**W O R L D  M E T E O R O L O G I C A L  O R G A N I Z A T I O N**

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# POLAR SPACE TASK GROUP

# (PSTG)

## SIXTH SESSION

**ESA ESTEC**
**NOORDWIJK, THE NETHERLANDS**

**13-15 SEPTEMBER 2016**

## FINAL REPORT

## WMO General Regulations

### Regulation 42

Recommendations of working groups shall have no status within the Organization until they have been approved by the responsible constituent body. In the case of joint working groups the recommendations must be concurred with by the presidents of the constituent bodies concerned before being submitted to the designated constituent body.

### Regulation 43

In the case of a recommendation made by a working group between sessions of the responsible constituent body, either in a session of a working group or by correspondence, the president of the body may, as an exceptional measure, approve the recommendation of behalf of the constituent body when the matter is, in his opinion, urgent and does not appear to imply new obligations for Members. He may then submit this recommendation for adoption by the Executive Council or to the President of the Organization for action in accordance with Regulation 9(5).

## MEETING SUMMARY

### 1. WELCOME AND OPENING REMARKS

M. Drinkwater as Chair and ESA host welcomed attendees to the sixth meeting of the Polar Space Task Group (PSTG). Apologies had been received from the following Members of PSTG for not being able to attend: B. Bojkov (EUMETSAT), M. Hori (JAXA), S. Hosford (CNES), and L. Hothem (USGS).

He pointed out that PSTG addressed the wider needs for space agency coordination in support of polar and cryosphere science and applications. The PSTG SAR Coordination Working Group meeting preceding the session discussed SAR-specific issues to meet the objectives of PSTG. After COP-21 and the Paris Agreement, there is much stronger interest in the work of the Group, at technical and high level, and the pay-offs of delivering datasets are coming through. He noted that this is a golden age for studies of polar regions and the cryosphere.

He expected that participants should further develop the shared vision of PSTG, and to identify areas where they could contribute to its work.

The outgoing ESA Director for Earth Observation, Volker Liebig, addressed the Group on 14 September, emphasising the importance and climate influence of polar regions and cryosphere.

M. Drinkwater explained logistical details about the ESA ESTEC site, and on the scheduled visit to the spacecraft integration facility.

### 2. INTRODUCTIONS TO PARTICIPANTS

In a tour-de-table, participants introduced themselves (see attendance list in Appendix I).

### 3. APPROVAL OF AGENDA

In explaining the key topics for the session, M. Drinkwater pointed out that at a high level PSTG responds to the needs of Global Cryosphere Watch, which has been approved as a Programme at WMO Congress in 2015. Support to the Year of Polar Prediction (YOPP) is a key objective for the years to come, in tandem with the plans for the **M**ultidisciplinary drifting **O**bservatory for the **S**tudy of **A**rct**i**c **C**limate (MOSAiC) field experiment. He recognized the Group on Earth Observations (GEO) Cold Region Initiative and the U.S. White House Arctic Science Initiative as important high-level activities underway this year.

A key part of the meeting will be updates on Agency commitments to fulfil science requirements, as identified in the PSTG Strategic Plan 2015-2018.

J. Key pointed out that scope of PSTG is not only the cryosphere, but also space-based observations of the atmospheric and oceanic domain in the polar regions. M. Drinkwater acknowledged this an important point, while qualifying that gaps in observations or products would need to be identified where PSTG can have a role.

The session subsequently adopted the proposed draft agenda (Appendix II).

All meeting documents are available at http://www.wmo.int/pages/prog/sat/meetings/PSTG-6.php.

## 4. KEYNOTE PRESENTATION 1: SENTINEL-1 CONSTELLATION AND APPLICATIONS

P. Potin, Sentinel-1 Mission Manager, introduced the ESA/EU Sentinel-1 polar orbiting mission and its objectives, now that first two satellites (A and B) in the series are in orbit. ESA member states financed development of the A satellite, whilst the recurrent satellites (B, C, D) and operations of the satellite series are funded by the European Commission as part of its Copernicus Programme partnership with ESA. The repeat cycle (at the equator) is generally 12 days or 6 days with one (A) or two (A+B) satellites, respectively, decreasing towards higher latitudes. Priority of the mission is to serve the Copernicus core services, with main users the Copernicus Marine Environment Monitoring (CMEMS) and the Emergency Management (EMS) Services. Applications include the cryosphere (sea ice, glaciers) but are by far not limited, with national ice services as key stakeholders.

The Sentinel High-Level Operations Plan (HLOP) describes procedures to set priorities and allocate resources for data acquisition for various users. The full operational scenario will be achieved after a ramp-up phase. The main operational mode over land and oceans is the Interferometric Wide Swath (IW). The S-1 observation scenario is regularly published online (on a GEarth projection). Data access ensured through the Copernicus Sentinels Scientific Data Hub. The rolling archive has not yet been realized; ESA assert that all data will remain available online.

Through the forthcoming ramp-up to full operations of Sentinel-1B, the observational frequency will increase by a factor of two. The exact observation plans will take into account evolving user requirements from the Copernicus services, national requirements from Copernicus Participating States, and other requirements (including PSTG). EDRS is used to increase downlink capacity and to reduce data product latency.

S-1 will allow for regular acquisition of data over Greenland, and Antarctic ice sheets (coastal regions), for sea ice monitoring. Greenland will see 6-day continuous monitoring along the 6 identified tracks, using both S-1A and S-1B, and an annual ice sheet-wide acquisition campaign with 6-day repeat passes for four to six consecutive passes, using both satellites. Antarctica will see at least 12-daily continuous monitoring of margins (grounding lines) and critical areas (Antarctic Peninsula, Pine Island/Thwaites Glacier area) using both S-1A and S-1B, as well as annual monitoring of margins (grounding lines) in a yearly acquisition campaign of 12-day repeat passes for 4 to 6 consecutive passes, performed by steps (one area to the next) during local winter. In addition, for Antarctica, an ice-sheet wide acquisition campaign is to be performed every 3 years for coverage of the visible interior. There will be important contributions from other missions, for example the polar hole is expected to be covered by RADARSAT-2.

He also showed non-cryospheric applications of Sentinel-1: a UK map of crop classification 2015 based on S-1 data has been compiled. EMSA uses S-1 for oil spill detection. He showed examples for detecting ships (illegal fishing, in-harbour boats). Swell propagation benefits using the Wave Mode. The Copernicus Emergency Service benefits from S-1 for flood mapping. The International Charter Space and Major Disasters is also an important client, and so are earthquake science and post-earthquake relief agencies that benefit from displacement maps generated from S-1 data.

Daily maps of icebergs in Greenland waters are routinely reported. A 1-day mosaic from CMEMS using both S-1A and S-1B focuses on the European Arctic, but also covers parts of the Russian Arctic. Sea ice drift is reported using S-1A data and comparison with S-1B.

Ice charting services receive L1 data and usually process ice drift vectors themselves. Automation of ice charting has started, however, its full application is still some time away. S-2 is not operated routinely over Antarctica, though significant demand has led to summer acquisition campaign plans over the ice sheet.

Ice sheet surface velocity maps are routinely generated. The UK Centre for Polar Observation and Modelling (CPOM) and ENVEO in Austria currently host glacier and ice sheet monitoring results online.

He stressed that S-1 was also intended to spur business, and quoted the estimate that 1 Euro invested in S-1 yields 6-8 Euro of socio-economic benefit.

M. Drinkwater highlighted the advances in the use of SAR data for operations and studies that require short, regular revisit intervals, which is greatly different from the situation of infrequent or irregular coverage a decade ago. The Copernicus services are prime users of this wealth of data. Participants recognized that the S-1 mission was a real game-changer for the operations and use of SAR data.

Participants asked whether S-1B data acquired over the summer 2016 were available to the community. P. Potin agreed to investigate this possibility.

**ACTION 6.1: P. Potin to investigate whether S-1B data acquired over the NH summer 2016 could be made available to the community.**

## 5. REVIEW OF ACTION ITEMS

The PSTG Action items list was discussed and updated (see Appendix III, including the Actions agreed at this session).

## 6. ADDRESSING STRATEGIC INITIATIVES

### 6.1 Global Cryosphere Watch

#### 6.1.1 CryoNet In-situ Network

Jeff Key (NOAA) briefed on CryoNet (the “Cryosphere Network”), which is the core of the GCW surface network. CryoNet builds upon existing surface stations, to encourage WMO standards, best practices, and availability of data. Data from these sites may be useful for calibration of satellite instruments, and validation of products. Recommendations from the satellite community will be welcome if changes to the sites are necessary to satisfy their needs. For example, Switzerland is establishing a Swiss Alpine Remote Sensing Site with a dedicated study plot within the Weissfluhjoch-Davos CryoNet site.

