watch Team and FMI should discuss the benefits and feasibility of having a single contact point (person and/or agency) in each country to provide database updates and assist with QC. The potential role of national focal points in this activity should be considered.

3.4 GCW website snow material: Ross Brown provided a short summary of the GCW website (http://globalcryospherewatch.org/) on behalf of Jeff Key, Lead of the Website and Outreach Team. Ross raised the following issues for consideration by the Team and experts:

Snow trackers: It was noted at the meeting that the current CMC analysis is being replaced by a new land surface assimilation scheme in 2016 with the potential loss of this product as there could be no historical context for the output from the new scheme. Shortly after this meeting it was learned that the current CMC global snow depth analysis will not be replaced until sometime in 2018; discussions have been initiated with CMC to ensure that the tracker is supported when the new global analysis becomes operational. This issue raises the question of what potential there could be for developing trackers from other real-time or NRT products? (5-10 day latency would probably still be acceptable)? It was noted that the NOAA IMS-24 daily product could be used to complement the CMC snow cover extent tracking. Ideally GCW should be tracking SWE from multiple datasets in light of the documented spread in SWE products, but data latency is an issue.

It was noted that there has been a request for regional trackers in support of WMO Polar Regional Climate Centres. Regional trackers may require more careful validation as there is greater potential for issues to appear at the regional scale (e.g. model bias, resolution issues, treatment of perennial snow, etc).

Assessments: Expert input is needed for occasional assessments of snow cover (SCE and SWE) for various regions including the Southern Hemisphere which is a major gap at present. An example is the timely assessment of *2015-2016 Alaska: Winter Temperatures and Snowpack prepared by* Rick Thoman of NOAA/NWS Alaska (and a member of the website and outreach team). A “scaled-down” version of the Arctic Report Card would be an example of a broader assessment that would be useful..

Snow Watch page: This page exists under "Activities" on the GCW website, **but nothing new has been added in quite a while**. Jeff is seeking suggestions for new material, with help being even more welcome

Gaps in GCW snow content? Feedback is welcomed as well as volunteers to provide material.

ACTION: The Snow Watch Team is requested to discuss these needs and identify potential contributions and experts to strengthen the snow content and the Snow Watch page on the GCW website.

ACTION: The development of multidataset SWE tracking and regional snow trackers, particularly for use by the Arctic-PRCC, will be discussed by the experts involved in tracker products (Brown, Luojus, Derksen)

3.5 The Satellite Snow Product Intercomparison and Evaluation Exercise (SnowPEx) - Overview and update: SnowPEx Principle Investigator Thomas Nagler (ENVEO) provided an excellent summary (Doc 3.5) of current progress in the ESA SnowPEx project which was initiated in response to a recommendation from the GCW Snow Watch Meeting in Toronto, January 2013. Since the project was initiated in May, 2014, two international Workshops were held at NOAA, Washington DC, July 2014, and NSIDC, Boulder Colorado, September 2015, with more than 45 participants from all major organisations working in the field of satellite-based snow monitoring. SnowPEx has developed standardized protocols and reference datasets for evaluating snow extent (SE) and snow water equivalent (SWE) products.

Some preliminary conclusions from SnowPEx are:

- Protocols and methods for intercomparison and validation were elaborated and agreed by the EO snow community. These should be generally used for snow product intercomparisons. They can be obtained at: http://earth.esa.int/web/sppa/activities/qa4eo/snowpex.
- There is considerable inter-dataset spread for the Northern Hemisphere snow cover extent and snow mass products derived from satellite data, as well as for model-based snow products.
- The spread between satellite SE products varies with the snow regime and land cover class, and changes during the snow cover season. Intercomparisons of hemispheric SE products with Landsat snow reference data show RMSE values between 10% and 25%. SE products using different Landsat snow algorithms require a more detailed analysis on their performance.

- Multi-annual trend analysis of SE shows significant differences between individual SE products, in particular during late spring. The causes of these differences need to be assessed in more detail.
- Satellite SWE retrievals show a RMSE between 42 mm and 72 mm compared to in situ data. Assimilation of in-situ snow measurements in the retrieval algorithm improves performance.
- Additional intercomparisons of products for different time steps and for different variables (e.g. snow melt) are warranted.

A number of recommendations were made based on the experience obtained in SnowPEx to date:

- ***Snow Melt Products***: Since the launch of Sentinel-1A, followed by Sentinel-1B systematic repeat pass acquisitions of SAR data are available, providing unique data bases for operational monitoring of snow melt area. Prototype algorithms for retrieving snow melt by means of SAR are available at various institutions.

Recommendation: In order to promote and consolidate the use of these data, it is proposed to develop standardized protocols for validation and to intercompare/evaluate SAR- based snow melt products within upcoming SnowPEx activities.

- **International Satellite Snow Product Intercomparison Workshops**: There is high interest for regular SnowPEx meetings in order to continue the international coordination of R&D for EO-based snow products and to further promote the use of these data for science and operations.

Recommendation: GCW recommends holding an International Satellite Snow Product Intercomparison ISSPI-WS every 2 to 3 years, as a continuation of ISSPI-1 and 2.

- The SnowPEx project team conceived a ***System for ongoing evaluation of NH snow products*** using high resolution satellite data (Sentinel-2, Landsat) of globally distributed key regions around the globe using protocols developed within SnowPEx (see bullet below). This concept allows ongoing quality assessment of operational hemispheric snow products.

Recommendation: GCW recommends further investigation and testing this concept.

- ***Algorithms for mapping SE from Landsat and Sentinel-2 data*****:** Landsat and Sentinel-2 are major cost-effective data sources for high resolution snow maps, a main basis for validating NH / global snow extent products. However, the SnowPEx exercise revealed significant differences between snow maps retrieved by different Landsat snow mapping algorithms, depending on land cover type and topography steepness of terrain.

Recommendation: It is recommended to investigate the causes for these differences and to assess the uncertainty of the SE algorithms using Sentinel-2 and Landsat data in different environments and improve SE retrieval from these data.

- ***Retrieval of cloud-free snow products from optical satellite data:*** Cloud/snow discrimination has been an ongoing issue for years. Hence the question of how to retrieve cloud-free snow products from optical satellite data (see MODIS Collection 6 snow products). There are various methods to address the problem, such as aggregating daily snow extent products of various days, using PMW data, etc.

Recommendation: It is recommended to evaluate methods used for "cloud clearing" to derive cloud-free snow products from optical satellite data.

ACTION: The GCW Snow Watch Team should include these recommendations in their report to the GSG and identify associated human and financial resource requirements.

4. DEVELOPMENT AND VALIDATION OF SNOW COVER PRODUCTS

4.1 GlobSnow SWE and Snow Extent products: Kari Luojus provided an overview of DUE GlobSnow-2 SWE and Snow Extent (SE) datasets and their future evolution (Doc 4.1). This included comparisons with other hemispheric snow products. ESA GlobSnow has produced NH snow extent (SE) and snow water equivalent (SWE) climate data records (17 and 35 years respectively, of snow cover information). The Near Real Time (NRT) processing system is still online, although the projected has been completed and additional information and data are available at www.globsnow.info. Of importance, is that **SWE NRT production moved under the EUMETSAT HSAF initiative.**

In the future evolution, they plan to develop a combination of SE and SWE information (for improved SWE time series) and are moving to 5km resolution with SWE. *These next steps are important to meet user needs, especially for hydrological applications.* Future plans (assuming available funds) include:

- Improved snow emission model for SWE
- Improved handling of SWE in forests and lake rich regions
- Incorporation of dynamic snow grain size in SWE retrieval
- Use of Sentinel-3 data in SE
- Improved cloud masking & FSC retrieval for SE
- Extending the SE time series back from 1995 (possibly to 1980)

The presentation generated some discussion on the ability to achieve a 5 km SWE product [Kari – what were the issues? I don't have any notes about this]. There was also some discussion about the appropriateness of using monthly SWE time series for trend analysis especially in the spring period. It was suggested that if a daily SWE product was not feasible, then a 5-day pentad might be a suitable time-step. *There was some concern expressed about validating products against in situ observations where those products incorporated in situ data in their retrievals. However, there are a number of ways this circularity can be avoided.*

4.2 MODIS and S-NPP VIIRS NASA Snow Products: Dorothy Hall provided a detailed discussion on NASA's work to extend snow product production from MODIS to Suomi - National Polar-orbiting Partnership (NPP) Visible Infrared Imaging Radiometer Suite (VIIRS). MODIS Terra and Aqua global daily, 8-day composite and monthly snow-cover maps are available beginning February 2000 and June 2002, respectively, representing 16+ years of MODIS snow maps. Snow maps are used worldwide for regional and global climatology studies for monitoring snow-cover extent and duration, for hydrological modeling and validation of model output and updating surface variables. With the launch of the S-NPP VIIRS in 2011, there is potential to extend the MODIS snow-cover record for eventual development of a moderate-resolution daily snow-cover climate-data record (CDR). Although there are many similarities between the MODIS and VIIRS sensors, creating a smooth extension of the MODIS snow-cover record is challenging. The challenges were fully articulated in the presentation (Doc 4.2). She also emphasized that users are much more sophisticated now and want the best fractional snow cover even over small areas. This demand for high resolution products is a recurring finding when assessing user needs for snow products. It was also noted that VIIRS will be on the JPSS-1 satellite to be launched in 2017. It was suggested in discussion that NASA and NOAA NESDIS should compare their VIIRS-derived algorithm and products for snow cover to maximize the outcome of their efforts and ensure each group's needs are met.

As an outcome of Snow Watch-1, NASA has been an active participant in the SnowPEx intercomparison, providing several years of MOD10A1 data products in the format and projection required for the project. The tiles were then mosaicked (by SnowPEx) into a 500-m resolution global product. They are looking forward to see the results of the snow map comparisons that might have been done with the data provided. The major issue with remote sensing of snow-cover extent is still cloud cover and cloud masking. This was also noted by Thomas Nagler. In addition, consistent MODIS – VIIRS snow-cover data products are needed to develop a moderate-resolution (375 – 500 m) climate-data record (CDR). Dorothy suggested that these are priority issues that GCW Snow Watch could help address.

Recommendation: Cloud cover and cloud masking should be a priority issue in defining future initiatives.

ACTION: The Snow Watch Team should define its role in supporting ongoing development of climate data records by different institutions.

4.3 NOAA Climate Data Record: Dave Robinson presented the NOAA Satellite Snow Cover Extent Climate Data Record at its 50 year mark (Doc 4.3), the longest satellite-derived environmental series. The NOAA Visible Weekly SCE Climate Data Record (CDR) has evolved to the current Interactive Multisensor Snow & Ice Mapping System where SCE is derived from multiple sources by trained analysts. The product is maintained in its original weekly binary (snow / no snow) format on 190.5 km resolution polar stereographic grid over the NH. This involves substantial degradation of the daily 24-km SCE product that forms the basis of the NOAA-CDR product since 1998. The dataset is used extensively by the climate research community for validation of climate models, studies of climate variability and feedbacks, and for climate monitoring (e.g. IPCC assessments and BAMS State of Climate reports). The dataset is maintained at Rutgers University along with various derived information such as rankings of NH SCE, and daily and monthly snow cover departures from a 1981-2010 reference period. The dataset and methods used in charting snow cover have evolved over the 50-years of the NOAA-CDR product and evaluation against in situ data over NA suggests that snow cover was underreported in the pre-IMS period. Recent efforts are focusing on developing a climate data record from the NOAA IMS-24 km product.

He offered some issues that require consideration at local to regional to hemispheric scales, including timing of season, length of season, average and extreme snow depth, average and extreme snow water equivalent and associated physical and societal impacts. As noted by others, this relates very much to meeting user needs. Moving forward, Dave argued for: ongoing/improved monitoring for both in situ and satellite systems and the development of integrated products; change detection/attribution investigations; ongoing assessments of snow cover within the system data and model driven outputs; and, cooperation with social scientists. The latter point emphasizes again the need to go beyond analysis of just the physical system. It is important to understand the needs and contributions of other socio-economic needing/using snow information.

ACTION: Snow Watch Team should discuss how to expand initial regional user surveys, such as done by CryoLand, to other regions as a GCW contribution to WMO OSCAR.

4.4 Status and further development of CryoClim global Snow Cover Extent product: Rune Solberg provided an update on the continuing development of Norway's global CryoClim snow extent product, including the development of climate change indicator products for snow season length, and the first and last day of snow (Doc 4.4). The CryoClim product provides daily SCE at a global 5 km resolution from 1982 based on a multi-sensor Bayesian approach (passive microwave and AVHRR) which mitigates the cloud cover and darkness constraints of products based solely on visible satellite data. Validation against in situ data indicates an overall accuracy of ~93% with lowest accuracies in the autumn and highest in the spring. The Himalayas (too much snow mapped) and coastal areas (mixed pixels) are two problem areas that need further work. Providing uncertainty estimates for multi-sensor data is a challenge but they are getting results that make sense using a probabilistic approach. The system has been operationalized, assuring updates for decades into the future based on operational Sentinel-3 data and passive microwave.

The objectives of CryoClim phase 2 (2015-2017) are to:

- Mitigate weaknesses in the Version 1.0 single sensor components of the algorithm (optical and passive microwave radiometers) and multi-sensor/multi-temporal data fusion to further increase the accuracy and robustness of the product.
- Extend the product with uncertainty estimates at the product and per-pixel levels.
- Advance the algorithms and processing chains with the inclusion of Sentinel-3 OLCI and SLSTR data.
- Perform more extensive validation of the product in space and time, including focus on inter-sensor issues in the time series, and include the results in the CryoClim processing chain for snow

The presentation clearly outlined progress on each of these issues and identified their next steps.

It was emphasized that SnowPEx has been a very valuable contribution to the snow community. However, it was noted that inter-comparison does not provide absolute validation; hence it is suggested that a follow-on to SnowPEx should be conducted doing absolute validation (for snow cover). WorldView-3's 16 bands do allow use of advanced retrieval algorithms, which make it possible to study absolute accuracy of most current retrieval algorithms, but these are expensive. The idea is not to use World View for everything, but to use it for certain things, like to test how the algorithms perform, to calculate bias, to study snow melt season, etc. This might be tested using a mountain area. Also, use of data currently in the Copernicus data warehouse might offer data to be used for such tests.

Recommendation: GCW Snow Watch supports the need for a SnowPEx-2 follow-on intercomparisons study, which could include absolute validation of products as one of its objectives.

