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Workshop Report: 1st International Arctic and High-Latitude Products Validation and Evolution Workshop, Ottawa, Canada, 12-13 November 2014

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Workshop Report: 1st International Arctic and High-Latitude Products Validation and Evolution Workshop, Ottawa, Canada, 12-13 November 2014.

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1 SUMMARY

In response to the strategic priorities common to all High-Latitude and Arctic Nations, most of which are also Member States of the European Space Agency (ESA), ESA with LOOKNorth and the Canadian Space Agency (CSA) organized a Workshop on Arctic Products Validation and Evolution (APVE) in Ottawa, Canada, 12-13 November 2014.

The objectives of this first Arctic and high-latitude Products Validation and Evolution Workshop – APVE, were to foster the development, assessment and improvement (evolution) of the broad spectrum of capabilities offered by current space-based Earth Observation technologies to address high-latitude and Arctic stakeholders information needs addressing National, Regional, and International interests. Participants were provided with the opportunity to present their latest research results, including the evolution of products and algorithms, the development of validation and inter-comparison methodologies, as well as new EO data usages.

The APVE participants were asked to specifically address high-latitude and Arctic EO algorithm and validation issues, primarily for optical imaging, but also from radar, passive microwave sensors, and mixed/fusion retrievals. The workshop agenda (see Appendix A) consisted of 37 presentations with 70 participants from industry, government agencies, academia and national centres of excellence from Canada, US and Europe, structured into the following five themes:

1. User Perspectives Session
2. Land Session
3. Lake/Coastal Session
4. Cryosphere Session
5. Atmosphere Session

All presentations are available online at the ESA Cal/Val Portal (http://calvalportal.ceos.org/events/ave-workshop/presentations). The list of participants is given in Appendix B. The list of acronyms and abbreviations is given in Appendix C.

1.1 SESSION HIGHLIGHTS AND RECOMMENDATIONS

The key recommendations from each session are summarised in the tables below.

User's perspective

Reference	Summary
User's perspective session	• **Importance of remote sensing for northern commercial activities** o Significant potential for growth of EO-based services. o To capitalize on this, socio-economic and environmental complexities of the Arctic must be addressed. ▪ Arctic and high latitude observational data. o Research output feeds into decision processes of national operational departments. o Transition to operational application requires on-going communication of research output (especially reliability). o Free data for users is important, as is reliability of access, particularly for operational services o Level 1 data are needed by some developers & users, other have limited capacity to use primary data (L1), they need large/regional data sets and products (L3) o It is important for the users to understand the limitation of the data/products (i.e. confidence, consistency). • **Ocean colour remote sensing in the Arctic** o Significant progress in quantifying Arctic water constituents through recent and on-going research. o More in-situ data is required to facilitate algorithm extension and portability across regions. ▪ Resilience of Arctic regions to climate change. o Validating results through involvement of local stakeholders is vital to ensure accuracy and relevance. o Best possible products for input into the analysis needs to be effectively communicated. o It is important to involve the experts in instrument design, i.e. new missions concepts for coastal/oceans.

Land session

Reference	Summary
Land	**General:** • Multi-temporal analysis shown as important in all presentations. • Important Intellectual Properties issues exist, e.g. industrial simulators for sensor definitions. • The Landsat images archives are very important for multiple users (ex: land trend disturbances & changes: 1985-2012) • CSA expressed interest in continuation of CCRS MODIS large scale (including circumpolar Arctic). • Canadian hyperspectral mission warranted. • Include natural resources exploitation applications in the future. **Validation and evolution:** • In the Arctic there are few control/validation data for biophysical parameters, thus it is hard to perform extensive EO product validation. • EO remote sensing data and information are key components of CHARS and ABoVE development. • CHARS & ABoVE (Canada/NASA): collaboration, coordination should be a priority to improve efficiency and reduce duplication. • EO remote sensing data and information are key components of CHARS and ABoVE development. **Simulations:** • Simulators may not be sufficiently robust to be reliable for sensor definition. • Signal to Noise (S/N) requirements for sensors would be useful to run simulations.