J. Key pointed out the complex structure of cryospheric surface observation sites, often distributed over a relatively small area, managed by one or more institutions. CryoNet uses the terms “stations” and “sites”, the latter being composed of several stations. The minimum set of measurements to be addressed at each site is yet to be defined; however, they usually include in-situ measurements of snow, permafrost, glacier properties, and automatic weather stations. Stations are distinguished by core and contributing stations. Stations need to provide metadata information, including uncertainty of measurement.

He showed the list of currently approved and candidate CryoNet sites.

#### 6.1.2 Product Validation / Intercomparisons

M. Drinkwater stressed the value of product intercomparisons and quality assessments. These help to assess strengths and weaknesses in products. Combinations of products from several agencies are critically dependent on knowing biases and uncertainties, and so is the generation of Essential Climate Variable (ECV) records. Independent reference data from in-situ or aircraft data can serve for this purpose. PSTG should think about common ground-based reference sites equipped with appropriate instrumentation.

For intercomparisons, key preparatory steps include the definition of common elements, and standards in determining uncertainty. A prime example for intercomparison efforts is the Group for High Resolution Sea Surface Temperature (GHRSST), which monitors and assesses SST products using a defined reference network, and brings a diverse set of SST satellite products from many operators into a common evaluation framework.

Intercomparisons will also be required when combining Surface Elevation Change products using laser and radar altimeters, as experience from the ESA CCI project showed. The Satellite Snow Product Intercomparison and Evaluation Experiment (SnowPEx) aimed at intercomparing snow products, identified a common set of reference datasets, and analysed trends.

In concluding, he raised the following questions:
- whether such product intercomparisons were the domain of the CEOS WGCV, or PSTG;
- whether there was interest in PSTG in expanding on the example of SnowPEx for other cryosphere products;
- how to nurture future joint agency efforts under GCW;
- how to combine model output (analysis/forecast update) with in-situ/satellite products in a tracker-like environment (GCW SnowWatch example);
- how to organize collective funding.

### 6.1.3 Key Contributions: Snow Watch, SnowPEx; SnowEx [DOC[1]]

**Intercomparisons of sea-ice thickness**

J. Key reported on intercomparisons of satellite-derived sea ice thickness. He held that sea-ice thickness measurements from altimeters were probably the most direct (and best) measurement for thicker ice, although value could also be demonstrated from an energy budget approach with AVHRR, MODIS, and VIIRS. He referred to a paper by Wang et al. (2016) published in *Remote Sensing* titled "Comparison of Arctic Sea Ice Thickness from Satellites, Aircraft, and PIOMAS Data". Datasets used in the paper included APP-X, ICESat, CryoSat-2, IceBridge data, and SMOS.

**SnowPEx – The Satellite Snow Products Intercomparison and Evaluation Exercise**

T. Nagler briefed on main results from SnowPEx.

Community participation in the experiment was much higher than expected, and from all other the world. He showed one example of a comparison of snow cover. Northern Hemisphere snow cover intercomparisons 2007/2008 differ by up to 30% in unforested areas. Differences are largest in Northern Hemisphere spring, at the margins of the snow season. Results include that algorithms used for Landsat-8 and Sentinel-2 data should be reviewed, given the significant differences between products. Spread is also large for Snow Water Equivalent (up to 50%). SnowPEx ends in 2016. Future steps could address SAR-based wet snow algorithms, potential multi-sensor synergistic snow products, evaluation of the performance of Landsat-8 / Sentinel-2 algorithms in different environments, assessment of the quality of cloud-clearing procedures in optical snow products.

S. Howell reported on work undertaken by Environment and Climate Change Canada on sea-ice thickness comparisons, following the framework proposed by T. Nagler. The critical importance of airborne campaigns was recognized.

**Agency commitments**

The NASA SnowEx airborne campaign is attempting to address snow cover in forested areas.

[1] DOC indicates that a document is available to support this item at http://www.wmo.int/pages/prog/sat/meetings/PSTG-6.php

The Group discussed whether PSTG should engage in developing a framework for such intercomparisons, bearing in mind that agencies are responsible for the proliferation of products in the different domains.

In instances where multiple satellites are contributing, C. Dobson suggested that intercomparisons should be budgeted as an essential part of mission related cal/val.

M. Drinkwater and J. Key proposed the idea of supporting the intercomparison of sea-ice thickness products. At the ESA Cryosphere science meeting planned for March 2017, a PSTG position should be communicated.

**ACTION 6.2: M. Drinkwater and J. Key to formulate a PSTG position on support to the intercomparison of sea-ice thickness products, for communication at the ESA Cryosphere science meeting in March 2017.**

### 6.1.4 Agency Inventory on In-situ Snow Activities

Agencies were asked to present on this subject as part of their agency briefing under item 9.

## 6.2 Year of Polar Prediction

T. Jung recalled the mission of YOPP, the status of YOPP and results of the YOPP planning meeting held 5-7 Sep 2016 in Reading, UK. The end of YOPP preparations is foreseen for mid-2017. Modelling extends between NH summer 2017 until NH summer 2019. Special Observing Periods should be Feb-Mar 2018, and Jun-Sep 2018, as well as Feb-Mar 2020; additional data should come from buoys, Intensive Observing Periods (IOPs), extra modelling, MOSAiC, modelling post-YOPP. Endorsement of projects is a separate task in YOPP, and there are currently 30 recognized projects (http://apps3.awi.de/YPP/endorsed-projects). Endorsement by YOPP can also be for institutional contributions.

YOPP recognizes the importance of multi-sensor sea ice thickness products, because this parameter is a source of seasonal predictive skill in the Arctic.

YOPP satellite-related activities are:

- Provide YOPP community with list of operational products (as per agreed Action, this should be initiated by YOPP and iterated by PSTG; see new Action below)
- Discuss additional research and products (contributions to Special Observing Periods, or SOPs, and IOPs)
- PSTG and PPP-WG to combine efforts in pushing for a strong YOPP buoy component
- PSTG acknowledges the strong ties between YOPP and MOSAiC
- Need for multi-sensor sea-ice thickness products (including uncertainties)
- Institutional YOPP endorsement

It is expected that satellite-based products will be useful for comparison with model output, as well as for assimilation. Many modelling groups are now assimilating satellite products (including sea extent/concentration and ice thickness) in their (coupled) model frameworks – significant progress has been made in this area. He showed modelling results of sea ice cover and thickness, including leads. Both operational and research modelling groups should be given access to these datasets.

Reanalysis may serve as a baseline for YOPP, but specific reanalyses during YOPP will depend on funding.

**ACTION 6.3: T. Jung on behalf of YOPP to initiate a list of parameters that should be provided for by operational satellite products in support of YOPP; PSTG to iterate with YOPP based on the initial list.**

### 6.3 MOSAiC: Multidisciplinary drifting Observatory for the Study of Arctic Climate (2019 – 2020) [DOC]

Markus Rex as coordinator of the MOSAiC programme presented on behalf of the MOSAiC international consortium. MOSAiC is a multidisciplinary year-round expedition into the central Arctic, aiming at better understanding the coupling between atmosphere, ocean, sea ice, biogeochemistry, and ecosystems in the Arctic. The experiment also targets improving climate models describing the Arctic, citing the discrepancy between model predictions and observations of sea-ice cover. It is being planned to contribute to YOPP, during the period autumn 2019 to summer 2020.

YOPP focuses strongly on improving NWP models and polar predictions, whereas MOSAiC emphasizes process understanding.

MOSAiC will consist of the research vessel Polarstern being frozen into sea ice, and a network of stations on the sea ice in a radius of 50km. A comprehensive measurement programme is being set up, including on-ice and under-ice instruments and devices. The vessel would then drift through the sea ice for 12 months and is expected to reach the Fram Strait, with navigation reduced to a minimum (Lagrangian trajectory). Rendezvous with icebreakers (for supplies) will provide additional geographic coverage. Supplies and scientific teams will also be brought by aircraft.

Thematic groups have been set up for the various domains. A mix of autonomous and manned observing system will be deployed in a nested approach. Expressions of interest have been received by other research vessels (Russia, China).

Polarstern offers an opportunity for an all-year cal/val campaign for satellite instruments (especially in winter), with no limitations on power and weight. Currently, there remains a budget shortfall of 14 Mio Euro (50 Mio budget, 36 Mio commitments).

Gunnar Spreen briefed on the remote sensing component of MOSAiC, coordinated by Ron Kwok (JPL) and himself. Satellite imagery will be important for operations and scientific planning (getting RV Polarstern into the ice and finding the right floe, support to supply vessels). The different types of satellite missions have been defined that would contribute (SAR, etc.). Current focus is on data to infer on sea ice variables, for which a broad range of sensors is required. Useful datasets include near-coincident SAR acquisitions, and high-resolution optical data (such as Worldview-2, Pleiades).