4.5 Update of AMSR2-JAXA work: Richard Kelly provided an update on the GCOM-W1 AMSR2 snow detection and snow depth product (Doc 4.5) in which he is involved. JAXA requested that the approach be constrained to only AMSR2 data without dynamic in situ or other satellite data. The new approach uses two channels and both polarizations (18 and 36 GHz) and two polarizations (V and H). The retrieval methodology uses derived snow temperature to estimate grain size and snow density. Snow depth is obtained from a one-layer DMRT-ML retrieval. Product delivery to JAXA and testing are imminent. The product is anticipated to be released later this year which will provide another snow product for evaluation by the research community. There was discussion on the approach, especially using a single layered snowpack which may not be adequate for higher latitude snowpack.

Richard has also provided information of the situation now and moving forward for publicly available data via NSIDC and JAXA/EORC:

I. Currently-available products

a) NASA AMSR-E SWE product. (AMSR-E failed in 2011). The current available algorithm is based on a combination frequency differences between 18 & 36, 10 & 18 and uses the 89 GHz for shallow snow detection. The reference for this work is Kelly (2009). This is a space-based product that does not use near real-time *in situ* or ancillary satellite observations. Daily, Pentad and Monthly products are available in EASE-grid projection.

b) JAXA AMSR-E snow depth product (AMSR-E failed in 2011) - same as 'a' above except for a different set of projections and calibrated for snow depth. The current available algorithm is based on a combination frequency differences between 18 & 36, 10 & 18 and uses the 89 GHz for shallow snow detection. The reference for this work is Kelly (2009). This is a space-based product that does not use near real-time *in situ* or ancillary satellite observations. Products are available as swath (daily), and plate carrée + polar stereo projections (daily and monthly).

c) JAXA AMSR2 (launched in 2012) standard snow depth product. - same as 'b' above except for a different set of projections. The current available algorithm is based on a combination frequency differences between 18 & 36, 10 & 18 and uses the 89 GHz for shallow snow detection. The reference for this work is Kelly (2009). This is a space-based product that does not use near real-time *in situ* or ancillary satellite observations. Products are available as swath (daily), and plate carrée + polar stereo projections (daily and monthly).

II. Impending updates to the available products
a) NASA AMSR-E and AMSR2 SWE product. There is a high probability that two products will become available for the AMSR-E - AMSR2 series of observations.

(i) the Tedesco algorithm which is based on a DMRT inversion and snow grain size climatology. (this was part of the SnowPEx evaluation)

(ii) an updated Kelly algorithm based on the Kelly et al (2003) paper that dynamically estimates grain size, density and snow temperature for single layer DMRT inversion (single layer). This was not ready in time for the SnowPEx experiment.

Both algorithms are likely to provide a combination of grain size and/or density estimates to the users. Daily, Pentad and Monthly products are likely to be available in EASE-grid projection. *Both algorithms are likely to replace Ia above*.

b) JAXA AMSR2 standard snow depth and SWE product. As briefly explained above, an updated algorithm (the Space-based Microwave Snow Algorithm) based on the Kelly et al (2003) paper that dynamically estimates grain size, density and snow temperature for single layer DMRT inversion (single layer) is being developed. This was not ready in time for the SnowPEx intercomparisons, but has been in development for JAXA and is scheduled to be delivered in July. Products are to be available as swath (daily), and plate carrée + polar stereo projections (daily and monthly). Snow grain size, density and recent variance will be provided to the users. *This will replace Ic above initially and probably Ib as well*.

4.6 Update of NASA AMSR work: This topic was not discussed as the presenter was unable to participate due to illness.

4.7 Update on proposed satellite missions for snow monitoring: Chris Derksen presented a timely perspective on planning future satellite missions for terrestrial snow cover (Doc 4.7). Environment Canada and Climate Change (ECCC) has identified moderate resolution (~1 km) snow water equivalent (SWE) with frequent revisit as a priority observational gap which limits the development of enhanced operational environmental monitoring, services, and prediction. While a radar-based mission would address this measurement requirement, SWE retrieval algorithms and forward models require development and validation, and robust first guess model derived information on SWE and snow microstructure are likely required as retrieval inputs. Building on the heritage of previous missions (i.e. SASS, NSCAT, QuikSCAT) advanced spaceborne radar measurements would also provide suitable measurements to develop products related to:

-sea ice (type, concentration, extent, motion, melt and freeze onset)
-land ice (snow accumulation, melt onset, glacier and ice cap/shelf velocity)
-coastal ocean vector winds

ECCC is working closely with the Canadian Space Agency to define a new mission that addresses the need for SWE information, but also could provide new information with respect to other components of the cryosphere and coastal vector winds. The snow community is small; it needs to leverage what it can from secondary science drivers. This would offer a much stronger case than trying to argue for a snow only mission.

Given the range in potential snow applications/products, it is essential that mission development activities have a science driver with clearly articulated measurement requirements. Mission development activities are summarized for Canada, ESA, and NASA in the presentation.

In summary, Chris posed the following issues for consideration:

- New mission concepts should be pitched to cover multiple cryospheric and non-cryospheric variables to address as wide a range of user needs as possible (not just terrestrial snow!)
- How does GCW engage with, and contribute to, CSA, ESA, and NASA in ongoing mission development activities?
- Identifying international partnership opportunities are vital: ESA Earth Explorer 10; NASA Earth Venture? NRC Decadal Survey?
- How do we move from inter-connected but independent activities to jointly funded proposals?

ACTION: Snow Watch and GCW GSG need to discuss GCW engagement in mission development activities and in identifying and fostering international partnership opportunities and jointly funded proposals.

4.8 EUMETSAT snow-related activities / GCW needs and expectations: Bojan Bojkov provided an important perspective on EUMETSAT (Doc 4.8), where he is now head of remote sensing and products. He previously was able to support GCW through ESA support for SnowPEx. EUMETSAT is an intergovernmental organisation with 30 member states and 1 cooperating state to establish, maintain and exploit European systems of operational meteorological satellites, taking into account as far as possible the recommendations of WMO. A further objective is to contribute to the operational monitoring of climate change. Bojan noted that although EUMETSAT is an organisation with an operational mandate, it has nearly 100 scientists working on product improvement and new developments, especially for Hydro-Met and Climate requirements under H-SAF programme (http://hsaf.meteoam.it/overview.php). Current cryospheric products include snow cover (extent, wet snow area, SWE) and sea ice (surface temperature, concentration, edge, type, drift, emissivity). A close relationship between EUMETSAT and GCW will be mutually beneficial for developing, validating and implementing cryosphere products and services. EUMETSAT has stable funding out to 2030.

In considering satellite requirements, Bojan identified the following needs/issues:

1. Need for independent "in situ" data for validation and intercomparison of satellite datasets

Two considerations:

- *Data needs to be quality controlled, measurements characterized with traceability to "standards", and with SOPs or "Best Practice" for traceability*
- *Timely availability and preferably centrally coordinated?*

Recommendation: With some planning and clear "user" requirements, GCW (through the WMO and its Member States) is in a unique position to respond to this need for snow product validation datasets.

2. Need for "ancillary datasets"

Ancillary datasets such as air temperature, and precipitation timing, amount and phase are critical for (timely) interpretation, diagnostics, and improvement of snow products… ancillary data can also be complimentary for other satellite retrievals (especially when considering EO data on the hemispheric scale)

Recommendation: GCW is in the unique position within WMO to recommend the most appropriate ancillary data to use and to help facilitate its access for EO needs.

3. Defining the “base” or “minimum” measurements for GCW CryoNet? sites
Ground-based measurements (“in situ”) at remote sites (high-latitude, mountainous) should be complete/comprehensive, covering snow parameters, but also, for example the upper air, the atmospheric composition (including aerosol and clouds), as well as radiative properties (BSRN), etc. The benefit of having the additional variables beyond cryosphere specifically is huge and will add to the overall value of the CryoNet sites; this is invaluable to the space agencies.

Recommendation: GCW is in the unique position to implement the snow monitoring programme within the GCW observing network and to coordinate within WMO with the Upper Air Network, GAW and other “bodies”, to ensure that this can be met in CryoNet.

4. The satellite agency requires continued activities on “standardization” through GCW
In addition to the “in situ” requirements and “SnowPEx” EO intercomparison aspects, there is also a need for continued standardization and the development of “Best Practices” to ensure a high level of interoperability and transparency for end-users and services

Recommendation: GCW continue efforts to promote best practices and standardization across the EO community through establishment of priorities and targeted expert meetings such as ISSPI-3

In summary, EUMETSAT provides stable and reliable observation services for weather and climate, providing a large portfolio of products and services with a timeframe until 2040 and beyond. Cooperation with the GCW is essential for improvements to cryospheric EO products and offers opportunities to reinforce partnerships with Space Agencies on the definition of requirements and activities.

4.9 **Multi-dataset SWE products:** Chris Derksen provided an update on the SWE datasets being evaluated in SnowPEx (Doc 4.9). Five gridded, daily Northern Hemisphere SWE datasets derived from satellite passive microwave measurements (25 km) and reanalysis driven land models (0.5° to 1°) were assessed as a contribution to SnowPEx. The focus was on analysis of the spatial and temporal consistency of the products (*spread*); comparison to independent in situ reference datasets (*absolute uncertainty, bias*); climatological *trends*. The overall goal is to improve the ‘observational’ basis for the determination of trends, evaluation of climate models, forecast initialization/verification. The multi-dataset product on a NH 1 degree lat/long grid is available via NSIDC: “CanSISE Observation-Based Ensemble of Terrestrial Snow Water Equivalent, Version 1”. It covers the 1981-2010 period (daily).(http://nsidc.org/data/nsidc-0668)

Efforts to better characterize uncertainty in snow products (i.e. through ESA SnowPEx) provide the observational foundation for CMIP6 land MIPs (i.e. LS3MIP; ESM-SnowMIP). It was found that there is considerable inter-dataset spread in Northern Hemisphere snow mass and snow cover extent derived from available terrestrial snow products, leading to the following conclusions::

- Standalone passive microwave SWE products are problematic
- Products based on modern era reanalysis are highly correlated to each other, but are not ‘better’ with respect to independent in situ data (RMSE, bias)

- Hemispheric, cloud-free, daily SCE datasets are very limited
- Inferring SE from SWE is very sensitive to the SWE threshold used, and can introduce large uncertainties; it would be useful to compare SE from optical data with SE from SWE.
- Very few hemispheric, daily, snow products rely solely on satellite data
- The relatively coarse spatial resolution of many gridded datasets limits some applications
- At present, it is important to not reject any datasets, but to seek to understand why they are different.

Development of the multi-dataset SWE product was spurred by SnowPEx. The current multi-dataset SWE product covers one climatological normal period and it will require continual updating for annual climate assessments, applications such as seasonal prediction, etc. GCW can help arrange this updating.

ACTION: Snow Watch and SnowPEx are requested to address the challenge of how to best advance the progress made in SnowPEx.

ACTION: GCW/Snow Watch is to define a framework for updating the current multi-dataset SWE product using guidance provided by Derksen et al.

INVITED PRESENTATION:

The team was pleased to have Dr. Bryan Mark, Byrd Polar and Climate Research Center, Ohio State University, present "**Andean cryospheric observation from a transdisciplinary perspective".** The talk was very relevant to GCW and Snow Watch initiatives. Their approach is transdisciplinary coupling the biophysical system with the human dimension. He noted the lack of continuous observations, with only one site continuously observed more than 30 years. They are re-installing observing sites in the same places where there were sites in the 40s and 50s. The key to their success is partnerships across institutions (e.g. weather stations have been installed with the help of Austria and France). The basic approach is to measure glacier change and evaluate hydrological changes and modeling glacier-climate over time (glacier mass, downscaling). Changes are occurring much faster than expected so what does that mean for water resources? Glacier melt water is a very important resource. They have strong interaction with community water users (forestry, agriculture, commercial, labour, tourism, etc) and all report progressive loss of water availability. Analysis indicates that in many basins, we have already passed peak catchment water – there are not decades ahead of abundant water. Many challenges and opportunities are included in the talk.

A key message: To really understand what is happening, you need to integrate observation, modeling and social science, with OPEN SHARING OF DATA.

5. IN SITU AND SNOW ANALYSIS PRODUCTS

5.1 Russia and Canada in situ snow depth and snow survey programs: Ross Brown presented this document on behalf of himself and Olga Bulygina (Doc 5.1). Canada and Russia account for close to 60% of the NH terrestrial winter snow covered area and both countries share similar snow climates, but have contrasting approaches to in situ snow data collection and management. For various reasons, Russia has benefitted from a much stronger commitment to maintaining national in situ snow monitoring networks. In both countries however, the number of snow depth stations in the national network has declined over the past 20-30 years but much more precipitously over Canada than Russia. . In Canada, the current limited number of stations with long-term snow depth observations is a major constraint for climate monitoring and there is no coordinated effort to maintain a national archive of historical snow survey data. In Russia, however, the national in situ snow monitoring programs are essential elements of a structured climate monitoring program and in situ snow observations contribute to clearly defined climate monitoring and applied products/information.

Recommendations/actions were provided for implementation by GCW/Snow Watch:

Recommendation: It is recommended that Snow Watch develop a GCW dataset of climate stations with quality controlled, homogeneous, long-term (1950?-) continuous daily snow depth observations for a global assessment of in situ snow cover change, following that of Magnuson et al. (2000) for historical trends in lake and river ice cover in the northern hemisphere.

ACTION: An initial inventory should be initiated to identify candidate series and regional gaps. Potential series may exist in GHCN-D and GSOD but these datasets do not provide consistent global coverage over time. For countries such as Canada, this will require a dedicated effort of station joining and homogeneity assessment similar to that carried out for temperature and precipitation.

ACTION: Clear guidelines for evaluating the QC and homogeneity of historical daily snow depth observations need to be established. One can draw on earlier work e.g. Robinson (1989), Brown and Braaten (1998)

Recommendation: A separate parallel activity should be performed for mountain regions, which might be linked to CryoNet activities.

In discussion, Bojan Bojkov noted that in Europe the EU spends a lot on monitoring the status of in situ observations, but does not put any money into supporting the observations. Barry noted that Canada cut back on support of in situ snow observing networks to save money in the belief that remote sensing would do the job. Barry suggested that GCW could play a coordinating role in Canada for the various agencies with in situ snow measurement programs.