Cryosphere session

Reference	Summary
Cryosphere	**General:** • **Significant advances** in quality of products at national, regional and global scale using more sophisticated algorithms and incorporation of in-situ data. • Requirement for **near real-time access** to satellite and in-situ data; data needs to be freely available and accessible, hence efficient data exchange protocols are essential –interoperable data centers/portals. • SWE still at coarse scale and **deep snow and mountain regions** not resolved – how to address this weakness? • There is a need for moderate to high resolution (~250 – 50 m) SWE products. Current satellite missions are not suitable to provide this information – need a suitable sensor in space developed for monitoring SWE at high resolution. • **Uncertainty** - don't know the range of SWE within a grid cell or associated

Reference	Summary
	uncertainty - need further discussion on issue of uncertainty for satellite and in-situ products. • Historically, **lack of assessment among products – SnowPEx** is a response to this need for snow extent and SWE. • Soil moisture/ Freeze-thaw (SMAP launch planned for 29 January 2015) o **Lack** of soil, vegetation and soil moisture ground data for validation to assess freeze-thaw. o Need for **integrated evaluation/application** of land surface Freeze/Thaw and snow products. **Integrated reference sites for algorithm development and product Cal/Val:** • **Build on successful in-situ programs** reference measurement program) - demonstrated how Sodankyla offers an ideal reference site for integrated studies of cryosphere, atmosphere and ecosystems, providing an excellent example of "**integrated environmental monitoring**" that can address Earth system science more holistically. • Satellite and modeling validation – need to learn from the protocols developed at Sodankyla for validation using ground, airborne and satellite – what works, what doesn't - **scaling** is an important issue for intercomparisons and validation. • **Sustained funding** for continuing operation of reference sites (space agencies, modeling groups, polar institutes, research council?) **Intercomparisons:** • **Essential** for both ground and satellite product measurements – e.g. intercomparison of ground based samplers (density, snow depth, precipitation). • **Metadata –** Report it! Use it! • **SnowPEx:** o Ongoing major international **community project.** o **Commitment of 15 SE + 5 SWE products** – different sensors, different algorithms, different resolutions – a technical challenge. o SWE: gap is mountains, deep snowpacks. o Quality / Uncertainty of the **reference data** is a big issue – in-situ (scale-issues). o HR Optical sensors: uncertainty in SE retrieval. o Developing protocols for validation of SE and SWE with Landsat and in-situ and intercomparison of products. o **Funding for ongoing** intercomparisons is essential – who is responsible for this? • Dataset intercomparisons like SnowPEx are underway - are more intercomparisons for other variables (i.e. sea ice concentration) needed? *Note: The observational community should adopt an 'ensemble' approach as used in climate modeling. A single climate model is never run just once. The strength of activities like CMIP5 lies in the use of multiple members from multiple models. The observational community (at least for snow and sea ice) tends towards using*

Reference	Summary
	individual 'best' datasets, instead of determining inter-dataset spread and how to use independent datasets to quantify uncertainty. SnowPEx is a major step in the right direction in this regard. • Comprehensive Cal/Val sites are needed for a wide range of activities. Enhancement of current sites requires international multi-disciplinary collaboration and sustained funding. A multi-disciplinary workshop focused on this issue would be useful. • Combining sources of imagery are yielding new insights in variability and trends in the cryosphere (i.e. combination of optical and passive microwave data for sea ice concentration). • Novel datasets for validating sea ice motion and volume flux are possible from upward looking sonar, but data processing and scaling challenges are significant. • There is strong user interest in DInSAR deformation information for northern infrastructure. DInSAR stacking provides sufficient signal to see cumulative seasonal changes. Multiple techniques for validation are available, but are largely qualitative. • Polar View provides a wide range of products to a diverse user community. Validation activities for these products are typically conducted within the network via the users.

Lake and Coastal session

Reference	Summary
Lake and Coastal	The session provided rationale and an overview of operational and research products related to Arctic lake ice: • Lake ice products covered include ice concentration (fraction), ice areal extent (and open water area, freeze-up and break-up/ice cover duration, ice thickness, areal extent of floating and grounded ice (shallow lakes), snow/ice albedo (broadband), and snow/ice surface temperature. • A summary and outlook (list of recommendations on the way forward) was given at the end of the talk (see presentation for details). • The lack of sufficient funding was identified as a major impediment to further advancement (development and evaluation of products) in university lab during the question period. • Covered the development and validation/evaluation of land surface and lake surface temperature products generated from MODIS and AATSR data at the University of Waterloo. • Improvement of the AATSR level 2 product currently distributed by ESA was also presented. • Areas of applications that need these products were also identified (e.g. climate monitoring, evaluation of lake and climate models, assimilation/integration in permafrost and NWP models). • More frequent observations from upcoming Sentinel-3 SLSTR (1 km res.) and GCOM-C1 SGLI (500 m res.) were identified to be of great interest for lake and