The question was raised on which data needs are of a tactical, near real-time nature, and which ones are of scientific nature and can be provided in delayed mode. Some processing and visualization capability will be set up on the vessel, while most planning will occur on mainland. Tactical support should be organized through the International Ice Charting Working Group (IICWG; meeting in October 2016), since the trajectory of the ship will touch on several domains of responsibility. Communication bandwidth with the ship will be limited to areas with Iridium connectivity.

Some dedicated satellite calibration measurements are planned in the frame of MOSAiC, which offers a unique possibility for such measurements (see presentation).

Details on tailored acquisitions in support of satellite missions need to be discussed. Airborne campaigns could provide satellite underflights (e.g., of CryoSat, SMOS, ICESat-2). PSTG agencies

will have to find out the planning of instrumentation. A fuel depot will be set up on Bolshevik Island to support aircraft campaigns. The MOSAiC timeframe is likely overlapping with the commissioning phase of RADARSAT-CM.

**ACTION 6.4: Y. Crevier to introduce the MOSAiC coordinators to the IICWG contact John Falkingham regarding tactical ice charting support to the campaign.**

The question was raised whether CNES could support MOSAiC through providing high-resolution (<10m HR) optical data.

**ACTION 6.5: A. Lifermann and S. Hosford to investigate with MOSAiC coordinators detailed requirements of the experiment for high-resolution optical data.**

MOSAiC representatives should investigate the rolling AO maintained by ASI for access to COSMO-SkyMed data.

It was suggested to have MOSAiC again on the agenda for the next PSTG meeting to revisit some of the key follow-up items.

**ACTION 6.6: Add MOSAiC status and PSTG support to the agenda of the next PSTG meeting.**

On-request agency support may be needed with 5-day lead times (and in particular as a function of the forecasting quality of the drift). It was noted that the operational planning requires different planning timescales and constraints depending on the satellite, and that this would be a specific function of the required sensor product.

**ACTION 6.7: M. Gottwald to find out the instrument and operational planning of the HALO in support of MOSAiC, and to get in touch with Manfred Wendisch, DFG Coordinator of HALO.**

The MOSAiC implementation plan provides more detail regarding satellite data needs.

### 6.4 GEO Cold Regions Initiative [DOC]

J. Key updated the Group on the GEO Cold Regions Initiative (GEOCRI), which was recently approved by the GEO Programme Board. It focuses on broad coordination of stakeholders of the cryosphere, and data sharing. The Implementation Plan mentions PSTG, and PSTG continues to function as a contributor to the various goals of GEOCRI. GEO is a driving force to some institutions (e.g., the European Commission), including some large space agency initiatives (e.g., for the Forest Carbon Observation Initiative in support of REDD+), and the relationship between PSTG and GEOCRI should continue. The requirements by users identified by PSTG contribute to the building of communities of practice in the area of polar and cryosphere. Highlighting contributions of PSTG in the GEO Work Plan is an option to leverage the GEO mechanism for user priorities identified in PSTG (e.g., in view of defining research programmes). Jeff Key continues to serve as the main interface between PSTG and GEOCRI.

### 6.5 Polar Reanalyses [DOC]

C. Dobson presented slides on behalf of Thomas Wagner (NASA) on the need for polar reanalyses. Systematic Improvements to Reanalyses of The Arctic (SIRTA) is a U.S. initiative, investigating reasons for change in the Arctic. Focus areas are snow thickness on sea ice, and surface mass balance. Reanalyses are needed to understand ice mass balance. Models poorly represent the boundary layer, and here, improvements are needed to better constrain ocean-atmosphere fluxes. Studies suggest that models represent snow cover quite well.

Opportunities may arise for aircraft-based investigations in the next NASA Decadal Survey that is due for publication next year. A potentially stronger role of small satellites to atmospheric science is also recognized.

B. Scheuchl informed that ice-sheet model comparisons have been undertaken, and again compared with satellite observations. PSTG agencies have some experience in interacting with modelling groups in their countries. Reanalyses are used as comparison baseline against long-term datasets, e.g., on clouds. The International Winds Working Group (IWWG) is also an important venue where modellers and satellite experts will meet in relation to atmospheric motion vectors and satellite derived wind datasets. In Europe, satellite experts are embedded in NWP centres (e.g., ECMWF) to facilitate effective data uptake; the ERA reanalyses capture much of European (and other) satellite data. It is expected that ESA's ADM-Aeolus Doppler wind profiling lidar, EarthCARE future European Sentinel and MetOp/EPS-SG missions will provide ice cloud and moisture profiles of the atmosphere, contributing to improved atmospheric dynamics, radiation balance and boundary layer understanding at high latitudes.

ISRO perform assimilation for forecasting, currently do not entertain a structured dialogue on reanalysis. CONAE informed of reanalyses focussing on soil moisture.

The CEOS-CGMS Working Group on Climate is in charge of coordinating space agencies in generating satellite-based climate data records, following requirements for Essential Climate Variables (ECVs). The Group has interacted with modelling centres and reanalysis experts to ensure that the assembly of multi-agency climate datasets brings the combined benefit of long-duration ECVs.

### 6.6 US White House Arctic Science Ministerial [DOC]

M. Drinkwater briefed on the results of this upcoming meeting. Many agencies have been asked to make a commitment to this initiative, derived out of UNFCCC COP21 and the Paris Agreement. It aims at addressing Arctic climate science challenges and how improved understanding of the Arctic leads to sustainable development. Climate impacts on ecosystems have a bearing on humans and biodiversity. One key deliverable focuses on permafrost-related research, with a number of supporting countries (including the European Union) and projects. The projects will be highlighted at the forthcoming Arctic Science Ministerial meeting. MOSAiC and YOPP are similarly recognized.

Endorsement of projects by the Arctic Science Ministerial helps put projects on a firmer basis over the longer term (in some countries independent of changes in government). In the U.S., only approved projects were submitted as contributions. The Group recognized that polar research and monitoring has gained attention at Ministerial level.

## 7. PSTG SAR-COORDINATION WORKING GROUP: REPORT FROM 5TH MEETING

Y. Crevier gave a brief overview of results from this meeting. He asked about the formal status of the CWG under PSTG - whether it was an ad-hoc group or a standing group. The Terms of Reference of the CWG are final and it was noted that they have never been formally endorsed by PSTG. Contributions by commercial providers are critical to some agencies, and their participation in the Group is important, at least on an ad-hoc basis. Progress since last year includes (i) continued SAR data contribution and collective acquisitions in response to science requirements of PSTG, (ii) updated coordinated space agency acquisition plan;

**ACTION 6.8: PSTG to endorse the Terms of Reference of the SAR Coordination Working Group.**

He explained the Data Compendium which will be updated over the year; an electronic version will be generated. A new set of requirements from glacier community is expected. The Group welcomes the participation of new agencies – CONAE, ISRO, NASA.

The CWG should be the place for coordination of complementary SAR data acquisition, and for sharing workload.

F. Battazza raised the question whether a similar sub-group on optical sensors was required. M. Drinkwater informed that this issue had been raised in the past, recognizing that most acquisitions of optical data other than of very high resolution optical were performed on a routine basis, and that a lead agency for establishing such a group was needed. The agency reports should include information on non-SAR sensors and data.

For the future, it was deemed useful to explicitly recognize the SAR-CWG in the PSTG Terms of Reference. PSTG members subsequently endorsed the Terms of Reference of the PSTG SAR Coordination Working Group (http://www.wmo.int/pages/prog/sat/documents/PSTG-SARCWG_ToR-Nov2014.pdf).

## 8. KEYNOTE PRESENTATION 2: CRYOSAT: ESA'S ICE MISSION ACHIEVEMENTS

On behalf of ESA and the CryoSat mission manager Tommaso Parrinello, M. Drinkwater briefed on the CryoSat mission objectives; a primary objective is determination of regional and basin-scale trends in marine and land ice thickness. The altimeter is a 1D SAR-based instrument whose high along-track resolution allows ice freeboard measurement. Determination of the angular origin of the echo by interferometry over ice sheets allows removing the ambiguity in height assignment over steeply sloping ice sheet margins.

The goal is to maintain CryoSat mission operations until after 2020, and overlap with ICESat-2 is planned. Covering as much of the pole hole as possible is critical to correctly estimate ice mass and so a non sun-synchronous drifting orbit was chosen (a similar altimeter on a lower inclination sun-synchronous polar-orbiting platform such as Sentinel-3 is estimated to miss as much as 50% of the total volume of Arctic sea ice).