5.2 Global snow data collections and monitoring at NOAA/ NOAA's National Centers for Environmental Information: Jay Lawrimore provided an update on in situ snow cover datasets at NCEI, the sources of snow data, the stations reporting snow depth in the US and globally and associated Quality Assurance procedures (Doc 5.2). A key point is that data volume and sources contributing snow depth observations to the GHCN-Daily archive vary considerably over time, with the most extensive data for the United States (~10000 stations) compared to ~4000 stations reporting from outside the US. Recently the CocoRaHS network has become one of the main sources of snow depth observations in the US along with the National Weather Service COOP network. Data may be accessed at www.ncdc.noaa.gov/snow-and-ice. Jay endorsed GCW efforts to promote greater exchange of snow depth observations on the GTS and the effort to promote mandatory reporting of zero snow depths. A question was raised about metadata for observing practices. Jay responded that the US was in good shape, but globally there are issues.

Recommendation: GCW should assess availability and access of metadata for snow measurements in the GCW observation network, including CryoNet sites.

5.3 National Ice Center (NIC) and NOAA NESDIS snow products: Sean Helfrich provided the update (DOC 5.3), which included discussion of VIIRS Snow Cover/Fraction (Binary and Fractional, NDE (New) versus IDPS (legacy); the IMS/Blended Snow Products for snow cover and snow depth; MIRS algorithm Products for snow Cover, SWE, snow grain size; AMSR2 products of snow cover, snow depth, SWE; and AUTOSNOW / GMASI.

Evaluation/validation initiatives and planned revisions are also discussed. Currently, the JAXA AMSR2 products are currently identical to NASA products. The trend at NIC is toward higher resolution (e.g. a 1-km IMS snow extent product was initiated in 2014), snow cover fraction products based on VIIRS, and a new blended snow depth product based on AMSR and surface observations. These activities are being driven by user needs for higher resolution snow cover information for NWP and hydrometeorological applications.

5.4 ECMWF snow data assimilation: Patricia deRosnay gave a very complete update of snow data assimilation (DA) at ECMWF (Doc 5.4), showing the major developments in DA in the past few years and the large impact on NWP. OSEs show that combined DA of in situ snow depth and IMS snow cover significantly improve T2m forecasts. There are gaps in in situ SD reporting, notably in the USA and China, but additional National data in Europe have contributed to improve near surface weather forecasts at ECMWF. NMHSs are encouraged to report snow depth on the GTS; it would be extremely helpful for the USA and China to put all their snow data on the GTS. As well, although there are challenges in retrieving SWE (or snow mass as the modelers refer to it) from satellite measurements, Patricia supported new novel mission concepts for measuring SWE. This generated considerable discussion on a new satellite mission for SWE. In response to Bojan Bojkov's question on requirements for such a mission, Patricia indicated that it has to provide data quickly, ideally with a latency of 3-4 hours, provide daily global coverage, preferably with 10km coverage to match NWP scale (aiming for 5km globally in 2025). Data are especially valuable near the snowline which has implications for mission planning i.e. repeat coverage, swath width, and hence resolution. ECMWF does not want to assimilate products which already incorporate in situ data (e.g. GlobSnow); they need a satellite only data input to the DA.

ACTION: GCW, with the assistance of the WMO Secretariat, should assess the current situation with respect to exchange of snow depth data on the GTS from nations where there are gaps (e.g. USA, China, South America) and identify next steps to improve the situation regionally and globally.

Recommendation: GCW needs to support and be active in planning a novel SWE mission, perhaps building/broadening on the existing Canadian efforts with CSA.

5.5 UK Met Office snow data assimilation: Samantha Pullen provided Snow Watch with an update on: the UK Met Office NWP systems, including the land surface model and land surface analysis from satellite; NH snow analysis for global NWP; snow analysis for UK NWP; requirements for NWP; and plans for the future (Doc 5.5). **ANNEX 9** captures the requirements for NWP and provides guidance on the data and products that they need which is especially useful in developing snow products and designing satellite missions with NWP as one of the users. In the longer term they will include station snow depth assimilation in global model and make use of dense national networks now available on GTS and zero snow reports which are needed to better define the snowline. They plan to use complementary satellite observations, such as wet snow extent from SAR (EU SEN3APP project) and SWE from passive microwave (AMSR-2 v2). Novel observation sources including crowd sourcing (guided by the UK Met Office) and GPS receivers will also be investigated. It is hard for any single (remote-sensed) snow dataset to fulfil requirements for NWP assimilation; the best approach may be to exploit the best features of a number of products to use in a complementary way.

Several issues or gaps were raised which should help GCW Snow Watch plan its activities. Satellite-derived SWE (NRT, global) is needed (again supporting the call from many previous speakers) with improved uncertainty, given the current WMO OSCAR threshold uncertainty requirement for SWE for NWP of ±20mm (±10mm optimum) and being able to provide information in forested regions. Observations of density and grain size are also needed. Snow cover is still important, but complementary data sources are needed for forested and cloud affected regions. As noted, highly derived, combined data sources are less useful for NWP.

Ground-based snow depth still requires improved exchange of dense national network data and routine reporting of zero snow (the goal being for this to be mandated). Finally there needs to be support for operationally robust, long-term datasets (succession planning between instruments).Many of these have been iterated by others from beyond the NWP community.

Recommendation: GCW needs to continue its effort on data exchange of snow depth and zero snow reporting with CBS and WMO Regional Associations.

Recommendation: Snow Watch and GCW are asked to consider the requirements for NWP in planning in situ and satellite sensing of snow.

5.6 Snow data at NSIDC: Amanda Leon updated the Team on the snow products archived by NSIDC and made available to the scientific community (Doc 5.6). The snow datasets include:

- Global Snow Extent: MODIS/VIIRS NASA Products; Near-real-time SSMI/SSMIS (NISE);
- Northern hemisphere Snow Extent: Weekly Snow Cover (NSIDC-0046); NASA MEaSUREs Snow Products (NSIDC-0530, NSIDC-0534, NSIDC-0535); IMS Daily Northern Hemisphere Snow and Ice Analysis (g02156);
- Global SWE: AMSR NASA Products;
- Northern hemisphere SWE: CanSISE Observation-Based Ensemble (NSIDC-0668);
- CMC Daily Snow Depth Analysis (NSIDC-0477);
- Regional Snow Products: SNODAS Snow Cover; CLPX;

Considerable effort has been put on Discoverability - Accessibility – Usability. NSIDC data and metadata are interoperable with other Data Centers. The GCW portal is interoperable with NSIDC. NSIDC handles heterogeneous data formats, projections, and metadata. content/completeness. The products are "fit for use". However, sustaining data production is funding dependent and all NSIDC activities are supported. The NSIDC DAAC can provide services and data access for select non-NASA products, but is limited contractually. Product updates are limited by funding – they can take in data, but not update it. Hence, the user must understand the future of a data set and determine whether it can be supported in the future. Products cannot just be created as funding is needed. There is a process to follow for data to be submitted to NSIDC.

6. UPDATES AND ITEMS FOR DISCUSSION

6.1 SnowEx meeting feedback: Dorothy Hall updated Snow Watch on SnowEx: a NASA airborne campaign leading to a snow satellite mission (Doc 6.1). SnowEX is a multi-year airborne snow campaign designed to collect multi-sensor aircraft data and ground truth measurements to enable algorithm development and design of a future satellite mission. SnowEx is about challenging the sensing techniques and algorithms… to learn when, where and how each technique works alone, or in synergy with other techniques, and why. The driving questions are what is the optimum combination of sensing techniques to measure regional (global) SWE and global snow melt/energy balance (where, when, how fast).

The sites selected are Grand Mesa and Senator Beck in Colorado as they best met the site requirements: probability of wet snow is very low; existence of a shallow to deep gradient in snow depths and SWE; snow-covered area with flat terrain that is larger than airborne instrument swath widths; and there are forested stands with variable density and height. The core sensor types for Year 1 are: Lidar; Radar (SAR); Passive Microwave; Passive VIS/IR; Radiometer for sensing BRDF. The aircraft instrument payload has been designed to determine what combination of sensors provides the optimum results for measuring SWE, BRDF, surface temperature and mass. Campaigns are planned through 2020-21 depending on annual budgets.

Discussion noted the benefits of linking with the efforts of the Canadian mission planning (Doc 4.7). It is planned that these connections will be developed to the extent feasible. A suggestion was whether it is possible to operate a ground-based site at all SnowEx sites during all experiment years even if there is no airborne campaign. This would provide information on the representativeness of the single year with the airborne mission and help identify possible inconsistencies.

6.2 Guidelines/best practices for observing/measuring the cryosphere: Barry Goodison provided the current status and plans of the Best Practices Task Team which was established to compile best practices, guidelines and standards for observing/measuring cryosphere variables, building on what has been compiled to date and available on the GCW Website (Doc 6.2; see **ANNEX 10** for the status and timeline). The Team is to prepare a GCW Guide to Cryospheric Practices and then a more comprehensive Manual of Best Practices, which will be part of WMO technical regulations.

In short, the task entails:

- Inclusion of in-situ and satellite based observations.
- Engagement of experts from different countries and regions will be essential.
- Experts will be drawn from GCW teams and working groups and nominees through national focal points and partner organizations.
- Small sub-groups may be established to work on individual components of the cryosphere.
- Existing links on the website must be checked. New manuals, guides, best practices need to be added, including national guides which may have to be translated so the material can be incorporated as appropriate. Existing WMO practices included in WMO Guides (e.g. CIMO, Climate, Hydrology, AgMet) would be included.
- Ongoing regional efforts should be incorporated whenever possible (e.g. HarmoSnow in Europe).
- The guide and manual will include best practices suitable for research and operational purposes

ACTION: The GCW Snow Watch Team is requested to seek experts on observations in the snow community and recommend nominees to the Best Practices Task Team for inclusion on a snow sub-group.

6.3 Update on HarmoSnow EU COST Action: Patricia deRosnay provided Snow Watch with information on HarmoSnow, a European COST Action (Doc 6.3). COST is an intergovernmental framework for European Cooperation and it supports networking activities within the COST action. There is a COST Action on snow: A European network for a harmonised monitoring of snow for the benefit of climate change scenarios, hydrology and numerical weather prediction". This COST Action on snow (known as HarmoSnow) is a 4-year project aimed at building a better connection between snow measurements and models and among snow observers, researchers and forecasters for the benefit of various stakeholders and the entire society (see also: http://www.cost.eu/COST_Actions/essem/Actions/ES1404; http://costsnow.fmi.fi/**).** HarmoSnow has 29 countries participating but COST also welcomes near-neighbour countries and international partners.

The HarmoSnow objectives are:

1. **Establish a European-wide science network** on snow measurements for their optimum use and applications benefitting on interactions across disciplines and expertise.
2. **Assess and harmonise practices, standards and retrieval algorithms** applied to ground, air- and space-borne snow measurements.
3. **Develop a rationale and long term strategy** for snow measurements, dissemination and archiving.
4. **Advance snow data assimilation** in European NWP and hydrological models and show its benefit for relevant applications.
5. **Establish a validation strategy** for climate, NWP and hydrological models against snow observations and foster its implementation within the European modelling communities.
6. **Training of a new generation of scientists** on snow science and measuring techniques with a holistic perspective linked with the various applications

A key activity includes questionnaires on observations/instrumentation (with 92 responses) and on snow data assimilation (26 responses) (http://costsnow.fmi.fi/index.php?page=Questionnaires). The information gathered is not only valuable for HarmoSnow, but also would be extremely useful for GCW, and especially the Snow Watch and the Best Practices Teams. HarmoSnow wishes to extend the questionnaires to the international community seeking responses by September 26 2016. It would be especially helpful if US and Canadian colleagues could contribute. This is an opportunity for GCW to learn and build on the efforts of other initiatives. It was noted that they are also looking at hydrological applications, aiming to improve not only NWP, but also hydrological models. It was suggested that Snow Watch should look also at this aspect.

Recommendation: Snow Watch is invited to help in engaging the international community by informing its organizations and partners of the questionnaire and asking them to participate as appropriate.

ACTION: A letter will be drafted and distributed to members of all GCW Teams and to all GCW focal points asking them to engage the snow community both within and external to the NMHSs in completing the questionaires as applicable. (P. deRosnay, S. Pullen, Secretariat; to be distributed by July 20).

Recommendation: Snow Watch should proactively broaden its scope to include links to hydrological modelling in their activities.

ACTION: Recognizing that some Snow Watch members are engaged in hydrological applications, including hydrological modelling, the Snow Watch co-leads are urged to ensure hydrological applications and modelling are more entrained in Snow Watch and GCW activities.

6.4 Polar Space Task Group Strategic Plan: 2015-2018: Kari Luojus gave the PSTG presentation on behalf of Mark Drinkwater, ESA chair of PSTG (Doc 6.4). The PSTG Strategic Plan 2015-2018 is given in INF. 5). PSTG was established in 2011 under auspices of WMO EC-PHORS. PSTG members are nominated by Heads of Space Agencies, upon invitation by WMO Secretary General. Its objectives are to:

- provide coordination across space Agencies to facilitate acquisition and distribution of fundamental satellite datasets based on user needs
- provide support to development of specific derived products required for cryospheric scientific research and applications;

- Actively seek realisation of benefits from the growing constellation of polar orbiting satellites, by mobilising the unique and complementary capabilities of the respective participating Agencies, in response to the Polar science priorities.

Strategic priorities for snow include:

- Assure continuity in routine continental scale monitoring of snow areal extent and SWE data in support of GCW Snow Watch and snow applications and service development;
- Plan SAR data as complement to passive microwave (SSMIS; AMSR-E; AMSR2; MWI; MWRI) and >500m optical data (MODIS; VIIRS; Sentinel-3 OLCI, SLSTR) for continental scale snow extent/SWE – and in Alpine regions and rugged topography where other methods fail;
- Establish less than three day repeat SAR monitoring (ascending/descending combinations) of European Alpine region and other selected mountain regions (Scandinavia, Canadian Pacific mountains) during seasonally-limited snow melt time window;
- Establish common polarization/mode observation strategy between SAR missions
- Demonstrate routine snow melt data processing;
- Pilot a snow melt service (seasonal snow melt/runoff/hydropower/water resource availability);
- Expand temporal/spatial revisit to operationalize services.