	permafrost research. • Provided description of a study that used thousands of SAR (RADARSAT-1/2 and ASAR Wide Swath) and Landsat 4/7 to document changes in ice cover conditions on 11 lakes of the Canadian Arctic Archipelago (CAA). • K-means was used to segment the SAR images complemented with Landsat images during cloud-free conditions. • Results presented showed that the lakes are experiencing generally earlier melt onset, earlier summer ice minimum and earlier break-up from 1997-2011. • The relative coarse spatial resolution of the SAR images (100-150 m) was found to be a limiting factor for analysis over smaller lakes in the CAA. • The temporal resolution, sometimes 5 days between acquisitions (1-2 days would be ideal), was also identified as a limitation.

Atmosphere session

Reference	Summary
Atmosphere	**Validation is a long-term process:** • Need to understand how to validate for the life of one mission and through many missions. • Long-term support – financial and institutional – is essential. **Space missions:** • Many current missions are beyond their planned lifetime. Space agencies may shut them down even if they still work • New missions are planned, but fewer • Space and ground-based measurements need to be understood as a single integrated system, e.g. OCO-2 and TCCON **Space measurements:** • Composition: o Ozone still important because of the Montreal protocol. o GHGs have more emphasis recently – CO2 and methane are especially relevant to the Arctic. o Pollutants are important for air quality – becoming important in the Arctic. • Aerosols and Clouds o Issues with accuracy and frequency of measurement and extent of ground-based measurements. **Ground-based Measurement Sites:** • Location is very important. • If Arctic capacity is lost, it is very expensive to resuscitate it later.

	Links to Models: • Use of models to integrate measurements with (slightly) different characteristics. • Measurements should challenge the models to do better. • Assimilation of measurements into models is an emerging trend. **New Instruments:** • Instrumentation development must occur or we will have no new measurement techniques. **New Space Missions:** • There are new mission proposals that could offer significant improvements in coverage for the Arctic, e.g. highly elliptical orbits.

2 PROCEEDINGS

The main points arising from the presentations and discussions are summarised below. Recommendations are identified when they arose in the meeting, and collected in Table 1 in section 1.1.

Day 1: 12 November 2014:

Introduction

Yves Crevier (CSA, Canada), Bojan Bojkov (ESA, Italy) and Guy Aubé (CSA, Canada) introduced the EO challenges, products and services for the Arctic and High-Latitudes and the Workshop objectives.

Yves Crevier (CSA, Canada) introduced the objectives of the APVE WS.
He first introduced the APVE WS in the context of a similar initiative - MORSE, which occurred 6 years ago.

Outcomes of MORSE:

- Supported the development of a statement of user requirements - still meaningful and purposeful.
- Provided a focus on the monitoring of the Arctic with an aim to enhance the use of Satellite based data for the development of practical and innovative applications.
- Several projects were supported with key Arctic stakeholders.

Next steps, which is the APVE WS:

- Addresses the downstream segments of the EO value chain - development, assessment and improvement of the broad spectrum of capabilities offered by Space- based Earth observation technologies.
- Covers issues related to a) the definition of algorithms, b) the validation, accuracy and uncertainties assessment of information products, c) the assimilation of products in models for decision making, d) *in-situ* data networks, e) inventories of scientific activities that contribute to the operational adoption of satellite-based product, f) the user perspective in the north, etc.

Overview of the participation of the APVE WS:

- 70 participants (see Annex A, including the Organization Committee)
- Representation from Canada, US and Europe:
    - Industry: Value added, products and services, consulting, data providers, NGOs
    - Government: Science, policy, enablers, end-users, data providers, products and services.
    - University: Canadian, foreign, all sectors / workshop themes.

Context of the APVE for Canada:

- APVE is relevant to the objectives of Canada's policy framework in the Arctic, the Canada New Space Policy Framework, and the Canadian Space Agency activities related to terrestrial monitoring in Canada.