Many validation campaigns have been undertaken by ESA (CryoVEx) to estimate the uncertainties in the CryoSat ice thickness products. He showed science results on sea-ice thickness time series, and other additional products such as bathymetry, wave height in tropical storms, river discharge. Over ice sheets recent results indicate that SAR interferometric altimetry offers the possibility of continuous mapping of the ice sheet grounding line. A combination of the CryoSat-2 Ku- and the AltiKa Ka-bands has demonstrated potential to be used to retrieve snow depth over ice. Use of NRT capabilities will be maximized for forecast communities (meteorology, marine, sea ice).

## 9. STATUS OF AGENCY RESPONSES TO PSTG STRATEGIC PLAN

### 9.1 Evolution in user requirements: Ice Sheets, Permafrost, Snow, Floating Ice

M. Thibeault expressed his wish to understand the contribution of L-band SAR to addressing the user requirements. T. Nagler pointed out that inferring on SWE is a possibility due to advantage of the longer wavelength for snowpack penetration.

**Permafrost**

A. Bartsch summarized an update to user requirements, and to the degree these are being fulfilled. The case was made successfully with JAXA to focus ALOS-2 PALSAR acquisitions over five cold

spots. Sentinel-1A IW data have been requested through ESA DUE GlobPermafrost. She pointed out that most the recent research projects make use of high-resolution optical data.

A new request to collect user requirements is underway. A white paper on monitoring sites encompasses 49 sites, some of which CryoNet sites. Suggested goals for GCW CryoNet regarding permafrost in the "Primer to the GCW CryoNet" recognize the use of remote sensing techniques. The ESA GlobPermafrost project (www.globpermafrost.info) addresses many of the requirements formulated in the PSTG context (with focus on 10 sites out of the 49) and using Sentinel-1 and Sentinel-2 data. Within this project, users identified physical subsurface properties as the most required parameter, with preferences for horizontal resolution of 10-30m, and bi-weekly temporal resolution. Due to the fragmented nature of tundra, mixed pixel effects strongly affect accuracy of land cover classification, therefore high-resolution datasets are necessary. So far, the community purchases high-resolution optical data on a case-by-case basis.

Optical imagery help in surveying thaw slumps. Quicklooks from Cosmo-SkyMed were also used. Only very few scenes were cloud-free over the summer of 2016 (on the order of 5 out of 100).

The LPS 2016 proceedings paper provides an update of user requirements. Franz Meyer is working on an update especially on subsidence.

An update of the list of required cold spots and transects will be provided by the end of 2016 (PSTG **Action 5.7**). No update of the user requirements document is planned before 2017.

**Snow Monitoring**

T. Nagler provided an update on snow monitoring user requirements. He briefed on the comparison of various snow cover products (hemispherical, continental, …) as undertaken in SnowPEx.

OLCI on Sentinel-3 misses the 1.6µm shortwave infrared band which is needed to discriminate clouds from snow. A combined snow mapping algorithm is therefore needed (using OLCI and SLSTR) particularly for fulfilling the requirement for continuity in the snow extent mapping at sub-km scale in Europe (as for instance in the EU CryoLand service http://www.cryoland.eu/).

The wet snow user requirements for HR is 100m, and revisit time 1 day. The product type of the current C-band SAR is extent of snow melt area based on backscatter sensitivity to wet snow, but with very limited sensitivity to dry snow. He explained the Dual Polarization Retrieval Method used for Sentinel-1. Forests are usually excluded from all these analyses. A demonstration service for wet snow has been developed within CryoLand based on Sentinel-1.

The Copernicus Land Service uses some of the optical data.

He outlined some of the advantages of combining optical and SAR data: obtain both overall snow extent, and wet snow, and melting snow below clouds. He showed the concept for a system for snow monitoring with ongoing quality assessment by Sentinel-2, aiming at global / hemispheric snow products from VIIRS/Sentinel-3, Sentinel-1 with high-resolution snow products from Sentinel-2 and Landsat-8. Satellite coverage for such a system would have to be:

Medium Resolution Optical Sensors (Sentinel-3A OLCI+SLSTR, VIIRS, MODIS, etc.):

- daily close to global coverage

SAR:

- High temporal sampling during melting season needed; some acquisitions during high winter / autumn used as reference images.
- Sentinel-1 A&B: for several regions (Europe) all data acquired. ESA / EC plans a complete Land coverage every 12 days;

- RSAT-2: Good coverage in Canada

He recalled the SAR-related science requirements for snow measurements.

**Floating Ice**

S. Howell introduced the sea ice theme and noted that meeting the requirements has been easier than for the other user groups, since strongly relying on SAR data. He briefly touched upon the four basic requirements. CSA would be interested in supporting MOSAiC. To achieve 3-day Pan-Arctic coverage (the requirement is 6 days) using Sentinel-1 and Radarsat-2, additional contributions from other agencies would be most valuable over the Siberian and Chukchi Seas, ideally twice a week on a routine basis. No data are currently regularly acquired in these areas (other agencies may have a role to fill gaps).

The Group pointed out that the need for pan-Arctic coverage using Sentinel-1 has to be expressed through user fora such as the Copernicus User Forum and the Copernicus Services, since support to science is not the prime mission of the Sentinels. Even if the gap over the Eastern Arctic will be filled, some additional acquisitions will be needed over the pole hole.

MOSAiC could use very high resolution SAR imagery for campaign planning.

Areas of mixed ice type are where L-band SAR could serve a useful purpose during the melt season, to distinguish first-year and multi-year ice. Derived drift vectors improve during the melt season with L-band due to higher penetration.

**Ice Sheets**

T. Nagler presented an update of ice sheet monitoring, taking results from the ESA Greenland Ice sheet CCI and Antarctic Ice-sheet CCI projects. A Sentinel-1 IV map of Greenland has been produced taking about 11 months processing time, and with some ionospheric effects visible. Data source is burst mode data. The Ice Velocity Map of Greenland using Radarsat-2 was also shown. Only 6 tracks of Sentinel-1 are required to regularly map the Greenland ice sheet margins, implemented by ESA in June 2015. For some fast outlet glaciers, high-resolution TSX or CSK data are useful for accurate mapping. For 315 outlet glaciers, “gates” have been defined, to estimate ice discharge. Depth-dependent velocity profiles can be calculated.

Two revised Sentinel-1 acquisition scenarios over Greenland are proposed:

- For continuous monitoring of margins, apply current Sentinel-1 acquisition plan also to Sentinel-1B, resulting in 6-day repeat regular acquisitions

- For an annual ice sheet-wide ice velocity product, extend the current Sentinel-1 campaign with Sentinel-1B, providing 4-6 day repeat observations with a 6-day interval using both satellites

L-band could have a significant contribution in Southern Greenland, West Antarctic Ice Sheet, and Antarctic Peninsula, where significant melting occurs.

Seasonal cycles in Antarctica outlet glaciers can be detected with repeated coverage. Trends in grounding line (an objective parameter) are investigated in the Antarctica_CCI using TerraSAR-X, Sentinel-1 and other data types (more than 1000 grounding lines, detected automatically). A round-robin experiment was done.

A concept for monitoring Antarctica should include:

(i) Continuous monitoring of margins / grounding zones
(ii) Annual ice sheet wide ice velocity map with polar gap (using Sentinel-1)

(iii) 3 or 5-yearly complete ice velocity field of ice sheet

He showed an example for mapping elevation change detection over time using DEM differencing. A proposal was made for an EE9 mission (SESAME) to enable SAR interferometry using multi-static acquisition geometries. He showed the Cryoportal (http://cryoportal.enveo.at), showing recent updates as well as time series of parameters.

A dedicated campaign would be needed to fill the pole hole over Antarctica. M. Drinkwater noted that the user community has matured to be able to ingest large amounts of data acquired on a routine basis; it is reassuring to the agencies that the large volumes of collected data are appropriately used and that the products were becoming available via the various data portals.

**Glaciers**

On behalf of F. Paul, T. Nagler presented an update from the perspective of the glacier community, and satellite-based acquisitions of data over glaciers. He showed benefits of acquiring 30 years' time series of glacier data from Landsat. Primary datasets are glacier outlines, elevation, etc. Data were provided for years by ASTER. High resolution data should have horizontal resolution of 10m or better. Time series help elucidate glacier surges and formation of glacial lakes (increasingly a hazard for populations downstream). Geo-coding has to be checked. Using DEM differencing allows calculating mass balance of Patagonian ice fields (caps).

Regarding the 10-m resolution data provision from Landsat-8 and Sentinel-2, he pointed out some issues regarding orthorectification in complex terrain, where a regularly refreshed DEM is needed to capture the more rapid glacier surface elevation changes. Higher resolution, all-weather analyses of glaciers require data from sensors such as TerraSAR-X and Cosmo-SkyMed.

He summarized the data needs identified by the glacier community re ASI, DLR, JAXA, NASA and USGS sensors.