To address scientific requirements for freshwater budget and reducing uncertainties in solid precipitation and mass balance in the polar regions, it is proposed to:

- Develop snow product intercomparison exercise in connection with GCW to assure product validation, and quality assurance (via engagement in activities such as SnowPEx)
- Develop new methods for snow depth retrievals on sea ice (e.g. Operation Ice Bridge/CryoVEx)
  --> e.g. Snow on sea ice intercomparison Exercise (SoS IE)?

Such priorities certainly coincide with many of the needs identified in this Snow Watch meeting. Several questions were also presented for consideration by the Snow Watch Team;

- What are Snow Watch needs in relation to CryoNet future product validation/ intercomparison (or diagnosing effects of inter-satellite bias)?
- What is the relationship, if any, between Snow Watch and the SnowEx campaign activities?
- What is the interest of Snow Watch to extend the domain to ice sheets/sea ice?
- Of what interest are SAR-based products for mountain regions?
- What are the main observation gaps?
- What is the potential for PSTG and the GCW Snow Watch efforts to interlock
- How could CryoNet sites be exploited to treat product validation, and/or product inter-comparison efforts - and how if at all the Space Agencies are impacted (or need to react).
- Lessons learned from SnowPEx would be useful, e.g. in terms of what aspects of in-situ capability are needed to diagnose/resolve understanding of differences in product performance (or root-causes of product biases, perhaps between sat. instrument L1b data).

An agenda item at PSTG6 is the potential for PSTG and GCW interaction/collaboration and PSTG would welcome feedback from Snow Watch on potential interactions. Jeff Key, GCW Senior Science Advisor to the GSG, is a member of PSTG and serves as the liaison with PSTG. Bojan Bojkov will also attend this meeting. Some of the questions above have been discussed at the meeting and actions or recommendations identified. The questions on the relationship between Snow Watch and CryoNet are important ones and need to be discussed further. Currently, no member of the CryoNet team has participated in Snow Watch meetings and this gap should be addressed.

ACTION: Potential interactions between Snow Watch and PSTG activities should be identified by Snow Watch for consideration at the PSTG meeting. (Kari Luojus, Bojan Bojkov, Jeff Key, Secretariat).

ACTION: Snow Watch shall invite representatives from the Observations Working Group and Information and Services Working Group to actively participate with Snow Watch on issues of mutual interest/need and participate in telecons and meetings, as necessary. (Snow watch and WG co-leads, Secretariat)

6.5 Snow Watch support for a Polar Regional Climate Centre: Barry Goodison briefed the meeting on GCW support for an Arctic Polar Regional Climate Centre-Network, a new WMO initiative (Doc 6.5 and INF. 9), which has now been accepted by Executive Council as a trans-regional RCC (RAII, IV and VI). The concept is given in INF. 9. To ensure the efficient operation of the proposed Arctic PRCC-Network, it is important to liaise with and build strong partnership with various international communities either beyond the WMO scope or WMO initiatives with significant non-NMHS participation. Those include but are not limited to the Arctic Council (AC), **Global Cryosphere Watch (GCW)**, the Global Integrated Polar Prediction System (GIPPS), the Year of Polar Prediction (YOPP), Aboriginal Communities, and so on. RCCs are operational, with regular products. GCW and its teams will be asked for input.

GCW may ensure a comprehensive, coordinated, and sustainable system of observations and information to allow for a more complete understanding of the cryosphere and to contribute to improved observations, research and services. The core GCW surface network – CryoNet – could support the RCC mandatory and highly recommended functions. GCW products, tailored to the pan-Arctic region, and the associated assessment and intercomparison of cryosphere products, would be a contribution to the PRCC effort. In addition, GCW efforts in, for example, establishing guidelines/best practices, terminology, user requirements and services, data rescue, validation should support PRCC operations. As well, it is expected that GCW contributions will include both national and collaborative pan-Arctic inputs.

The Arctic-PRCC Concept will be reviewed by stakeholders, then refined and endorsed by EC-PHORS to serve as basis for an IP. It is acknowledged that representatives of existing international efforts, such as GCW, that can provide operational and sustainable support to PRCC-Network need to be closely involved and their potential roles adequately captured in the IP. There will be a meeting of potential contributors of the network in late 2016 with a demonstration phase initiated tentatively in 2017.

There are challenges for GCW, including:

- Determining which GCW contributions can be aligned to an Arctic-PRCC timeline
- Increasing the number of GCW reps engaged in national PRCC implementation (currently, Rick Thoman (USA), Vasily Smolyanitsky (Russia))
- Snow Watch team identifying products and information to support Arctic-PRCC. GCW needs to start looking at products, and tailoring them for the region and for the users there.
- How GCW juggles its timeframes and activities to cooperate with PRCC
- How GCW builds links between GCW and PRCC national groups?

A GCW priority is providing support to the development and implementation of an Arctic-PRCC.

ACTION: Snow Watch Team is requested to identify a member who would serve as the point of contact for the Arctic-PRCC. (Co-leads)

ACTION: GCW Snow Watch should review the user needs identified in the initial survey by the PHORS/PRCC SG and identify snow products and information needed to meet user needs, including satellite and in-situ observations required for producing/developing products and services.

ACTION: Snow Watch is requested to identify potential products (regional or pan-Arctic) which could be offered as contributions to the Arctic PRCC. This could be done through national bodies depending on the structure implemented for the PRCC. Some new products may have to be developed to meet user needs.

ACTION: All Snow Watch Team members/participants are requested to contact their national Arctic-PRCC team to initiate dialogue on snow related services which GCW may be able to help with or provide to the PRCC.

6.6 Real-time SWE reporting on GTS – can it be done? Ross Brown kept everyone thinking when he led a discussion on real-time reporting of SWE on the GTS (Doc 6.6). As Ross found out, terminology and understanding cryosphere terms, can still be a challenge in WMO. For clarity, the topic is "real-time reporting of the water equivalent of snow lying on the ground" (not snowfall water equivalent or solid precipitation). For the following reasons, it is timely to think about ways to enhance the exchange of real-time reporting of snowpack SWE:

- Automated measurements of in situ snowpack SWE are becoming more widespread
- Automated SWE measurements (e.g. the SNOTEL network in western US) provide information in mountainous regions not well-represented by the global synoptic station network
- SWE is a more useful variable than depth for assimilation in land surface schemes

He posed the question ""Is there is a mechanism (e.g. code in SYNO's) to report real-time observations of in situ SWE to WMO via the GTS?" He received the following responses:

- **Atsushi Shimazaki OBS Department, WMO:** "Water equivalent of solid precipitation on ground" can be reported in the group 933RR in Section 3 of SYNOP but no country registered reporting of 933RR in the Manual on Codes…."
- **Bruce Ingleby ECMWF:** "I can't see any way of reporting the water equivalent of lying snow in the current BUFR code"
- **Patricia de Rosnay, ECMWF:** "I am not sure reporting SWE is possible with the current regulation."
- **Matthew Menne, NCEI:** "All of the SWE information we have [in GHCN] comes from pathways other than the GTS…. all SNOTEL data are now added to GHCN-Daily."

Hence, the questions…..

- Is real-time reporting of snowpack SWE a priority issue for GCW?
- Is there a creative way to do this in the current BUFR code?
- If not, are there other alternatives? e.g. GHCN-Daily
- Is there a natural linkage to the proposed global historical SWE archive at FMI?

There was good discussion that said reporting of SWE should be a GCW priority. The question remains whether the BUFR code could be used, and if not, what alternative methods could be implemented effectively. FMI would be willing to host the data and produce a bi-weekly product which in turn would be useful as a building block for other related activities such as QA testing. A global snow course archive could be built, including US SNOTEL data.

Recommendation: The exchange of SWE data would be a good test of WIS being able to move "irregular data" from NMHSs, partnering agencies and researchers. GCW should ask WIS to establish a mechanism to exchange SWE data from various operators.

ACTION: The BUFR code was able to be used for the exchange of snow depth data; could it be used for SWE? Use of the BUFR code shall be tested to exchange SWE data on the GTS (deRosnay, Luojus, Brown, Secretariat)

ACTION: GCW shall work with WIS to exchange SWE and snow course data to the global snow course archive at FMI. This will be a prototype test of the WIS system to exchange non-standard cryosphere data. (Luojus, Brown, Secretariat)

ACTION: FMI will be requested to operate the SWE archive and to produce bi-weekly products suitable for use by GCW and the Arctic-PRCC.

7. NEXT STEPS FOR GCW SNOW-WATCH

7.1 Rapporteur summary of discussion: The rapporteurs, Ross Brown, Sean Helfrich, Chris Derksen and Samantha Pullen, captured activities and actions for each of the four sessions. Their recommendations and action items are reported under each topic above. Overall priority actions are given in 7.2. Individual actions are still to be actioned by the Team or GCW, as appropriate.

7.2 Discussion, definition and assignment of action items: The action items have been collated and summarized in **ANNEX 11** for follow-up**.** These were used to identify the following as key issues requiring the attention of the Snow Watch Team. A workplan will be developed for discussion and approval at the next GSG meeting:

Observation and exchange of snow data:

- continue efforts to implement the observation and exchange of snow depth and reporting of zero snow depth in real-time on the GTS through the WMO regulatory process (CBS and Regional Associations) and through members' individual efforts with GCW partners and regional activities (e.g. COST Action HarmoSnow); fill national gaps
- work with WIS to exchange SWE and snow course data to the global snow course archive at FMI; this will serve as a prototype test to exchange non standard cryosphere data in real and non-real time using WIS
- review and advise on snow measurement procedures and requirements for GCW Observation Network, including CryoNet;
- Contribute to GCW Guide and Manual on Best Practices

Satellite missions: planning, products, assessment:

- Coordinate satellite snow mission planning activities for ~1 km daily global SWE product (EUMETSAT, CSA, NASA SnowEx, ESA, etc) to fill a fundamental gap in the observing system
- SnowPEx follow-on activities: publication of results, ISSPI-3, define objectives for next phase
- Discuss how to expand initial regional user surveys for snow products and information, such as done by CryoLand, to other regions as a GCW contribution to WMO OSCAR and for satellite mission planning.
- investigate and test the concept proposed by SnowPEx for ongoing evaluation of NH snow products using high resolution satellite data
- investigate the causes for SE differences in snow maps retrieved by different Landsat snow mapping algorithms, including assessment of uncertainty in different environments

Snow products:

- Development of multi-dataset SWE tracking and regional snow trackers, particularly for use by the Arctic-PRCC
- Develop a GCW dataset of climate stations with quality controlled, homogeneous, long-term (1950?-) continuous daily snow depth observations for a global assessment of in situ snow cover change; establish clear guidelines for evaluating the QC and homogeneity of historical daily snow depth observations.
- Review the user needs identified in the initial survey by the PHORS/PRCC SG and identify snow products and information needed to meet user needs, including satellite and in-situ observations required for producing/developing products and services.
- Continue development of the snow products dataset inventory on the GCW website and assess the need and modality for an associated evaluation page.

Data and Analysis:

- expand the historical SWE database at FMI and ensure its inter-operability through the GCW Portal;
- Produce a paper on NH in situ SWE trends for AR6. Ditto for long-term snow depth stations.
- Identify national contacts for contributing to and updating the historical snow depth and SWE archive at FMI; update Canadian historical SWE dataset from 2003
- Assess availability and access of metadata for snow measurements in the GCW observation network, including CryoNet sites.

Communication and Outreach:

- Ensure Snow Watch Team has required expertise to execute Snow Watch activities from regional to global scales
- Identify potential contributions and experts to strengthen the snow content and the Snow Watch page on the GCW website**.**
- Strengthen linkages with the hydrological community (observation, applications, modelling), particularly in high alpine areas
- Contribute expertise to development and refinement of snow terminology
- invite representatives from the Observations Working Group and Information and Services Working Group to actively participate with Snow Watch on issues of mutual interest/need and participate in telecons and meetings, as necessary

ANNEX 12 provides the membership for the GCW Steering Group, Working Groups and Teams for the Team's use when implementing several of the action items.

7.3 Next meeting - timing, location: The next Team meeting will be held within 2-years. No location was discussed. Telecons will be held about every 6 months. There will be need for support for some team members to address priority actions and to work with other team members on joint actions and to represent Snow Watch on other WMO initiatives, e.g. Arctic PRCC.

8. CLOSING

The meeting adjourned at 1715 on June 14, at which most joined the Eastern Snow Conference welcome reception.