Mutual responsibilities under the APVE WS:

- Provide end-users with exploitable EO-based derived products:

- Increase our collective efforts on the downstream segment of the EO Value chain.
- Focus our attention on the generation of derived information that is useful, relevant, reliable, sustainable and cost-efficient for the end-users.
- Ensure that derived products and services are accessible and assimilable.

- Ensure increased awareness on the use of EO satellite data and products.
- Assume openness for - and stimulate a multi-sectorial and multi-level collaboration framework for improved usage satellite-based data and derived information products and services.
- Think about APVE as an initial stage for the conceptualization of a thematic framework focused on the development and implementation of a service application platform requiring the involvement the of the public, private and academic sectors to serve public needs in the Arctic.

He concluded with an overview of the programme (http://calvalportal.ceos.org/events/ave-workshop/presentations).

Bojan Bojkov (ESA, Italy) presented a summary of the EO challenges in High-Latitudes and the workshop objectives.

He opened his talk with a key question: **Why a workshop on Arctic and High-Latitude product evolution and validation?**

- **Motivations for this workshop:**
  - High-Latitudes areas and the Arctic are sparsely populated, extremely remote, with a challenging and harsh environment.
  - These sensitive areas are undergoing tremendous changes – human access, exploration, environmental changes, etc.
  - These areas are impacted by (human activity at) Mid-Latitudes through long-range transport.
  - All parameters are being affected throughout the Arctic and High-Latitudes: Snow, Land Cover, Methane, DEM, water bodies, soil moisture, land surface temperature, freeze/thawing, therefore must be addressed for further Products Validation and Evolution.
- **Challenges:**
  - Earth Observation has a tremendous potential for High-Latitudes by: *Monitoring sea ice change; Monitoring hemispheric temperature change*, *Identifying land cover changes and permafrost change*; *Help estimate river runoff (with models) but, the High-Latitudes are challenging for EO, especially for optical type measurements: Extended polar night and periods with (very) high solar zenith angles*; *High cloud occurrences (and all the related problems of layering, shadows, snow, etc.)* and the *difficult environment* for *validation (and few validation data).*
- **Expectations of the APVE WS:**
  - **To clearly identify the areas for improvement for existing algorithms and products in High-Latitude and the Arctic** – this includes new approaches, improved auxiliary information (RT, met data), **and additional products.**
  - **To formulate requirements for validation of High-Latitude and Arctic products** – including proposed improvements to the ground-based observation networks, such as WMO/GCW, National sites, Sustained Arctic Observing Networks (SAONs), or the creation/addition of new measurement capabilities.

- **Define key EO reference sites/areas targeting specific representativity issues (mountainous areas, coastal zones, climatic variability)** - for example the use of the Province of Quebec for snow products due to its geographic and climatic variability (recommendation from the SnowPEX ISSPI WS) or planning of targeted field/aircraft campaigns.

Guy Aubé (CSA, Canada) presented the downstream EO products and services for the Arctic: CSA Support for Canadian Governmental Organizations, Industry & Academia.

He first introduced the challenges as mentioned by Yves Crevier (CSA, Canada) and Bojan Bojkov (ESA, Italy) and questioned: **How can Earth Observation (EO) technology help?**

- EO sensor systems collect accurate and timely geo-spatial data; data archives.
- Provision of EO-based information products at synoptic (or detailed) spatial and temporal scales for l.
- Example: Improvement of forecasting and enhancing prediction services (land, lake/coastal, cryosphere, atmosphere).

CSA support for EO applications, products and services:

- The EOAU division manages programs and activities that support and promote the development and use of EO technologies, applications, products and services
- Since 2000, EOAU have managed and supported over 250 projects in partnership with the Government of Canada (including the Provinces and Territories), industry and universities (i.e. EOADP, GRIP, SOAR).

Goals:

- Support EO products and services development in Environment, Resource and Land Use Management, and Security and Foreign Policy.
- Increase the use of EO data in public and private sectors.
- Facilitate EO data access and it's integration into operational services and solutions (i.e. benefits).