### 9.2 Update to Table of Commitments

Agencies should focus their presentation on:

- Evolution of commitments since Oct. 2015
- New Planned Activities/Products/Missions/Airborne Campaigns
- Specific new Contributions to Strategic Initiatives

**DLR**

M. Gottwald said that the position and commitments of DLR are unchanged relative to last year. The planned missions are in the pipeline. Users interested in atmospheric products have to extract orbital products and then generate gridded products, or products focused on Polar Regions. In DLR's view, a dedicated sub-group of PSTG is currently not needed for atmosphere, since the data are routinely acquired.

There is no information regarding in-situ snow activities by DLR.

**NASA**

C. Dobson informed that ICESat-2 is on its way to a FY 2018 launch (after experiencing some issues with the laser instrument). The NISAR mission is well on its way and has just transitioned to its implementation phase. GRACE-FO is well supported and a launch in the 2020 timeframe is possible. The Oceans Melting Greenland (OMG) mission is starting, including interferometry and

GLISTIN altimetry radar. GLISTIN also collecting topographic coverage of the mountain glaciers in continental U.S.

Underflights of Envisat, CryoSat-2 and Sentinel-3A have been performed during Operation IceBridge. Comparisons between CryoSat-2 and data from such flights have led to interesting insights. The ESA-NASA IMBIE project has led to comparing estimates of Greenland and Antarctica ice mass balance using a range of techniques; the project is continuing.

NASA seeks collaboration with ESA on comparisons of snow thickness on sea ice, which is the largest contributor to uncertainties in the thickness of Arctic sea ice derived from altimetry.

From the Group, the question was raised whether this engagement will be part of a larger initiative, or aimed at intercomparison of different algorithms, and on the linkage to MOSAiC. J. Key noted that a sea ice and snow intercomparison project would be an important development if the PSTG could stimulate that.

C. Dobson pointed to trends in the NASA programme: surface mass balance/firn compaction, near-term sea level rise, cloud-radiative balance, use the ice as the record to infer on Earth system change.

Geolocation and orthorectification issues with Sentinel-2 and Landsat are currently being addressed by an ESA-USGS working group. Agencies should use a common terrestrial reference frame, to make optical imagery useful for glacier and ice sheet studies.

**ACTION 6.9: USGS to provide a formal response to PSTG on their acquisition campaign over Greenland, Antarctica, and high-mountain glaciers, including details on geolocation and the DEM used for this purpose.**

On the question of the international framework to organize the intercomparison of sea ice parameters, the calibration/validation group (CEOS WGCV) was mentioned. There is a NASA-ESA working group on this topic; are other agencies needed?

**CSA**

Y. Crevier provided an overview of CSA contributions to PSTG. Canada is an Arctic-centric country, with the current government making the space contribution to societal benefits in the Arctic a priority. Canada is strongly engaged in PSTG and chairs the SAR-CWG, and is committed to continue to do so. CSA recognize the necessity of calibrating and validating its products. Through the coherent, long-term RADARSAT archive and ongoing operational support to the RADARSAT mission, CSA directly contributes to the understanding of the impacts of climate change and provides tactical support to activities in the Arctic. The weather and climate payload on the PCW mission has been de-scoped, but continues to be considered by Environment and Climate Change Canada (ECCC, formerly Environment Canada) and CSA.

Looking forward:

- The RADARSAT Constellation Mission will continue to enhance the use of SAR support Government of Canada operations as well as internationally
- CSA support a mission concept study on terrestrial snow mass
- CSA support the Raven proposal for EE-9 to provide a full suite of limb sounding measurements of atmospheric composition
- CSA support a mission concept for observations of air quality and GHG in the Arctic

He also provided information on in-situ snow activities by Environment and Climate Change Canada.

**ESA**

M. Drinkwater reported that a launch window with Vega has been determined and committed by ESA for ADM-Aeolus, for the end of 2017. Accomplishments regarding floating ice that include ESA are results for ocean surface topography of ice-covered oceans from CryoSat-2, sea-ice thickness projects combining CryoSat-2 and SMOS, and products published online, lake ice products. The ESA Arctic+ initiative has launched feasibility studies initially focusing on (i) enhanced snow retrievals on sea ice, (ii) enhanced quantification of freshwater fluxes, (iii) sea-ice mass formal intercomparison exercise, (iv) enhance polar predictions and EO data assimilation in NWP and climate models. He showed details of the CryoSat validation experiment (CryoVex), addressing data gaps and temporal change in land and sea ice physical properties, and to verify upgraded CryoSat L1 and L2 processors. He showed details of the new SnowLAB snow campaign, targeting snow retrieval methods using new remote sensing techniques including tomography.

GlobSnow is now being transferred to the EUMETSAT Satellite Application Facilities.

Through earth.esa.int, there is a new on-demand SAR processing service of ERS/Envisat data.

The CryoSat Science Meeting is planned for 20-24 March 2017 in Banff, Alberta, Canada.

**CONAE**

M. Thibeault informed on SAOCOM plans with two satellites measuring in L-band to be complementary to the ASI Cosmo-SkyMed constellation. Use of quad polarization, with SNR > 30dB is a requirement. The acquisition scenario is based on maritime surveillance of Argentine waters including Antarctica and Antarctic waters (resolution 100m azimuth and 10m), TWSP swatch width is 200km. The mission has no commercial basis, and data should in principle be available for science. The data policy has not yet been decided. An AO is planned for next year. Regions of Interest (ROI) have been defined for “snow and ice” and “glaciers” along the Andean Cordillera, the latter including the Patagonian ice fields. These regions have been determined based on the statistics of user requests for other data. Two observations of these areas per year are the baseline.

The Group recommended that acquisitions planned in the mountains should ideally be on both ascending and descending passes to be able to image both sides of the mountains.

To capture evolution of snow, consideration of a higher frequency of acquisitions would be welcome.

Science leads should provide feedback on the current CONAE SAOCOM acquisition plan, noting the uniqueness of the L-band mission, its complementarity to other SAR missions, and the prime priority of the mission to measure over Argentina. No acquisitions are planned over Europe, where Cosmo-SkyMed takes precedence.

**ACTION 6.10: Encourage all science leads to look at the current CONAE SAOCOM acquisition plan and provide feedback to Marc Thibeault, with the understanding that Argentina is the highest priority of the mission, by 31 Jan 2017.**

There are two global background missions, in support of forest carbon tracking, in support of Siberia.

M. Drinkwater stresses the value of SAOCOM, and the complementarity with other missions. Multi-frequency studies in selected areas, such as the MOSAiC trajectory, could well use L-band data from SAOCOM.

**CNES**

A. Lifermann provided an update for the period 2014 until now. The SPIRIT-1 campaign built a large archive of SPOT imagery over Antarctica that has led to generation of a 40m DEM and a number of publications. A second SPIRIT campaign 2013-2014 was carried out, to preclude the deorbiting of SPOT-5. Many key SPIRIT sites were targeted, but complete coverage was not possible. Data from the stereoscopic survey are available.

Pleiades data can be shared with any science user from a public institution once it has signed a specific agreement with CNES (to be initiated by an email to steven.hosford@cnes.fr). This opens the possibility of systematic acquisitions available to wide international science teams. Systematic Pleiades stereo acquisitions of 22 WGMS glaciers are underway.

Microwave sensors include SARAL/AltiKa with unique Ka observations, providing continuity to ERS/ENVISAT. There is a Phase 0 study toward designing an altimetry missions focussed on ice, based on AltiKa feedback. There are annual research AO and workshops.

She showed a sea-ice fracturing product based on AltiKa. She also showed results inferring snow depth over the ice using a combination of Ka and Ku bands (AltiKa and CryoSat-2). M. Drinkwater commented that data from Sentinel-3 will also be useful in this regard to maximise the crossovers and collocated data.

**ASI**

F. Battazza explained how ASI is positioning itself in support of polar and cryospheric studies. Italy is an observer to the Arctic council. Activities are performed by INGV, CNR, and ASI. ASI is in contact with these governmental institutions to coordinate these activities. ASI itself does not perform science, but is in charge of missions. Commercial entities are in charge of operating missions such as Cosmo-SkyMed (CSK). ASI is involved in Council of EUMETSAT, and represents Italy in ESA. ASI has a voice in the Copernicus User Forum, and coordinates the Italian position with other institutions such as CNR.

CSK is the main ASI asset to contribute to PSTG, consisting of four satellites. Acquisitions have focused on ice sheets and the Fram Strait, the NE and NW passages. Science support occurs through AOs, on occasion jointly with other institutions such as CSA. Monitoring of selected glaciers in Antarctica has been done since 2008. Since 2011, a CSK background mission applies a systematic low priority acquisition strategy (over 90 glaciers, Fram Strait, NE and NW passages, Antarctic and Greenland coastlines, see Data Compendium), with generally a good chance of acquisition since high-priority users often have priorities in other regions.