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ANNEX 1

GLOBAL CRYOSPHERE WATCH (GCW)
Snow Watch Team Meeting
Second Session

AGENDA

VENUE: Byrd Polar and Climate Research Center of The Ohio State University, Columbus, Ohio, United States

DATE/TIME: 13 June 0900 – 14 June 1700

1. ORGANIZATION OF THE SESSION

- Welcome and opening (Dr. Ellen Mosley-Thompson; Dr. Barry Goodison)
- Participant introductions (Participants)

1.3 Local arrangements (M. Durand)
1.4 Adoption of the agenda, assignment of rapporteurs (R. Brown)

2. SNOW WATCH BACKGROUND

2.1 GCW update (B. Goodison)
2.2 Snow Watch Team – Current membership and Terms of Reference (R. Brown)
2.3 Overview of action items from 2013 Toronto Snow Watch meeting (R. Brown)
2.4 Meeting Objectives (R. Brown)

3. REVIEW OF PROGESS

3.1 Snow depth reporting: real time data exchange and reports of zero snow reporting (P. de Rosnay and S. Pullen)
3.2 Dataset directory/Historical snow depth archive (R. Brown)
3.3 FMI Arctic historical in situ snow data archive (K. Luojus)
3.4 GCW website snow material (R. Brown)
3.5 The Satellite Snow Product Intercomparison and Evaluation Exercise - Overview and update (T. Nagler)
3.6 Discussion: Issues, Gaps, GCW priorities and contributions

4. DEVELOPMENT AND VALIDATION OF SNOW COVER PRODUCTS

4.1 GlobSnow SWE and Snow Extent products (K. Luojus)
4.2 MODIS and S-NPP VIIRS NASA Snow Products (D. Hall)
4.3 NOAA Climate Data Record (D. Robinson)
4.4 Status and further development of CryoClim global Snow Cover Extent product (R. Solberg)
4.5 Update of AMSR2-JAXA work (R. Kelly)
4.6 Update of NASA AMSR work (M. Tedesco)
4.7 Update on proposed satellite missions for snow monitoring (C. Derksen)
4.8 EUMETSAT snow-related activities / GCW needs and expectations (B. Bojkov)
4.9 Multi-dataset SWE products (C. Derksen)
4.10 Discussion: Issues, Gaps, GCW priorities

INVITED PRESENTATION:

Andean cryospheric observing program: Dr. Bryan Mark (OSU)

5. IN SITU AND SNOW ANALYSIS PRODUCTS

5.1 Russia and Canada in situ snow depth and snow survey programs (R. Brown)
5.2 Global snow data collections and monitoring at NOAA/NCEI (J. Lawrimore)

5.3 National Ice Center (NIC) snow analysis products (S. Helfrich)
5.4 ECMWF snow data assimilation (P.de Rosnay)
5.5 UK Met Office snow data assimilation (S. Pullen)
5.6 Snow data at NSIDC (A. Leon)
5.7 Discussion: Issues, Gaps, GCW priorities

6. UPDATES AND ITEMS FOR DISCUSSION

6.1 SnowEX meeting feedback (D. Hall)
6.2 Update on HarmoSnow EU COST Action (P. de Rosnay)
6.3 Polar Space Task Group Strategic Plan: 2015-2018 (K. Luojus)
6.4 Snow Watch support for a Polar Regional Climate Centre (B. Goodison)
6.5 Real-time SWE reporting on GTS – can it be done? (R. Brown)
6.6 Guidelines/best practices for observing/measuring snow depth, SWE and other important in-situ properties (B. Goodison)
6.7 Discussion: Issues, Gaps, GCW priorities

7. NEXT STEPS FOR GCW SNOW-WATCH

7.1 Rapporteurs summary of discussion (Rapporteurs)
7.2 Discussion, definition and assignment of action items
7.3 Next meeting

8. CLOSING REMARKS

ANNEX 2

GLOBAL CRYOSPHERE WATCH (GCW)
Snow Watch Team Meeting
Second Session

Columbus, Ohio, USA
13-14 June 2016

LIST OF PARTICIPANTS

Name	Role	Institution	Country	e-mail
Bojkov, Bojan	Invited Expert	EUMETSAT	Germany	bojan.bojkov@eumetsat.int
Brown, Ross	Snow Watch Team co-lead	Environment and Climate Change Canada, Climate Research Division, Montreal	Canada	ross.brown@canada.ca
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Durand, Mike	Invited Expert, Local Host	Byrd Polar and Climate Research Center, OSU, Columbus, Ohio	USA	durand.8@osu.edu
Goodison, Barry	Vice-chair GCW Steering Group, invited expert	Ex-officio WMO	Canada	barrygo@rogers.com
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Helfrich, Sean	Snow Watch Team Member	NOAA/NESDIS/OSPO Snow and Ice Product Area	USA	sean.helfrich@noaa.gov
Kelly, Richard	Invited expert	U. Waterloo	Canada	rejkelly@uwaterloo.ca
Lawrimore, Jay	Invited expert	NOAA, National Climatic Data Center	USA	jay.lawrimore@noaa.gov
Leon, Amanda	Invited expert	NSIDC	USA	amanda.leon@nsidc.org
Luojus, Kari	Snow Watch Team co-lead, GCW Steering Group Member	Finnish Meteorological Inst.	Finland	Kari.Luojus@fmi.fi
Mark, Bryan	Invited speaker	Dept. Geography, Ohio State University, Columbus, Ohio	USA	mark.9@osu.edu

Nagler, Thomas	Invited expert	Managing Director, Enveo IT GmbH, Innsbruck	Austria	thomas.nagler@enveo.at
Pullen, Samantha	Snow Watch Team Member	UK Met Office	UK	samantha.pullen@metoffice.gov.uk
Robinson, David	Snow Watch Team Member	Rutgers U	USA	drobins@rci.rutgers.edu
Solberg, Rune	Invited expert	Norwegian Computing Center	Norway	rune.solberg@nr.no

ANNEX 3

WORK PLAN FOR WMO GCW SNOW WATCH GROUP FOR PERIOD 2015-2016

Team composition (November 2015): Ross Brown, Kari Luojus, Chris Derksen, David Robinson, Patricia de Rosnay, Sean Helfrich, Samantha Pullen

No.	Task	Deliverable/Activity	Due	Responsible	Status	Comment
1	Organize a follow-up Snow Watch meeting in 2015-2016 time frame	Snow Watch meeting	End of 2016	**Luojus**, Brown, Derksen, Robinson	**OK**	13-14 June 2015, Columbus, Ohio, OSU campus, prior to ESC 2016
2	Organize periodic (quarterly/bi-yearly) teleconferences to follow the progress of Snow Watch activities	Minutes of telecon.	continuous	**Luojus**, Brown	**on-going**	
3	Populate the Snow Watch team with suitable additional people	Proposal submitted to GSG	03/2015	**Brown**, Luojus, Derksen, Robinson	**OK**	S. Helfrich (NOAA) and P. Rosnay (ECMWF) have been added to the team
4	Prepare a note (doc/ppt) on progress (and impact) of real-time exchange of snow obs and GCW-suggestion for future actions to be presented at Cg-18		04/2015	**Luojus**, De Rosnay	**OK**	Material intended for round-table discussion before congress;
5	Prepare a poster (also suitable as a handout) on Snow Watch activities to be presented (at/before?) Cg17		04/2015	**Luojus,** Brown, Derksen, Robinson	**OK**	Material intended for WMO congress (May-June 2015)
6	Include Oystein and Jeff Key with the preparations for snow inventory		03/2015	Brown	**OK**	Maturity aspects (Jeff); vocabulary made compatible with portal (Oystein)
7	Develop and maintain GCW Snow Products inventory	Snow products inventory on the GCW-website	06/2015	Brown	**on-going**	1st version to be available by February 2015
8	Identify person(s) to assist Jeff in developing Snow Watch section of the GCW website	"Snow Watch" section of the GCW website	06/2015	**Derksen**, Luojus	?	
9	Liaise with ESA SnowPEx consortium	Letter of collaboration	06/2015	**Luojus**, Derksen	**OK**	WMO GCW was presented at the SnowPEx workshop in Boulder, Sept. 2015

10	Prepare information on SnowPEx project to GCW website	SnowPEx info available on GCW website	By end of 2015	**Derksen**, Luojus		
11	Liaise with the people working on development of the global archive of historical in situ snow data (follow up from ECMWF workshop 10/2014)	Letter of collaboration	By end of 2015	**Brown**, Luojus, Derksen		

Updated: 17 November 2015

ANNEX 4

UPDATE ON GLOBAL CRYOSPHERE WATCH (GCW) ACTIVITIES

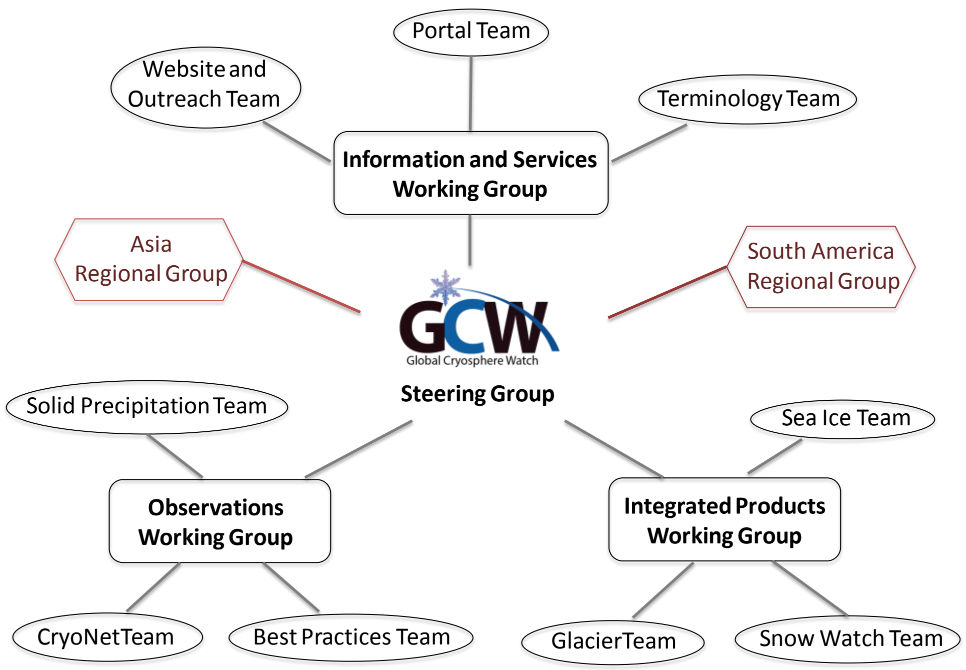
(Prepared by B. Goodison, J. Key and Secretariat)

1. This document provides a short update on the Global Cryosphere Watch (GCW) development and implementation. Participants are referred to the GCW website (http://globalcryospherewatch.org) for details and background documents on the GCW.

2. The Seventeenth World Meteorological Congress (Cg-17) recognized the achievements in furthering the WMO Polar Activities coordinated through the Executive Council's Panel of Experts on Polar Observations, Research and Services (EC-PORS). To this end, Congress included WMO Polar and High Mountain Activities as one of the seven priorities contained in the WMO Strategic Plan for 2016-2019.

3. The sixty-seventh session of WMO Executive Council (EC-67) refined the terms of reference for the Panel to address the Congress decisions and established the EC Panel of Experts on Polar and High Mountain Observations, Research and Services (EC-PHORS). Under this new ToR, the Panel will continue to guide the implementation of the Global Cryosphere Watch (GCW), with a priority to establish CryoNet, the GCW core, standardized observing network, and the GCW Data Portal to access cryospheric data.

GCW WORKING STRUCTURE



4. The GCW Working Structure is almost completed with the GCW Steering Group (GSG, Chair: Arni Snorrason, vice-Chair: Barry Goodison), the Observations Working Group (Chair: Wolfgang Schöner, co-Chair: Michele Citterio), the Information and Services Working Group (Chair: Øystein Godoy, co-Chair: J. Key), and the Integrated Products Working Group (Chair: TBD, co-Chairs: Kari Luojus, Vasily Smolyanitsky). The Best Practices and Terminology Teams proposed that new teams for sea ice, permafrost and glaciers be formed to assist in conducting gap analyses to refine what and how GCW can

best contribute. Efforts remain to be made to develop a working structure at the regional levels, as appropriate. So far Asia and South America Regional Groups have been established. The updated structure will be submitted to EC-PHORS-7 (Jan. 2017) for approval.

Observations

5. Pre-operational testing of CryoNet is in progress with the set of 36 sites approved by Cg-17The main objective of the pre-operational test is to apply and evaluate the CryoNet concept and establish data interoperability with the GCW Data Portal. Following the results of the test so far, the CryoNet concept was updated. As a result, several WMO documents will need to be updated, such as Manual on WIGOS. Similarly, the procedure for accepting new sites into CroyNet was updated. GCW will continue engagement with Regions to fill gaps in CryoNet, with a focus on the Tropics and high mountain areas. . The GCW website has all of the current documentation on these issues.

6. The Best Practices Team was activated and initiated work on compiling measurement guidelines, best practices and standards. An outline and timeline were developed for preparing a 30-40 page GCW Guide to Cryospheric Practices and then a more comprehensive Manual of Best Practices. In-situ and satellite-based observations would be included. Drafts of the components will be posted on the GCW website as “Draft for Comments” seeking community feedback. Then the documents would be submitted to CBS and CIMO for consideration.

Integrated Products

7. The Snow Watch Team is working on an improvement of the real-time flow and access to in situ snow measurements (e.g. non-reporting of snow depths by some countries) and more countries have begun to exchange these data. There are still gaps in the USA and China, although the USA is working on providing data.

8. “Snow anomaly trackers” by Finland (FMI) and Canada (CMC) were developed for GCW for monitoring daily changes on the hemispheric scale; see http://globalcryospherewatch.org/satellites/trackers.html. Further, regional snow trackers are under discussion to support, among others, Polar Regional Climate Centres.

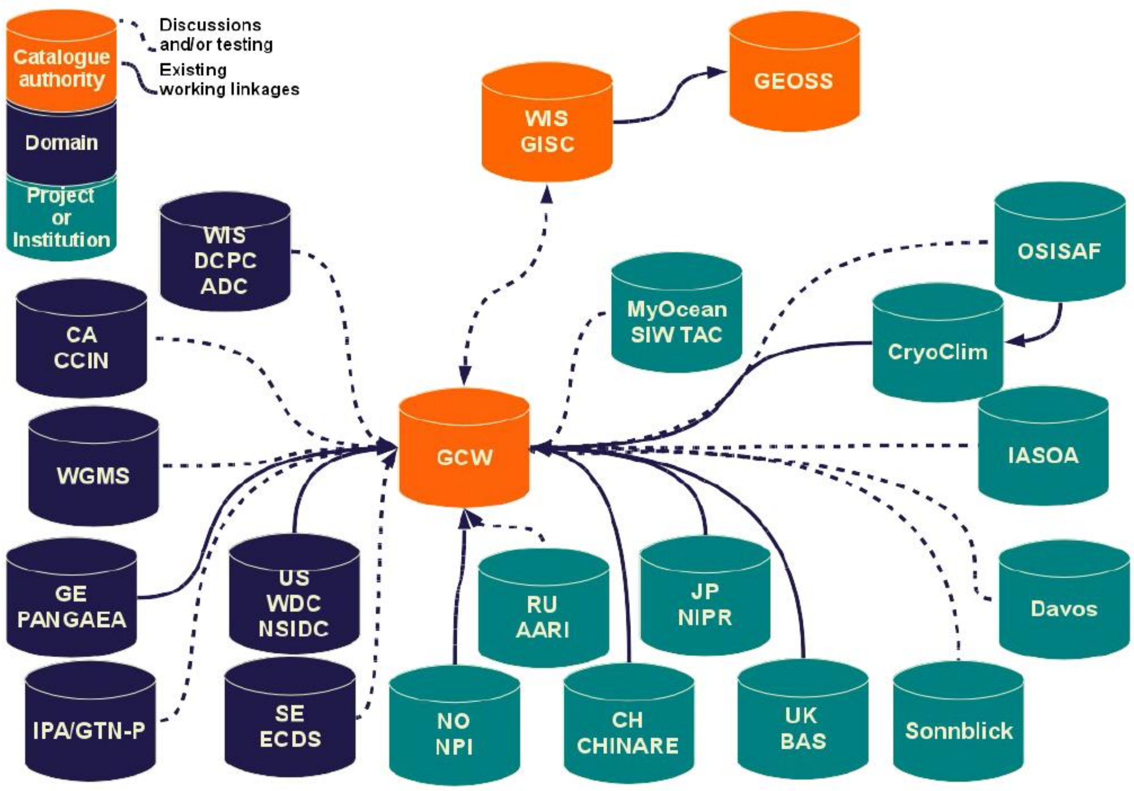
9. The Snow Watch Team is assessing the maturity and accuracy of snow products through the intercomparison project “SnowPEx”, which is supported by ESA. With this perspective in mind, it has developed an initial inventory of snow products that is available online. The inventory is provided in three categories: (1) Satellite-derived snow products and datasets, (2) Analyses, reanalyses and reanalysis-driven snow products and datasets, and (3) In situ snow products and datasets. GCW’s mandate is to be an authoritative source of cryospheric information for many users including the proposed Polar Regional Climate Centres. Therefore the inventory provides users with some guidance about the suitability of snow products and datasets for various applications.