User perspectives session

The user perspectives session chaired by Thomas Puestow (C-CORE, Canada) includes presentations from Bill Jefferies (LOOKNorth, Canada), Ralf Bennartz (University of Wisconsin) on Behalf of Ulrika Willén (SMHI), James Snider (WWF, Canada) and Marcel Babin (Takuvik, Canada).

Bill Jefferies (LOOKNorth, Canada) presented the growing Importance of remote sensing derived information to Northern commercial activities.

He first introduced LOOKNorth (Leading Operational and Observations for the North) and their mission, then clearly identified the LOOKNorth objectives:

- Identify needs and technology gaps for Northern resource development.
- Develop opportunities for Canadian Small-Medium Enterprises (SME) and researchers by creating the business case and co-funding technology valida3ons as a precursor to long-term implementation.
- Guide research and development (R&D) and technology commercialization where gaps presently exist.
- Enable transfer of relevant technologies from international research to Canada.

- Facilitate information sharing amongst stakeholders in Northern development including industry.

Primary applications:

- Land Oil Spills & Pipeline Leak Detection.
- Land Cover Disturbance.
- Green House Gas Monitoring.
- Water Monitoring.
- Tactical Navigation Support in the North.
- Maritime Awareness in the North.

LOOKNorth impacts:

- **Resource sector returns:**
  - Safer, more cost-effec.ve operations.
  - Increased understanding of environmental impact and optimum mitigation strategies.
  - Go/no-go of projects, capital cost reductions.
- **Small business returns:**
  - Increase in sales and highly qualified people.
  - Strategic inputs to R&D programs.
  - Position Canada as a world leader in the development and application of EO technologies in the resource industry.

Summary:

- Track record of providing positive return on investment and building SME capacity.
- Recognized support to sustainable development in Canada's North.
- Recognized support to Canada's northern communities.
- Seeking to expand portfolio through international co-operation.

Ralf Bennartz (University of Wisconsin) on behalf of Ulrika Willén (SMHI) presented the use of the Arctic and High-Latitude observational data for process studies and model evaluation at the Swedish Meteorological and Hydrological Institute (SMHI).

He introduced the use of EO for the Arctic and High-Latitude for SHMI Research department (Climate Research Rossby Centre, Meteorology, Hydrology, Oceanography, Remote Sensing and Air Quality) with examples then present the RS needs from SHMI.

SMHI Arctic and High-Latitude observations *applicable* (in the context of APVE WS) "Whish List":

- **Meteorology:** Supports PCW and more cloud observations, surface variables for assimilation (soli moisture, temperature, humidity, snow).

James Snider (WWF, Canada) presented Use of remote sensing in WWF's Rapid Assessment of Circum-Arctic Ecosystem Resilience (RACER) tool for conservation planning in a rapidly changing Arctic.

He introduced RACER then summarized the challenges as follow:

High level of correspondence, especially with KBHs:

- Emphasis on: Identifying "Drivers" i.e. key underlying geophysical processes and assessing persistence of key features into the future based on GCM projections.

Problem raised: the ease of the access to data.

Marcel Babin (Takuvik, Canada) presented Ocean color remote sensing for the study of Arctic marine ecosystems: I - Major research initiatives and scientific results.
He summarized the challenges as follow:

- **What impact on carbon fluxes?**
- **What impact on marine ecosystems and their productivity?**

In this context, Takuvik developed new remote sensing algorithms to address:

- Primary Production (PP).
- Dissolved Organic Carbon (DOCt).
- Particulate Organic Carbon (POCt).

Problems and limitations:

- Optical properties of Arctic seawater.
- Photosynthetic properties of phytoplankton.
- Deep chlorophyll maximum and under-ice blooms – Ice.
- Limitations: Low Sun elevation and Clouds and fog.

Perspectives:

- To deal with remote sensing problems.
- More validation of algorithms and models.
- Estimate of under-ice Primary Production (PP).
- Pan-Arctic estimates of trends in DOCt and POCt export.
- To further study changes in marine ecosystems

Land session (1/2)

The land session (1/2) session was chaired by Derek Peddle (ATIC, University of Lethbridge) includes presentations from himself, Robert H. Fraser (CCMEO, NRCAN, Canada), Ian Olthof (CCMEO, NRCAN, Canada), Canada and H. Peter White (CCRS, NRCAN, Canada).