There is a permanently open call for science related to CSK, for research studies. Selected projects will be supported for a maximum of two years, through a provision of a maximum of 100 free-of-charge CSK scenes. The science community should demonstrate their interest. Further data access is currently either commercially-based, or in the framework of a second project.

Participants noted that data archives of agencies are becoming increasingly accessible – for example the RADARSAT archive is available until 2007.

**NOAA**

J. Key summarized NOAA contributions to GCW (sea-ice thickness measurement intercomparison; new “trackers” on surface albedo, surface temperature, ice thickness based on AVHRR), YOPP (list of NOAA datasets has been compiled), MOSAiC (no planning as yet). The U.S. National Ice Center is contributing several products of relevance to YOPP. Polar reanalyses are using historical AVHRR polar winds, among other data sources. Sentinel-1 is being integrated into NOAA operations for ice and wind monitoring.

Regarding floating ice, NOAA has produced a climate data record (AVHRR Polar Pathfinder extended – APP-x) that includes ice thickness based on the energy budget approach. The CDR has been delivered to the National Centers for Environmental Information (NCEI; formerly NCDC) for distribution and archival. Much work has been done on validating VIIRS and AMSR-2 ice concentration with high-resolution (down to 14-40cm HR). VIIRS and AMSR-2 ice products will be operational soon.

He showed examples of the use of VIIRS and its day-night band for inferring river and sea ice. Work on comparison satellite-derived and reanalysis of cloud amount over the Arctic is underway.

GOES-R will be used in high latitudes (Alaska), and JPSS-1 will provide continuity to S-NPP snow and ice products (formation flying of JPSS-1 and S-NPP planned in the same orbit). GOES-R will be launched in November 2016; JPSS-1 is now scheduled for September 2017. There are recent AMSR-2-based ice motion results, and derivation of sea ice leads and width from MODIS, including statistics. There is renewed interest in leads in sea ice.

**ISRO**

Raj Kumar showed ISRO current and future missions for Earth Observations in GEO, LEO, and other orbits for land, water, and agriculture applications. He showed a list of sensors contributing to cryospheric studies, including IRS, Resourcesat, Cartosat, INSAT-3D/3DR, RISAT. He showed sea ice maps and trends derived from scatterometry and passive microwave, sea-ice thickness results from SARAL/AltiKa; surface melt in Antarctica based on scatterometry; Himalayan glacier inventory covering 35000 glaciers, using IRS LISS data. There are few changes in glacier extent seen in the Karakoram area. He also showed some results on ice velocity. A Himalayan glacier inventory (http://vedas.sac.gov.in) has been developed – data have not yet been provided to GLIMS.

He showed some activities of measuring atmospheric properties in Antarctica.

He showed an overview of ongoing and planned activities in the cryosphere, and availability of satellite datasets. MOSDAC (http://www.mosdac.gov.in/) is a portal for meteorological and ocean satellite data and some derived nowcasts and forecasts. The 30m DEM is available from Bhuvan (bhuvan.nrsc.gov.in) based on Cartosat.

A Ku-band scatterometer will be needed to discriminate first-year from multi-year sea ice. More discussion is needed how LISS and Resourcesat data can elucidate on the Third Pole.

### 9.3 Key Gaps and Mitigation Plan

Discussion of this item was deferred to agenda item 13.

For the technical visit, participants enjoyed a tour of the ESTEC Spacecraft Integration and Testing Facility, where the Sentinel-2B satellite was undergoing final testing prior to its scheduled March 2017 launch.

## 10. KEYNOTE PRESENTATION 3: Polar Regions and Cryosphere Monitoring from Space: Future Outlook

Pierluigi Silvestrin (ESA) presented the status of bringing current ESA Earth Explorer science missions and other research missions into an operational (Copernicus) framework. The basis is established from results of a workshop on polar and cryospheric user requirements organized by

the European Commission earlier this year. This aims at defining the evolution of the Copernicus programme, with a view to a possible expansion of services, and additional capabilities. The next generation (horizon 2030+) looks at enhanced continuity of observations of Copernicus Space Component and new capabilities to meet user requirements. A tentative ordering of mission concepts has been made starting in ~2025, including $CO_2$ fossil emissions monitoring, polar ice and ocean topography using interferometric SAR altimetry, polar ice imaging, low frequency PM, and others. Only a subset of the concepts can be realized.

Options for enhancement build upon each other. It was noted that there is a gap in higher resolution MW radiometry. A SMOS follow-on is being considered, given its proven value for science and a broad range of applications. The SMOS and CryoSat-2 combined product has value since their respective error characteristics are complementary for thin and thick ice conditions. Other experimental products are soil freeze/thaw status, snow density, etc. Studies are underway to investigate how these products could be improved.

For the polar atmosphere, the Polaris Hosted Arctic Imager (HAI) is one of the concepts studied. WMO identified an HEO mission as priority gap for 2025. An imager payload like SEVIRI on MSG (12 channels, 3km resolution, 15min repeat cycle) would be hosted on a satellite designed primarily for telecommunications. The high latitude observing requirements and concept are being refined together with EUMETSAT.

The Polaris “Polar Train” L-band concept would be a multi-frequency, near-simultaneous L+C (or L+X)-band SAR, as is crucial for polar applications like navigation safety. The concept is strongly operationally oriented and considers context (R-2, S-1 etc.). The goal is automated year-round high-resolution NRT (daily) ice charting.

For gravimetry, a proposed concept could consist of a 2x2 satellite constellation operated together by Europe and the U.S., to make progress in trading spatial and temporal resolution, while measuring the time-varying gravity field.

A passive microwave sensor to derive snow water equivalent (SWE) is also being considered, however, a technical solution is yet pending.

There is funding identified for preparatory studies in the context of the ESA Earth Observation Envelope Programme.

WMO is working on a Vision for the space-based constellation in 2040, based on anticipated user needs.

## 11. COMMUNICATIONS

### 11.1 Update on recent contributions [DOC]

Communications on websites and publications are generated by PSTG members on a regular basis. Regarding the ice sheets velocity map, a joint coordinated press release was organized. DLR published achievements of PSTG in a popular science journal.

Should more joint communication efforts be organized, for example on:

- (Consistent) Closure of the “polar gap”
- Monitoring the WAIS / Larsen ice shelf
- Other achievements that would not have happened otherwise?

### 11.2 What qualifies a PSTG accomplishment?

The group discussed what efforts could be qualified as a PSTG accomplishment, as opposed to a PSTG contribution or commitment. The group agreed that these can be qualified as results that could not have been accomplished without a combined efforts of other agencies.

The pan-Arctic SAR coverage may not be a scientific end in itself, but constitutes an accomplishment, given the combined efforts of CSA (RADARSAT-2), ESA (Sentinel-1A/B) and ASI (CSK).

The assembly and value of the identified requirements within PSTG should be acknowledged; they have catalyzed action within individual agencies and lead to such accomplishments.

### 11.3 Communicating the value of PSTG

Agencies should provide accomplishments to WMO Secretariat, for publication through the various WMO communication channels (websites, press releases, Facebook, Twitter etc.). PSTG members should identify contacts in their agencies to coordinate messages, and to amplify the value of these messages. A suggested phrase used for instance in the case of SAR is "The combined XX, YY and ZZ SAR data sets used in this paper/publication/report were acquired through the inter-agency acquisition plans developed by the WMO Polar Space Task Group SAR Coordination Working Group."

**ACTION 6.11: Agencies or Science Leads to propose achievements facilitated by PSTG, for communication through WMO channels, and through their own communication offices.**

The Chair called upon PSTG members and Science Leads to review the table of contributions and achievements.

**ACTION 6.12: PSTG members and Science Leads to review the Table of Contributions and Achievements. By 31 Jan 2017**

Participants provided an update on selected meetings and events:

- DLR TanDEM-X science conference: Oberpfaffenhofen, 17-20 October 2016
- North American CryoSat science meeting, Banff, Alberta, Canada: 20-24 March 2017
- EarSEL Land Ice & Snow workshop Bern, Switzerland: 7-9 February 2017.
- Arctic observing summit Prague, Czech Republic: 31 March – 2 April 2017

## 12. REPORTING

### 12.1 EC-PHORS

The next meeting of the WMO Executive Council Panel of Experts on Polar and High-mountain Observations, Research and Services (EC-PHORS) will be held in Ushuaia, Argentina, from 21-24 March 2017. The agenda has not been discussed in detail. The meeting will focus on the Panel's Terms of Reference and address WMO 17$^{th}$ Congress and 68$^{th}$ Executive Council decisions related to Polar and High-mountain activities. These include providing guidance to the GCW, discussing establishment of Polar Regional Climate Centres, International Polar Partnership Initiative (IPPI), GIPPS (Global(ly) Integrated Polar Prediction System), and YOPP.