Information and Services

10. Work on the integration of data from CryoNet sites into the GCW Data Portal was initiated, including tests conducted with three CryoNet sites: Weissfluhjoch-Davos (Switzerland), Sonnblick (Austria) and Sodankylä (Finland). Based on the experience from working with these stations, first versions of the GCW Portal Interoperability Guidelines and GCW Portal Operations Manual have been developed.

11. Currently metadata are routinely harvested by the GCW Data Portal from the following data centres: British Antarctic Survey; CryoClim; Chinese National Arctic and Antarctic Data Center; National Institute of Polar Research (Japan) – Arctic Data Archive System; Norwegian Polar Institute; and National Snow and Ice Data Center. These data centres are now harvested twice daily. In addition, testing is either ongoing or planned for a number of other data centres, as shown below.

STATUS OF GCW DATA PORTAL LINKAGES
(as of DECEMBER 2015)



12. The formulation of GCW observational requirements is an ongoing process. 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. The IGOS and OSCAR cryosphere requirements are available on GCW Website. In addition to the observational requirements listed on the GCW Website, the Polar Space Task Group (PSTG) is compiling user requirements. They are available on the PSTG website. At the recent meeting of the Integrated Observing Systems Panel, a discussion of users of GCW data and products ensued. The Panel was informed of the efforts of the EU FP7 project CryoLand on assessing user needs for snow and land ice as it clearly demonstrated the range and complexity of needs of cryosphere users.

13. The Terminology Team continues to expand the GCW cryosphere glossary. The database now has over 2900 entries from 21 sources, with over 1600 unique terms. It is available online at http://globalcryospherewatch.org/reference/glossary.php.

ANNEX 5

GLOBAL CRYOSPHERE WATCH (GCW)
TERMINOLOGY TEAM

Pan-Cryospheric Glossary

GCW has now incorporated the following 19 existing snow & ice glossaries (http://globalcryospherewatch.org/reference/glossary.php) including some 2500 cryospheric terms, 1500 of which are unique:

1. Australian Bureau of Meteorology
2. ASPECT
3. Canada National Climate Archive
4. Environment Canada
5. EU Climate-ADAPT
6. IACS-UNESCO Seasonal Snow on the Ground
7. IACS-UNESCO Glacier Mass Balance
8. IPCC WGII AR5
9. NOAA Hydrologic Terms
10. NOAA Snow/Ice
11. NSIDC
12. Sea ice nomenclature WMO No. 259, TP 145
13. USGS Glossary of Glacier Terminology
14. USGS Glossary of Selected Glacier-Related Terminology
15. UK Antarctic Place-Names Committee
16. WMO METEOTERM
17. WMO Sea Ice Nomenclature Version 1.0 by Bushuyev
18. IPCC AR5 WG1 Glossary
19. UNESCO-WMO International Glossary of Hydrology

GCW is considering incorporating the following 6 glossaries:

Multi-Language Glossary of Permafrost and Related Ground Ice Terms. 1998, revised 2005. IPA. http://nsidc.org/fgdc/glossary/

Terminological Guide of the South American Geocryology. D. Trombotto, P. Wainstein & L. Arenson. 2014.

Glossary of Permafrost and Related Ground-Ice Terms. National Research Council of Canada. 1988.

The Dictionary of Physical Geography, 4th Edition
http://www.wiley.com/WileyCDA/WileyTitle/productCd-111878233X.html

Illustrated Glossary of Snow and Ice. 1973. Terence E. Roberts, Brian Birley, Swithinbank, Charles, Armstrong.
http://www.amazon.com/Illustrated-Glossary-Snow-Terence-Armstrong/dp/0901021016

Photo glossary of glaciological terms
http://www.swisseduc.ch/glaciers/glossary/

GCW plans to enrich at first the glossary database with existing and authoritative published glossaries. In that regard suggestions from the community are being sought of relevant glossaries not already considered.

A second stage of the GCW "pan-cryospheric glossary" is to select a few hundred, or better even more than 1000, key concepts (entries) for which already existing definitions largely agree within different glossaries.

A third stage would be to discuss and agree upon a definition for concepts where the different existing glossaries do not completely agree, or do not agree at all, by either adapting existing definitions, or by creating a new consensus definition. For this stage expert groups for each cryospheric element (sea ice, glaciers, ice sheets, seasonal snow, lake & river ice, frozen ground) would have to be established, ideally from different backgrounds, different organizations and different nationalities. By and large, this last stage will definitely be the most challenging, although the "controversial" list of concepts is expected to be rather short.

In summary, it would be fantastic for the purpose of implementing such a "pan-cryospheric" glossary to draw on the collaboration from the cryosphere community at-large and also ideally the endorsement of all relevant Cryosphere Organizations.

ANNEX 6

INTEGRATED PRODUCTS WORKING GROUP - SNOW WATCH TEAM TERMS OF REFERENCE, MEMBERSHIP AND WORKING METHODS

Terms of Reference (June 17, 2016)

- Assess the maturity, accuracy and homogeneity of snow data, products and information
- Identify priority issues and actions for improved observing of global snow cover, including regional and national scales
- Provide advice to WMO on issues related to real-time reporting practices of in situ and remote sensing of snow cover
- Liaise with the cryosphere community, and WMO bodies, to maintain up-to-date knowledge of snow cover monitoring technologies, programs, datasets and products
- Provide information and advice accessible from the GCW Website on snow-related products and issues e.g. anomalous snow conditions, extreme events, snow assessments
- Contribute to establishing "Guidelines and Best Practices" for snow observing practices
- Contribute to defining/refining snow related terminology
- Provide progress updates to the Integrated Products WG and/or GCW Secretariat upon request
- Provide support to GCW Steering Group, Working Groups and Teams as required

Membership:

- Team members are recognized snow experts.
- Efforts should be made to encourage global participation. To the extent possible, the Team should include at least one expert from each WMO Region. The GCW focal points may be called upon to increase regional representation on issues.
- The Team will have two co-leads from different WMO Regions. The period for co-leadership is not limited, but should be rotated around the Team and reviewed on an annual basis.
- Members of the Team will be identified based on their capacity to respond to Team priorities; membership will be reviewed annually by the Team co-leads, in consultation with Team members, and submitted to the IP-WG for endorsement and subsequent approval by the GCW Steering Group

Accountability:

- The co-leads report to the chairs of the Integrated Products WG

Working Methods:

- Regular telecom/webex meetings will be held at least twice yearly with a face-to-face meeting approximately once every two years
- The chair of meetings will be rotated between the co-leads and the meeting chair is responsible for the reports of the meetings
- A draft agenda, proposed by the co-leads, will be circulated at least one month prior to the proposed meeting date with a request for discussion items
- Experts may be invited to participate in meetings to address certain topics
- Tasks defined by the Team will be on-going between meetings, as defined by the Team's workplan

Review:

- The Terms of Reference are to be reviewed annually

ANNEX 7

Reporting of Zero Snow Depth

The following report was submitted to the second meeting of the Inter-programme Expert Team on Data Representation Maintenance and Monitoring (May 2014) by Richard Weedon & Dr Samantha Pullen (UK Met Office). The document proposes changes to regulations for the reporting of Snow Depth. The meeting was requested to consider the changes and if in agreement to initiate amendments to the regulations as required. These are formal steps required to implement changes to the observing and reporting system.

References:

1. Manual on Codes Volume II - Regional Codes and National Coding Practices
2. B/C1 – Regulations for reporting SYNOP data in TDCF

Annexe:

1. B/C 1.8 State of Ground, Snow Depth, Ground minimum temperature <3 02 037>
2. Manual on Codes - International Codes - Volume I.1 ,FM 12 SYNOP, FM 13 SHIP, FM 14 SYNOP MOBIL, 12.4.6 *Group* (4E´sss)
3. Regional Reporting Practices – Manual on Codes Volume II

BACKGROUND

Ground based observations of snow are very important for monitoring, model validation, validation of satellite-derived data, and increasingly for assimilation into Numerical Weather Prediction (NWP) models. Snow depth reports from SYNOP stations are currently assimilated by several NWP centres, and preparations are underway to develop similar snow depth assimilation capabilities at the Met Office. However, the current reporting practice, for which regional guidelines exist, results in an inconsistent approach to the reporting of zero snow depths. Snow depth is generally only reported when snow is present (i.e. positive reports of zero snow are not made), with missing data recorded for snow depth in snow-free conditions. This leads to an ambiguity for data users as it cannot be known whether this missing data indicates “no snow” or a technical problem at the station, for instance an instrument failure or system outage. This “missing data” must therefore be discarded, though the majority of it could potentially contain valid positive reports of zero snow.

In NWP, a good representation of the snow extent (i.e. positioning of snow-covered and snow-free areas) is of great importance because of the huge effect that snow cover has on the surface albedo. Therefore, for assimilation purposes, reports of zero snow are as important as non-zero snow depth reports as they enable better analysis of snowy and snow-free area. If snow depth reports are not made when no snow is present, no observational information can be presented to the assimilation system, leading to asymmetry in the assimilation and loss of a huge amount of information.

There is the option at many stations of recording “state of ground” which includes codes that indicate whether the ground is snow-covered or not, and reports are sometimes submitted indicating snow-free conditions. However, these reports are not made systematically, but are very variable in space and time when snow is not present. They are also only available for manned stations and, like those for snow depth, regional guidelines again indicate the need to report only in the presence of snow.

The issue of non-reporting of zero snow depths is gaining recognition in the international community, and is specifically included in the Global Cryosphere Watch (GCW) Snow Watch initiative. We would like to propose the adoption of systematic reporting of snow depth in all situations (snowy and snow-free), along with reports of state of ground wherever station setup allows. This would provide the data user community with a huge amount of valuable additional data, providing positive observations of snow-free conditions, and remove the existing asymmetry resulting from the use of station snow depths for validation and assimilation purposes.

PROPOSAL

The status of the manual on codes (WMO-306) after the completion of the transition to Table Driven Codes, is currently unknown, it is hoped however that producers of SYNOP data will adhere to the B/C Regulations which in the case of SYNOP requires compliance with B/C 1.

The B/C regulations have been constructed to provide a link between the reporting practices for TAC data given in WMO Vol I.1 and Vol II and those for FM 94 BUFR given in Volume I.2.

Regulations for the reporting of the State of Ground and Snow depth within TAC, are given in *Volume II Regional Codes and National Reporting Practices* and such vary from region to region.

The equivalent B/C regulations (B/C 1.8.xx see annexe) reflect this variance by deferring the reporting of Snow to regional practices.

As a result of this approach, the reporting of snow depth is not mandated in all circumstances.

Changes are needed within the current regulations to ensure that all practices require the reporting of Snow Depth on a regular basis regardless of the state of ground. This will entail the reporting of Zero snow depth when the state of ground indicates that there is no snow present.
Changes to code table 3889 (Total Depth of Snow) will be also be needed as outlined below to allow for the reporting of Zero Cover.

<u>Code Table 3889</u>

Code figure		**sss *Total depth of snow***	**Changes proposed**
000		Not used	0 cm
001		1 cm	1 cm
. . . .		. . . .	. . . .
996		996 cm	996 cm
997		Less than 0.5 cm	Less than 0.5 cm
998		Snow cover, not continuous	Snow cover, not continuous
999		Measurement impossible or inaccurate	Measurement impossible or inaccurate
Note: See Regulations 12.4.6.1 and 12.4.6.2.			

Annex 1:

B/C 1.8 State of Ground, Snow Depth, Ground minimum temperature <3 02 037>

B/C 1.8.1 State of ground (with or without snow) - Code table 0 20 062.

State of ground without snow or with snow shall be reported using Code table 0 20 062. The synoptic hour at which this datum is reported shall be determined by ***regional decision.***

B/C 1.8.2 Total snow depth

Total snow depth (0 13 013) shall be reported in meters (with precision in hundredths of a meter). The synoptic hour at which this datum is reported shall be determined by ***regional decision.***

B/C 1.8.2.1 When total snow depth has to be reported, it is reported as 0.00 m if no snow, ice and other forms of solid precipitation on the ground are observed at the time of observation. A snow depth value of "– 0.01 m" shall indicate a little (less than 0.005 m) snow. A snow depth value of "– 0.02 m" shall indicate "snow cover not continuous".

B/C 1.8.2.2 The measurement shall include snow, ice and all other forms of solid precipitation on the ground at the time of observation. [12.4.6.1]

B/C 1.8.2.3 When the depth is not uniform, the average depth over a representative area shall be reported. [12.4.6.2]

Annex 2:

Manual on Codes - International Codes - Volume I.1

FM 12 SYNOP, FM 13 SHIP, FM 14 SYNOP MOBIL

12.4.6 *Group* (4E´sss)

12.4.6.1 The measurement shall include snow, ice and all other forms of solid precipitation on the ground at the time of observation.

12.4.6.2 When the depth is not uniform, the average depth over a representative area shall be reported

Annex 3:

Regional Reporting Practices – Manual on Codes Volume II

Region I

1/12.9.2 Group (4E´sss) — Snow-depth data shall be reported by all stations capable of doing so, and included at least once daily at either 0600 or 1200 UTC

Region II

2/12.10 *Group* (4E´sss)

2/12.10.1 Thi s group shall be included in the synoptic report only if there is ground snow or ice cover.

2/12.10.2 The group 4E´sss shall be included at least once daily, preferably at 0000 UTC (the morning observation time over most of Region II).

2/12.10.3 Code table 0975 shall be used for coding the indicator (E´) of the presence and state of snow or ice cover. E´ shall be transmitted by all stations where such observations are carried out.

2/12.10.4 The snow depth or the thickness of ice cover shall be reported in sss, in accordance with Code table 3889.

Region III

3/12.8 *Group* (4E´sss)

3/12.8.1 This group shall be made available for regional exchange. Where appropriate, the selection of stations for the inclusion of sss shall be decided nationally.

Note: This group is included only if ice and/or snow data are available.

3/12.8.2 This group shall be included at least once daily, preferably at 1200 UTC, if possible.

3/12.8.3 If the ground is covered by hail, this group shall be included in the next report.

Region IV

4/12.8 *Group* (4E´sss) This group shall be reported by all stations capable of doing so, and included at least once daily at either 0600 or 1200 UTC.

Region V

5/12.8 *Group* (4E´sss)

This group shall be included by all stations capable of doing so at least once daily at either 0000 or 1800 UTC, whenever data are available.

Region VI

6/12.7 *Group* (4E´sss)

6/12.7.1 This group shall be included only if snow or ice cover is observed on the ground.

6/12.7.2 Group 4E´sss shall be transmitted at least once daily, preferably at 0600 UTC (the morning observation time over most of Region VI). Members of the Region are also recommended to include this group at 1800 UTC.

6/12.7.3 Code table 0975 shall be used to code the indicator (E´) of the presence and state of snow or ice cover. E´ shall be transmitted by all stations making these observations.

6/12.7.4 The snow depth or the thickness of ice cover shall be reported for sss. Where appropriate, a selection of stations for the inclusion of sss shall be decided nationally.

Antarctic

7/12.7.1 Snow-depth data shall be reported by all stations capable of doing so, and included at least once daily at either 0600 or 1800 UTC.

Note: When appropriate, the relevant special phenomena groups for time at which precipitation given by RRR began or ended and depth of the snow freshly fallen since the last 0000 UTC observation shall be reported in lieu of the group 4E´sss.

ANNEX 8

SNOW OBSERVATIONS REPORTING (2014)

Atsushi Shimazaki (WMO/OBS/WIS)

The reporting of snow observation issues was discussed within WMO/WIS/WIGOS and its teams in 2014; one issue was approved by the fast-track procedure and the other by Commission for Basic Services (CBS) Ext. Session (2014).

1. BUFR template 3 07 101 (Snow observation): valid from 5 November 2014 (http://www.wmo.int/pages/prog/www/WMOCodes/WMO306_vI2/LatestVERSION/WMO306_vI2_BUFR_TableD_en.pdf)

This BUFR template (3 07 101) had been used by ECMWF member states when it was proposed. It is a very simple template specifically developed for snow depth reporting, which consists of minimum parameters, such as total snow depth, state of ground, method of snow measurement along with temperature and some metadata.

Anyone could use it now if it meets their requirements. The same data could be reported in the comprehensive template for surface observations (3 07 080). Only difference between 3 07 101 and 3 07 080 is that the former has information on "Method of snow depth measurement".

2. Zero snow depth reporting: no amendments

The CBS Ext. (2014) agreed that with respect to reporting zero snow depth:

2.3.12 Ground-based snow observations were important for monitoring, model validation, validation of satellite-derived data, and increasingly for assimilation into numerical weather prediction models. The Commission noted, however, that snow depth was generally reported only when snow was present and this led to an ambiguity in that users could not distinguish between missing snow depth data meaning no snow or meaning no observation due to a technical problem at the station, for instance an instrument failure or system outage. This had been identified as an issue by the Global Cryosphere Watch (GCW) Snow Watch initiative.

2.3.13 Explicit reporting of zero snow depth was standard practice in TDCF but was not possible in Traditional Alphanumeric Codes (TAC). The Commission had already decided that the TAC should not be changed, but recognized that the TAC were often used for collecting observations nationally. The Commission agreed to facilitate reporting zero snow depth by suggesting that those Members using TAC nationally might consider using the unallocated entry 000 of code table 3889 to indicate zero snow depth, so that the information would be available when national reports are converted to TDCF.

CBS recommended to use 000, which is officially "Not used", for reporting zero snow depth in FM 12 SYNOP without amendments to the Manual. It is a remedy, anyway.

Zero snow depth could be reported in the comprehensive template for surface observations (3 07 080), because snow depth is to be reported in m with scale 2 (= cm) in 3 07 080, i.e. zero is 0 m.

ANNEX 9

Met Office

Requirements for NWP

Continuity - operational robustness, long-term security to justify development work, succession of satellite sources…

Temporal resolution - daily sufficient for snow change timescales. Complementary data sources can have lower frequency

Level of derivation – preferably not assimilation products themselves, e.g. contain some model information (not consistent), contain ground-based obs (not suitable if model already assimilates)

Coverage - depends on model domain, global/NH common

Cloud cover - how extensively does it affect product? High temporal sampling can mitigate to some extent. Multi-sensor approach can allow gap-filling. Is it the only data source?

Errors - well-defined and documented, quality flags disseminated with product. SC 15-20%, SWE 10mm. Has to improve forecast/analysis to be used.

Availability in near-real-time - daily product within half a day, 6-hourly within 3 hours

Spatial resolution - guided by model resolution, doesn't have to match. Higher resolution allows fractional cover calculation on model grid. Too low, representativity issues.

ANNEX 10

Guidelines/Best Practices for Observing/Measuring the Cryosphere

1. A GCW Best Practices Team has been established to compile best practices, guidelines and standards for observing/measuring cryosphere variables, building on what has been compiled to date and available on the GCW Website. Þorstein Þorsteinsson (Iceland) & Charles Fierz (Switzerland) co-lead the team. Current membership includes Michele Citterio (GEUS), Wolfgang Schöner (U. Graz), Vasily Smolyanitsky (AARI), Petra Heil (AAD), Eric Holloway (NOAA), Jeff Key (NOAA). The team has prepared an outline and timeline for preparing a 30-40 page GCW Guide to Cryospheric Practices and then a more comprehensive Manual of Best Practices.

2. In-situ and satellite based observations would be included. Engagement of experts from different countries and regions will be essential. Experts will be drawn from GCW teams and working groups and nominees through national focal points and partner organizations. Small sub-groups may be established to work on individual components of the cryosphere. Existing links on the website must be checked. New manuals, guides, best practices need to be added, including national guides which may have to be translated so the material can be incorporated as appropriate. Existing WMO practices included in WMO Guides (e.g. CIMO, Climate, Hydrology, AgMet) would be included. Ongoing regional efforts should be incorporated whenever possible (e.g. HarmoSnow in Europe). The guide and manual will include best practices suitable for research and operational purposes. It was noted that IICWG is working on preparing a list of available guides and manuals from which it would select the best manual. Their starting point is WMO No.574; their timeline is JCOMM 2017. IACS could possibly create a WG to bring together scientists on best practices.

3. GCW documents have to be aligned with WIGOS guide and manual as well as other WMO Guides. The current goal is for the task being done over the next 3 years ultimately producing a guide and manual that would be translated; hence, the task has to be started immediately. The proposed timeline is provided below. It is recognized that components could proceed as individual tasks over different timelines. It was recommended that drafts of the components be posted on the GCW website as "Draft for Comments" seeking community feedback. Then the documents would go to CBS and CIMO as they are part of WIGOS. An essential step is to ensure community consultation and feedback so there is global acceptance.

4. Snow (and solid precipitation) is a major component of the cryosphere and methods of measurement can vary considerably among countries and regions. It is important that the Snow Watch Team be engaged actively in this process of developing a GCW Guide to Cryospheric practices and the more comprehensive Manual of Best Practices. The first session of Snow Watch identified this as one of its six priorities. This can now proceed within the Best Practices Team. Nomination of experts to the Team is welcomed.

An initial inventory of existing documents describing practices for cryospheric measurements is given below and is also available on the GCW website.

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)

Cryosphere Element	Existing Documents
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)

DEVELOPMENT OF A GCW GUIDE AND MANUAL FOR BEST PRACTICES

Draft suggestion for a Workplan/Timeline (CryoNet Team meeting, December, 2015)

Best practices team: Charles Fierz (WSL/SLF), Þorsteinn Þorsteinsson (IMO), Michele Citterio (GEUS), Wolfgang Schöner (UGraz), Vasily Smolyanitsky (AARI), Jeff Key (NOAA)

January-February 2016:

- Continued survey of existing manuals and reports.
- Focal points contacted and asked to deliver information about national reports/manuals.
- As a global effort GCW must produce a Guide and a Manual that will reflect specific conditions characterizing the cryosphere in different regions.

End of February:

- Short summary document and new draft workplan distributed to entire Cryonet group and GCW Steering Group.

March-April 2016:

- Decide what can be extracted from older reports/manuals (with permission), and what new developments in measurement techniques/data reduction need to be emphasised in a new guide/manual.

End of May 2016:

- Draft of the structure of a new GCW Guide to cryospheric practices ready (formal writing will start when the structure has been decided).
- Ideas for the structure of a GCW Manual being developed simultaneously.
- Collaboration with COST group on snow-related best practices?
- Relation to CIMO guide?
- Have outline/draft ready for september CBS meeting
- Input/feedback from WMO expert groups at this stage.

September-December 2016:

- Writing starts, 1st version of Guide ready by the end of the year.

Mid-year 2017:

- *GCW Guide to the Cryosphere* published
- Plans for GCW *Manual on Best Cryospheric Practices* fully developed

Mid-year 2017 – Congress 2019:

- Work on Manual: Compilation, discussion, writing, editing, publishing.
- **2020:** GCW in operational phase

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ANNEX 11

LIST OF ACTION ITEMS ARISING FROM THIS MEETING

No.	Ref.	Action Item	By whom	Deadline
	1	**ORGANIZATION OF THE MEETING**		
	2	**SNOW WATCH BACKGROUND**		
1	**2.1**	Update Snow Watch workplan for 2016-2018	**co-leads, Secretariat**	
2	**2.2**	Snow Watch members and experts were invited to join or contribute to the GCW Terminology Task Team to ensure all snow related terms are properly defined.	**All**	
3	**2.2**	Snow Watch Team members and experts were asked to identify potential CryoNet sites, particularly those in remote regions and those which include snow observations suitable for model and/or satellite validation/evaluation, and to encourage the site operators (agencies or researchers) to have the site considered for inclusion in the GCW observing network.	**All**	
4	**2.3**	The final terms of reference will be submitted through the Integrated Products WG to the GCW Steering Group for approval at its next meeting.	**co-leads, Secretariat**	**31 July 2016**
5	**2.3**	Membership is to be updated by September 2016 and submitted to the GSG for approval.	**co-leads, Secretariat**	**15 Sept. 2016**
	3	**REVIEW OF PROGESS**		
6	**3.1**	The Snow Watch Team shall continue its efforts to improve the exchange of snow depth and the reporting of zero snow depth on the GTS through the WMO regulatory process and through members' individual efforts with GCW partners and regional activities (e.g. COST Action HarmoSnow)	**Pullen deRosnay, Secretariat**	
7	**3.1**	All snow team members and experts are requested to talk to observing system colleagues to encourage other NMHSs to adopt these changed reporting practices.	**All**	
8	**3.1**	CBS and WMO Regional Associations are requested to support the GCW Observing System by implementing changes in the WMO Technical Regulations to implement the exchange of snow depth on the GTS in real-time and for the reporting of zero snow depth.	**Secretariat**	
9	**3.1**	There needs to be clarification on the measurement and reporting of patchy snow cover, particularly in the context of automation. The GCW Best Practices Team is asked to include this topic in the snow section of the GCW Guide and Manual.	**Secretariat**	
10	**3.2**	SnowPEx is requested to provide guidance on issues/problems in datasets based on the experience of their intercomparisons.	**Nagler, Luojus, Brown, Derksen**	
11	**3.2**	The Snow Watch Team shall continue the development of the dataset inventory and will assess the need and modality for an associated evaluation page.	**Brown**	
12	**3.3**	FMI is urged to work with Oystein Godoy, who oversees the GCW Portal, to make sure the Arctic historical in situ snow data archive is interoperable and accessible through the portal.	**Luojus, Godoy**	
13	**3.3**	The Snow Watch Team and FMI should discuss the benefits and feasibility of having a single contact point (person and/or agency) in each country to provide snow survey database updates and assist with QC. The potential role of national focal points in this activity should be considered.	**Co-leads, Secretariat**	

14	**3.4**	The Snow Watch Team is requested to discuss these needs and identify potential contributions and experts to strengthen the snow content and the Snow Watch page on the GCW website**.**	**Co-leads, Key, Secretariat**	
15	**3.4**	The development of multidataset SWE tracking and regional snow trackers, particularly for use by the Arctic- PRCC, will be discussed by the experts involved in tracker products	**Brown, Luojus, Derksen**	**15 Oct. 2016**
16	**3.5**	Recommendation: In order to promote and consolidate the use of SAR based snow melt products, it is proposed to develop standardized protocols for validation and to intercompare/evaluate these data within upcoming SnowPEx activities	**Nagler**	
17	**3.5**	Recommendation: GCW recommends holding an International Satellite Snow Product Intercomparison (ISSPI) workshop every 2 to 3 years, as a continuation of ISSPI-1 and 2.	**Nagler, Derksen**	
18	**3.5**	Recommendation: GCW recommends further investigation and testing of the concept proposed by SnowPEx for ongoing evaluation of NH snow products using high resolution satellite data (Sentinel-2, Landsat).		
19	**3.5**	Recommendation: It is recommended to investigate the causes for SE differences in snow maps retrieved by different Landsat snow mapping algorithms and to assess the uncertainty of the SE algorithms using Sentinel-2 and Landsat data in different environments and to improve SE retrieval from these data.		
20	**3.5**	Recommendation: It is recommended to evaluate methods used for “cloud clearing” to derive cloud free snow products from optical satellite data.	**Nagler**	
21	**3.5**	The GCW Snow Watch Team should include these recommendations in their report to the GSG and identify associated human and financial resource requirements.	**Co-leads, Secretariat**	
	4	**DEVELOPMENT AND VALIDATION OF SNOW COVER PRODUCTS**		
22	**4.2**	Recommendation: Cloud cover and cloud masking should be a priority issue in defining future initiatives.		
23	**4.2**	The Snow Watch Team should define its role in supporting ongoing development of climate data records by different institutions.	**Co-leads, Secretariat**	
24	**4.3**	Snow Watch Team should discuss how to expand initial regional user surveys, such as done by CryoLand, to other regions as a GCW contribution to WMO OSCAR.		
25	**4.4**	Recommendation: GCW Snow Watch supports the need for a SnowPEx-2 follow-on intercomparison study, which could include absolute validation of products as one of its objectives.	**Nagler, Derksen, Luojus, Solberg**	
26	**4.7**	Snow Watch and GCW GSG need to discuss GCW engagement in new satellite snow mission development activities and in identifying and fostering international partnership opportunities and jointly funded proposals.	**Derksen**	
27	**4.8**	Recommendation: With some planning and clear “user” requirements, GCW (through the WMO and its Member States) is in a unique position to respond to the satellite community’s needs for snow product validation datasets.		
28	**4.8**	Recommendation: GCW is in the unique position within WMO to recommend the most appropriate ancillary data to use and to help facilitate its access for EO needs.		
29	**4.8**	Recommendation: GCW is in the unique position to implement the snow monitoring programme within the GCW observing network and to coordinate within WMO with the Upper Air Network, GAW and other		