**ACTION 6.13: Secretariat to amend the PSTG interface diagram in the Strategic Plan, and remove the list of Space agencies (these are referred to in an Annex to the Plan).**

The Group highlighted that maintaining the links to CEOS through reporting to SIT is considered important.

### 12.2 CGMS-44 and Actions relevant to PSTG

At CGMS-44, the possibility of creating a CEOS Virtual Constellation for Sea Ice was raised:
"Consistent with the discussions held at CGMS-44, CGMS Secretariat to liaise with CEOS SIT Chair on the suggestion that CEOS develop a Virtual Constellation for Sea Ice - following its established process for this purpose, and in coordination with the activities of the WMO PSTG. An initial discussion will be held at 2016 CEOS SIT Technical Workshop (September 2016)."

The topic was triggered by concerns about the continuity in the passive MW record at the right frequency and resolution, to maintain the sea ice climate data record. Continuity of multi-frequency MW continuity such as from AMSR-2 on GCOM-W, and scatterometry, are currently not sufficiently supported. More in detail:

- Today DMSP SSM/I F19 is dead - with F20 unlikely to ever be launched, whilst both GCOM-W1 AMSR-2 and HY-2 MWRI (ongoing) and MetOp MWI (2022?) have different channels. Intercalibration/bias estimation and continuity in the data record are not assured.

- For scatterometers, whilst C-band continuity is assured by ASCAT and SCA, HY-2 Ku-band scatterometer does not produce ice images, and the L1b data (as far as I am aware is not available). A single scatterometer does not provide the daily global, or bipolar coverage - which is needed.

- there has been no continuity in sea ice thickness, as illustrated by the gaps in sea ice thickness record.

- there is no continuity assured beyond CryoSat and ICESat-2, at latitudes beyond 82N (i.e. Sentinel-3 inclination).

PSTG noted the effort required to put a new CEOS Virtual Constellation in place, including reporting duties. M. Drinkwater noted that such an initiative required a champion agency and drivers that would see the benefits of a VC for sea ice. PSTG could assist the effort in collecting information about current and future mission capabilities for sea ice.

A formal relationship of PSTG with CEOS was sought in 2013. At the time, CEOS recognized that PSTG was a well-functioning group and appreciated regular reports on PSTG activities.

### 12.3 CEOS SIT

Y. Crevier will use the results of PSTG-6 and SAR-CWG-5 to inform CEOS SIT.

## 13. SUMMARY OF PSTG-6 ACTIONS

Participants reviewed the Actions identified during the meeting. The final list is included in Appendix III.

The Chair called upon PSTG members and Science Leads to review the table of contributions and achievements.

## 14. PLANS FOR NEXT MEETING

Interest in hosting the next meeting was expressed by:

- ENVEO AG, Innsbruck, Austria
- University of Irvine or Scripps, CA, USA
- ISRO, Ahmedabad, India (Nov-Feb timeframe)

WMO Geneva, Switzerland, is an option as well.

November-December timeframe is preferable.

Participants showed equal preference for Innsbruck, Austria, and Ahmedabad, India, tentatively in the week of 20 November 2017.

## 15. ANY OTHER BUSINESS

M. Drinkwater thanked the Group for having participated in unprecedented numbers. The meeting was highly successful in engaging space agencies and the science communities. He expressed his expectation that interest in understanding and prediction change in Polar Regions and the cryosphere, including the Third Pole, will only increase in the future.

## 16. ADJOURN MEETING

The meeting adjourned at 16.00 on Thursday 15 September 2016.

# LIST OF PARTICIPANTS

## Members of PSTG

Fabrizio Battazza
ASI
Email : fabrizio.battazza@asi.it

Yves Crevier
CSA
Email: yves.crevier@asc-csa.gc.ca

Craig Dobson
NASA
Email: craig.dobson@nasa.gov

Mark Drinkwater (Chair)
ESA ESTEC
Email: mark.drinkwater@esa.int

Dana Floricioiu
DLR
Email: dana.floricioiu@dlr.de

Manfred Gottwald
DLR
Email: manfred.gottwald@dlr.de

Jeff Key (Vice-Chair and EC-PORS)
NOAA NESDIS
Email: jeff.key@noaa.gov

Anne Lifermann
CNES
Email : anne.lifermann@cnes.fr

Raj Kumar
ISRO
Email : rksharma@sac.isro.gov.in

Marc Thibeault
CONAE
Email: marc.thibeault@conae.gov.ar

## Invited Participants

Annett Bartsch
ZAMG, Austria
Email: annett.bartsch@zamg.ac.at

Stephen Howell
Environment and Climate Change Canada
Email: stephen.howell@canada.ca

Thomas Jung
Alfred Wegener Institute for Polar Research (AWI), Germany
Email: Thomas.jung@awi.de

Thomas Nagler
Enveo AG, Austria
Email: thomas.nagler@enveo.at

Pierre Potin
ESA
Email: pierre.potin@esa.int

Pierluigi Silvestrin
ESA
Email: Pierluigi.Silvestrin@esa.int

Markus Rex
Alfred Wegener Institute for Polar Research (AWI), Germany
Email : markus.rex@awi.de

Bernd Scheuchl
University of California, Irvine, USA
Email: bscheuch@uci.edu

David Small
University of Zurich, Remote Sensing Laboratories, Switzerland
Email: david.small@geo.uzh.ch

Gunnar Spreen
University of Bremen, Germany
Email: gunnar.spreen@uni-bremen.de

**Other Participants**

Don Ball, DB Geoservices Inc., Canada
Email: don.ball@rogers.com

**Secretariat**

Stephan Bojinski
World Meteorological Organization
Email: sbojinski@wmo.int
Tel: +41 22 730 8319

APPENDIX II

**AGENDA AND WORK SCHEDULE**

Room: Ba024

**Day 1 (13 September, pm)**

13:00 – 13:15

**1. Welcome and Opening Remarks**
ESA Welcome
Local host information / logistics

13:15 – 13:45

**2. Introductions to Participants**

13:45 – 14:00

**3. Approval of Agenda** (M. Drinkwater)

14:00 – 14:40

**4. Keynote Presentation 1: S-1 Constellation and Applications (ESA, P. Potin)**

14:40 – 15:10

**5. Review of Action Items** (Secretariat)

15:10 – 15:30 **Health Break**

15:30 – 17:55 (145')

**6. Addressing Strategic Initiatives**

6.1 Global Cryosphere Watch
6.1.1 CryoNet In-situ Network (J. Key) (15')
6.1.2 Product Validation / Intercomparisons (M. Drinkwater) (20')
6.1.3 Key Contributions: SnowWatch, SnowPEx; SnowEx [DOC], .. (All) (20')
6.1.4 Agency Inventory on In-situ Snow Activities (All) (20')
6.1.5 Discussion: (15')
- New intercomparison initiatives: e.g. sea ice thickness? (All)
- GCW-PSTG linkages (Y. Crevier/All)

6.2 Year of Polar Prediction 2017-2019 (YOPP) (T. Jung) (20') [DOC]
- Status after YOPP planning meeting 5-7 Sep 2016

6.3 MOSAiC: Multidisciplinary drifting Observatory for the Study of Arctic Climate (2019 – 2020) (M. Rex / G. Spreen) (25') [DOC]
- Discussion of potential contributions (All) (10')

18:00 ESA-hosted Aperitif (Aj020 – Lunch Corner)

**Day 2 (14 September): 09:00 start (Room: Ba024)**

09:00 – 09:20 Official Welcome (ESA, Director of Earth Observation Programmes)

09:20 – 10:30

**6. Addressing Strategic Initiatives (cont'd)**

6.4 GEO Cold Regions Initiative (J. Key) (20') [DOC]

6.5 Polar Reanalyses (C. Dobson/All) (30') [DOC]

6.6 US White House Arctic Science Ministerial (M. Drinkwater) (20') [DOC]

10:30 – 11:15

**7. PSTG SAR-Coordination Working Group: Report from 5th Meeting (Y. Crevier)**

11:15 – 11:30 **Health Break**

11:30 – 12:15

**8. Keynote Presentation 2: CryoSat: ESA's Ice Mission Achievements (ESA, M. Drinkwater)**

12:30 – 13:30 **Tray Lunch (*in lunch corner Aj020/Aj021)**

13:30 – 17:30

**9. Status of Agency Responses to PSTG Strategic Plan**

9.1 Evolution in user requirements: Ice Sheets, Permafrost, Snow, Floating Ice (Science Leads) (60')

14:30 – 14:45 **Health Break**

9.2 Update to Table of Commitments (Member Agencies) (140')
- Evolution of commitments since Oct. 2015 (All)
- New Planned Activities/Products/Missions/Airborne Campaigns (All)
- Specific new Contributions to Strategic Initiatives (All)

9.3 Key Gaps and Mitigation Plan (Discussion: All) (40')

17:30 – 19:00 Tour: ESTEC Spacecraft Integration and Testing Facility (including Sentinel-2B)

19:30 - Informal No-Host Dinner (Noordwijk, Restaurant TBC)

**Day 3 (15 September): 09:00 start (Room: Ba024)**

09:00 – 11:00

**9. Status of Agency Responses to PSTG Strategic Plan (cont'd)**

11:00 – 11:15 **Health Break**

11:15 – 12:00

**10. Keynote Presentation 3: Polar Regions and Cryosphere Monitoring from Space: Future Outlook (ESA, P. Silvestrin)**

12:00 – 13:00 **Lunch in ESTEC Cafeteria**

13:00 – 14:00

**11. Communications**

11.1 Update on recent contributions (All) [DOC]

11.2 What qualifies a PSTG accomplishment? (All) [URL]

11.3 Communicating the value of PSTG
- PSTG SAR CWG Data Compendium (Y. Crevier) [URL]
- Forthcoming Meeting Opportunities (All) [URL]

14:00 – 15:30

**12. Reporting**

12.1 EC-PHORS (Secretariat) (20')

12.2 CGMS-44 (40') [DOC]
- Actions relevant to PSTG (M.Drinkwater)
- Discussion (All)

12.3 CEOS SIT (Y. Crevier/All) (30')

15:30 – 16:15

**13. Summary of PSTG-6 Actions** (All)

16:15 – 16:45

**14. Plans for next meeting** (All)

**15. Any other business** (All)

17:30

**16. Adjourn Meeting**

**Reference documents**

Meeting URL: http://www.wmo.int/pages/prog/sat/meetings/PSTG-6.php

APPENDIX III

## ACTION ITEMS FOR PSTG

| I. Actions from PSTG-6 | |
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| ACTION 6.1: P. Potin to investigate whether S-1B data acquired over the NH summer 2016 could be made available to the community. | OPEN. |
| ACTION 6.2: M. Drinkwater and J. Key to formulate a PSTG position on support to the intercomparison of sea-ice thickness products, for communication at the ESA Cryosphere science meeting in March 2017. | OPEN. ESA-NASA bilateral discussion initiated about a potential Sea Ice Mass Balance Intercomparison Exercise (SIMBIE) - to complement the ice sheet effort. This would be a way of both confronting the models during YOPP, and a way to coordinate the satellite/airborne sea ice thickness product intercomparisons. |
| ACTION 6.3: T. Jung on behalf of YOPP to initiate a list of parameters that should be provided for by operational satellite products in support of YOPP; PSTG to iterate with YOPP based on the initial list. | OPEN. |
| ACTION 6.4: Y. Crevier to introduce MOSAiC responsibles to the IICWG contact John Falkingham regarding tactical ice charting support to the campaign. | DONE. |
| ACTION 6.5: A. Lifermann and S. Hosford to investigate with MOSAiC responsibles the details of requirements of the experiment for high-resolution optical data from CNES. | OPEN. |
| ACTION 6.6: Add MOSAiC status and PSTG support to the agenda of the PSTG-7 meeting. | OPEN. |
| ACTION 6.7: M. Gottwald to find out the instrument and operational planning of the HALO in support of MOSAiC and to get in touch with Manfred Wendisch, DFG Coordinator of HALO. | OPEN. |
| ACTION 6.8: PSTG to endorse the Terms of Reference of the SAR-CWG. | DONE. |
| ACTION 6.9: USGS to provide a formal response to PSTG on their acquisition campaign over Greenland, Antarctica, and high-mountain glaciers, including details on geolocation details and the DEM used for this purpose. | OPEN. |
| ACTION 6.10: Encourage all science leads to look at the current CONAE SAOCOM acquisition plan and provide feedback to Marc Thibeault, with the understanding that Argentina is the highest priority of the mission, by 31 Jan 2017. | OPEN. |

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| ACTION 6.11: Agencies or Science Leads to propose achievements facilitated by PSTG, for communication through WMO channels, and through their own communication offices. | OPEN. |
| ACTION 6.12: PSTG members and Science Leads to review the Table of Contributions and Achievements. By 31 Jan 2017 | OPEN. |
| ACTION 6.13: Secretariat to amend the PSTG interface diagram in the Strategic Plan, and remove the list of Space agencies (these are referred to in an Annex to the Plan). | OPEN. |
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| **II. Other Actions, and Status** | |
| ACTION 5.1: Personalized letter be sent by the WMO Secretary- General to the individual space agencies focusing on benefits, achievements, individual contributions of each agency since 16th World Meteorological Congress, and including a proposal to extend their mandate for another 4-year period to support the new WMO Priority of Polar and High Mountain Regions | DONE; 16 letters (to 13 existing members and 3 prospective ones – CONAE, ISRO, KMA); 10 responses: 2 new members (CONAE, ISRO), no response from KMA, 8 members confirmed; no response from 5 members Total membership August 2016: 15 agencies http://www.wmo.int/pages/prog/sat/documents/PSTG_Members.pdf |
| ACTION 5.2: B. Scheuchl to prepare a draft update of the Requirements Document. Deadline: mid-2016. | OPEN Will be sent out for community input; to finalize by end 2016 |
| ACTION 5.3: Frank Paul to provide User Requirement Document for Glaciers. The Secretariat to place User Requirement Document for Glaciers on PSTG webpage | OPEN Draft provided to PSTG-6; to be sent out for community input, formulated as a community statement not limited to ESA CCI; to finalize by end 2016 |
| ACTION 5.4: PSTG to formulate a list of operational products that PSTG believe are suitable to YOPP and this should be complemented by research products. This requires that space agencies make their commitments and provide a table of proposed products for YOPP; this could be an appendix to the YOPP Implementation Plan. | SUPERSEDED BY NEW ACTION 6.3 ~~OPEN Chair to develop a format to collect information on products (product, source, URL); agencies to fill out based on information on YOPP; YOPP community can be made aware of this compilation; YOPP needs identified at past meetings should be used as a starting point, to limit the scope of this compilation.~~ |
| ACTION 5.5: T. Jung to provide list of SAT products that are endorsed by national PIs | SUPERSEDED BY NEW ACTION 6.3 |
| ACTION 5.6: To add soil moisture in the Strategic Priorities 2015-2018 for Polar Prediction. | DONE; included in the Strategic Plan, in relation to permafrost needs |
| ACTION 5.7: Annett Bartsch to provide CNES with locations of cold spots and coastal sites for complementary HR optical data. | OPEN Subset of cold spots identified; publication to be determined; by end of 2016 ; details need to be determined on what data types are needed |

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| ACTION 5.8: PSTG members to provide an inventory of in-situ activities supporting technology advancement, algorithm development or airborne concepts, or in-situ activities for preparation of future missions addressing global snow and to stimulate work on in-situ activities and engagements of space agencies with in-situ partners. | OPEN; to be addressed under agenda item 6.1.4 |
| ACTION 5.9: CSA to provide a concept study for next 18 months on active radar for complete northern hemisphere coverage every two to three days for SWE. Science advisory team, Chris Derksen, should preparation follow-up ideas. NASA should conduct activities to support an instrument proposal | OPEN; Presentation on concept study by Chris Derksen available to PSTG for information |
| ACTION 5.10: Members of PSTG to refine agencies' contributions and commitments, see Annex IV. | SUPERSEDED BY NEW ACTION 6.12 |
| ACTION 5.11: CSA to provide text regarding a reference to SAR CWG on PSTG interfaces to be included in the Strategic Plan | DONE |
| ACTION 5.12: M. Drinkwater to seek membership from CONAE | DONE (Action 5.1) |
| ACTION 5.13: B. Scheuchl to contact P. Rosen to seek ISRO point of contact via NASA-India NISAR connection | DONE (Action 5.1) |
| ACTION 4.13: USGS to investigate how PSTG could interact with the Landsat Science Team in responding the user requirements presented at PSTG-4, in particular the permafrost-related needs. By 10 Jan 2014 | OPEN<br>Larry Hothem (USGS) investigating case studies showing Landsat-7/8 contributions to polar research, and plans for using Landsat-9 Landsat data are important for ice sheet requirements |
| ACTION 4.6: PSTG to nominate a focal point for the planning of YOPP and its planning summit in 2015, in order to refine the satellite-related data requirements. By 1 Dec 2014 | DONE. Pablo Clemente-Colón is focal point. |
| ACTION 4.14: USGS to nominate a new representative to PSTG, by sending a letter to WMO. By: 31 Dec 2014 | DONE. USGS confirmed that Larry Hothem is representative (see Action 5.1) |