		"bodies", to ensure that this can be met in CryoNet.		
30	**4.8**	Recommendation: GCW continue efforts to promote best practices and standardization across the EO community through establishment of priorities and targeted expert meetings such as ISSPI-3	**Nagler**	
31	**4.9**	Snow Watch and SnowPEx are requested to address the challenge of how to best advance the progress made in SnowPEx.	**Nagler, Derksen, Luojus**	
32	**4.9**	GCW/Snow Watch is to define a framework for updating the current multi-dataset SWE product using guidance provided by Derksen et al.	**Derksen**	
	5	**IN SITU AND SNOW ANALYSIS PRODUCTS**		
33	**5.1**	Recommendation: It is recommended that Snow Watch develop a GCW dataset of climate stations with quality controlled, homogeneous, long-term (1950?-) continuous daily snow depth observations for a global assessment of in situ snow cover change, following that of Magnuson et al. (2000) for historical trends in lake and river ice cover in the northern hemisphere.	**Brown**	
34	**5.1**	An initial inventory should be initiated to identify candidate series and regional gaps. Potential series may exist in GHCN-D and GSOD but these datasets do not provide consistent global coverage over time. For countries such as Canada, this will require a dedicated effort of station joining and homogeneity assessment similar to that carried out for temperature and precipitation.		
35	**5.1**	Clear guidelines for evaluating the QC and homogeneity of historical daily snow depth observations need to be established. One can draw on earlier work e.g. Robinson (1989), Brown and Braaten (1998)		
36	**5.1**	Recommendation: A separate parallel activity should be performed for mountain regions, which might be linked to CryoNet activities.		
37	**5.2**	Recommendation: GCW should assess availability and access of metadata for snow measurements in the GCW observation network, including CryoNet sites.		
38	**5.4**	GCW, with the assistance of the WMO Secretariat, should assess the current situation with respect to exchange of snow depth data on the GTS from nations where there are gaps (e.g. USA, China, South America) and identify next steps to improve the situation regionally and globally .		
39	**5.5**	Recommendation: Snow Watch and GCW are asked to consider the requirements for NWP in planning in situ and satellite sensing of snow.		
	6	**UPDATES AND ITEMS FOR DISCUSSION**		
40	**6.2**	The GCW Snow Watch Team is requested to seek experts on observations in the snow community and recommend nominees to the Best Practices Task Team for inclusion on a snow sub-group.		
41	**6.3**	Recommendation: Snow Watch is invited to help in engaging the international community by informing its organizations and partners of the HarmoSnow questionnaires on snow observation and data assimilation and asking them to participate as appropriate.	**deRosnay, Pullen, Secretariat**	
42	**6.3**	A letter will be drafted and distributed to members of all GCW Teams and to all GCW focal points asking them to engage the snow community both within and external to the NMHSs in completing the HarmoSnow questionnaires as applicable. (P. deRosnay, S. Pullen, Secretariat; to be distributed by July 20).	**deRosnay, Pullen, Secretariat, co-leads**	**20 Jul, 2016**
43	**6.3**	Recommendation: Snow Watch should proactively broaden its scope to include links to hydrological modelling in their activities.	**Co-leads**	
44	**6.3**	Recognizing that some Snow Watch members are engaged in hydrological	**Co-leads**	

		applications, including hydrological modelling, the Snow Watch co-leads are urged to ensure hydrological applications and modelling are more entrained in Snow Watch and GCW activities.		
45	**6.4**	Potential interactions between Snow Watch and PSTG activities should be identified by Snow Watch for consideration at the PSTG meeting. (Kari Luojus, Bojan Bojkov, Jeff Key, Secretariat).	**Luojus, Bojkov, Key, Secretariat**	
46	**6.4**	Snow Watch shall invite representatives from the Observations Working Group and Information and Services Working Group to actively participate with Snow Watch on issues of mutual interest/need and participate in telecons and meetings, as necessary. (Snow watch and WG co-leads, Secretariat)	**Co-leads, Secretariat**	
47	**6.5**	Snow Watch Team is requested to identify a member who would serve as the point of contact for the Arctic-PRCC.	**Co-leads**	
48	**6.5**	GCW Snow Watch should review the user needs identified in the initial survey by the PHORS/PRCC SG and identify snow products and information needed to meet user needs, including satellite and in-situ observations required for producing/developing products and services.		
49	**6.5**	Snow Watch is requested to identify potential products (regional or pan-Arctic) which could be offered as contributions to the Arctic PRCC. This could be done through national bodies depending on the structure implemented for the PRCC. Some new products may have to be developed to meet user needs.		
50	**6.5**	All Snow Watch Team members/participants are requested to contact their national Arctic-PRCC team to initiate dialogue on snow related services which GCW may be able to help with or provide to the PRCC.		
51	**6.6**	Recommendation: The exchange of SWE data would be a good test of WIS being able to move "irregular data" from NMHSs, partnering agencies and researchers. GCW should ask WIS to establish a mechanism to exchange SWE data from various operators.	**Secretariat**	
52	**6.6**	The BUFR code was able to be used for the exchange of snow depth data; could it be used for SWE? Use of the BUFR code shall be tested to exchange SWE data on the GTS	**deRosnay, Luojus, Brown, Secretariat**	
53	**6.6**	GCW shall work with WIS to exchange SWE and snow course data to the global snow course archive at FMI. This will be a prototype test of the WIS system to exchange non standard cryosphere data.	**Luojus, Brown, Secretariat**	
54	**6.6**	FMI will be requested to operate the snow course archive and to produce bi-weekly products suitable for use by GCW and the Arctic-PRCC.	**Co-leads, Secretariat**	

ANNEX 12

MEMBERSHIP OF GCW STEERING GROUP, WORKING GROUPS AND TEAMS
(as of 23 June 2016)

#	Name of Expert	GSG	Observations WG				Integrated Products WG				Information & Services WG			
			WG	CryoNet Team	Best Practices Team	Solid Precip Team	WG	Snow Watch Team	Sea Ice Team	Glacier Team	WG	Portal Team	Website & Outreach Team	Terminology Team
1	Árni Snorrason (IMO, PR of Iceland with WMO, arni.snorrason@vedur.is)	Chair												
2	Jenny Baeseman (SCAR, jbaeseman@gmail.com)	✓											✓	
3	Sue Barrell (BoM, Australia, WIGOS repr., s.barrell@bom.gov.au)	✓												
4	Gino Casassa (Geostudios, University de Magellanes, Chile, gino.casassa@gmail.com)	✓		✓						✓				Lead
5	Michele Citterio (GEUS - Geological Survey of Denmark and Greenland, Copenhagen, Denmark, mcit@geus.dk)	✓	Co-chair	✓	✓									✓
6	Mark Drinkwater (ESA, Chair, PSTG, mark.drinkwater@esa.int)	✓												
7	Charles Fierz (WSL Institute for Snow and Avalanche Research SLF, and International Association of Cryospheric Sciences (IACS), Davos, Switzerland, fierz@slf.ch)	✓		✓	Co-Lead							✓		✓
8	Øystein Godøy (Norwegian Meteorological Institute, Oslo, Norway, o.godoy@met.no)	✓									Chair	Lead		✓
9	Barry Goodison (4 Vezina Pl., Kanata, Ontario K2K 3G9, Canada, barrygo@rogers.com)	Vice chair												
10	Jeff Key (Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison, 1225 West Dayton Street, Madison WI 53562, USA, jkey@ssec.wisc.edu)	✓		✓	✓				✓		Co-Chair		Lead	✓
11	Hugues Lantuit (Alfred Werner Institute, Germany, Germany, Hugues.Lantuit@awi.de)	✓												
12	Kari Luojus (Finnish Meteorological Institute (FMI), Helsinki, Finland, kari.luojus@fmi.fi)	✓		✓			Co-Chair	Co-Lead				✓		
13	Tetsuo Ohata (National Institute for Polar Research, Tokyo, Japan, ohata.tetsuo@nipr.ac.jp)	✓												✓
14	Carven Scott (NOAA National Weather Service Alaska Region, 222 West 7th Avenue, Anchorage, AK 99513-7575, Carven.Scott@noaa.gov)	✓												
15	Vasily Smolyanitsky (Arctic and Antarctic Research Institute, St. Petersburg, Russian	✓	✓	✓	✓		Co-Chair		✓					✓

#	Name of Expert	GSG	Observations WG				Integrated Products WG				Information & Services WG			
	Federation, vms@aari.aq)													
			WG	CryoNet Team	Best Practices Team	Solid Precip Team	WG	Snow Watch Team	Sea Ice Team	Glacier Team	WG	Portal Team	Website & Outreach Team	Terminology Team
16	Wolfgang Schöner (University of Graz, Dept. of Geography, Heinrichstrasse 36, 8010 Graz, Austria, wolfgang.schoener@uni-graz.at)	✓	Chair	Lead	✓					✓		✓		
17	Cunde Xiao (Chinese Academy of Meteorological Sciences, 46 Zhongguancun Nandajie, Beijing 100081, China, cdxiao@lzb.ac.cn)	✓		✓										✓
18	Lawrence Hislop (CliC Director, lawrence.hislop@gmail.com)	✓												
19	Christophe Genthon (LGGE, Grenoble, France, genthon@lgge.obs.ujf-grenoble.fr)			✓										
20	Þorsteinn Þorsteinsson (Icelandic Meteorological Office, Reykjavík, Iceland, thor@vedur.is)			✓	Co-Lead							✓ (Data Policy)		
21	Sandy Starkweather (NOAA, USA, Sandy.Starkweather@noaa.gov)			✓								✓		✓
22	Hironori Yabuki (Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan, yabuki@jamstec.go.jp)			✓								✓		✓
23	Rodica Nitu (Environment Canada, MSC, Canada, rodica.nitu@ec.gc.ca) NOTE: NOT endorsed by PR of Canada					Interim Lead								
24	Ross Brown (Environment Canada @ Ouranos, 550 Sherbrooke St. West, 19th Floor, Montréal QC H3A 1B9, Montréal QC H3A 1B9, Ross.Brown@ec.gc.ca)							Co-Lead						
25	Chris Derksen (Climate Research Division, Environment Canada, Toronto, Ontario, Canada, chris.derksen@canada.ca)							✓						
26	Sean Helfrich (National Ice Centre, USA, sean.helfrich@noaa.gov)							✓	✓					
27	Samantha Pullen (Met Office FitzRoy Road Exeter EX1 3PB United Kingdom, UK, samantha.pullen@metoffice.gov.uk)							✓						
28	Dave Robinson (Department of Geography & Office of the State Climatologist Rutgers University, Piscataway, NJ 08854, USA, david.robinson@rutgers.edu)							✓						
29	Patricia de Rosnay (ECMWF, patricia.rosnay@ecmwf.int)							✓						
30	Julie Friddell (Canadian Cryospheric Information Network/Polar Data Catalogue Department of Geography & Environmental Management University of Waterloo, 200 University Avenue West, Waterloo, Ontario, Canada N2L 3G1, julie.friddell@uwaterloo.ca)											✓		

#	Name of Expert	GSG	Observations WG				Integrated Products WG				Information & Services WG			
			WG	CryoNet Team	Best Practices Team	Solid Precip Team	WG	Snow Watch Team	Sea Ice Team	Glacier Team	WG	Portal Team	Website & Outreach Team	Terminology Team
31	Bard Saadatnejad (Norwegian Meteorological Institute, Oslo, Norway, bards@met.no)											✓		
32	Rick Thoman (NOAA-National Weather Service, P.O. Box 757345, Fairbanks, Alaska, 99775, USA, richard.thoman@noaa.gov)												✓	
33	Tómas Jóhannesson (IMO, Iceland, tj@vedur.is)											✓ (Data Policy)		
34	Giovanni Macelloni (CONSIGLI O NAZ IONALE DELLE RICERCHE - ISTITUTO D I FISICA APPLICATA "Nell o Carrara", Firenze, Italy, g.macelloni@ifac.cnr.it)			✓										
35	Angel Corona (NOAA-National Weather Service, 222 West 7th Avenue, Anchorage, AK, USA, angel.corona@noaa.gov)			✓										
36	Eric Holloway (NOAA-National Weather Service, Alaska Pacific River Forecast Center 6930 Sand Lake Road, Anchorage, 99504 USA, eric.holloway@noaa.gov)				✓									
37	Peter Pulsifer (NSIDC, USA, pulsifer@nsidc.org)											✓		✓
38	Julia Boike (Alfred Werner Institute, Germany, Julia.Boike@awi.de)			✓										
39	Tony Worby (Ice, Ocean, Atmosphere and Climate, AAD, Hobart, A.Worby@utas.edu.au)								✓					
40	Rainer Prinz (Department of Geography and Regional Science, University of Graz, rainer.prinz@uni-graz.at) NOTE: NOT endorsed by PR of Austria			✓N						✓N				
41	Anett Bartsch, ZAMG, Austria NOTE: New nomination by PR of Austria			✓										
42	Petra Heil (Australian Antarctic Division, Australia, petra.heil@utas.edu.au)				✓									
43	Gianpaolo Balsamo, ECMWF	✓												

Notes:

1. Shaded areas: endorsement received from PR
2. Yellow areas: endorsement NOT received from PR
3. White areas: waiting for replies from PRs
4. Turquoise areas: No need for an endorsement