Derek Peddle (ATIC, University of Lethbridge) presented the use of Remote Sensing of Northern Forest Tree Species Products and validation using Spectral Mixture Analysis and Multi-Temporal Satellite Imagery, Northwest Territories, Canada.
He summarized the challenges as follow:

- Tree Species identification – important challenge – required for variety of territorial and national initiatives, as well as disturbance thresholds and development permits for industry and development in NWT.
- Used sub-pixel scale spectral mixture analysis of Landsat-TM data for regional scale applications.
- Large forested area in NWT - Fort Providence sites.
- End-member spectral definition, specification and measurement are important.
- Field and image-based end-member acquisition tested.
- Multiple End-member SMA tested – provides dynamic flexibility and improved sensitivity to per-pixel variability over larger areas.
- Results indicated that image based end-members preferable to field-measured end-member spectra.
- Multi-temporal analysis provided further improvement.
- Product validation performed using established ground plots.

- Species results on the order of 80% achieved for 4 conifer and deciduous species.
- Result deemed important and significant – tree species has been elusive, especially in the North.
- Future work based on further advances in algorithms, hyperspectral analysis and processing new areas. There is a critical need for a hyperspectral sensor.

Robert H. Fraser (CCMEO, NRCAN, Canada) presented detecting Landscape Changes in High Latitude Environments using Landsat Trend Analysis: 1. Visualization

He summarized the challenges as follow:

- Landsat stacks: Tasselled Cap - brightness, greenness wetness.
- Visualizations and trend images, can be used in NWT applications such as:
    - Disturbance, Fire.
    - Permafrost.
    - Land use change.
    - Lakes – Drainage and expansion.
    - Productivity (i.e. greening of the Arctic & warmer summers & winters)
    - Mining operations.
    - UAV: multicopter – high spatial resolution can be used for EO product validation and mapping over smaller area.

Ian Olthof (CCMEO, NRCAN, Canada) presented detecting landscape changes in High-Latitude environments using Landsat Trend Analysis: 2. Classification.

He summarized the challenges as follow:

- Scaling up to regional scale – NWT.
- Cumulative Impacts Monitoring Program – monitoring from scientific and traditional knowledge.
- Also multi-sector needs.
- Greening, erosion, deposition.
- Tasselled cap brightness, greenness wetness.
- Multi-temporal analysis important – Landsat.
- Temporal reference data and offsets required aligning temporal data.
- Validation data limited – need to integrate different data validation sources.
- Linear trend analysis also used, as well as decision trees.
- Cross-validation procedure used on individual polygons.
- Final product merged to 8 change processes: ~82% accuracy.
- Used > 100 Landsat scenes to build time series of peak growing season reflectance.
- Temporal misalignment issue needs further work.

H. Peter White (CCRS, NRCN, Canada) presented hyperspectral simulation of an Arctic landscape with ISDASv2.

He summarized the challenges as follow:

- Limited snow free periods and solar illumination.
- Hyperspectral important for rock minerals, geology, lichens etc.
- Not just magnitude but also spectral shape – continuous spectral shapes (signature).
- No spectral gaps: can also derive finer physical features.

- Hyperspectral missions will be important; needed.
- How to calibrate to surface reflectance.
- ISDASv2 hyperspectral software (Imaging Spectrometry Data Analysis System).
- Can simulate satellite response for different sensors for a given land cover and atmosphere specification.
- Simulated Landsat Sentinel and several hyperspectral sensors.
- Landsat 5,7,8 continuity.
- Assessment of simulations: – multisensory temporal coverage.
- Useful for testing variety of issues in space and time, and place.

Cryosphere session (1/2)

The cryosphere session (1/2) session chaired by Barry Goodison (GWC Steering Committee Group, Canada) includes presentations from Chris Derksen (EC, Canada), Kari Luojus (FMI, Finland), Pia Erikson (Stockholm University, Sweden and Thomas Nagler (ENVEO, Austria).

Chris Derksen (EC, Canada) presented validation needs for microwave derived terrestrial cryosphere products.
He summarized the challenges as follow:

- **Validating Snow Products with Ground Measurements:**
    - Lack of in situ observations.
    - Spatial representativeness?
    - Measurement deficiencies.
    - Poor reporting practices (non-zero snow depth).
    - Large distances between point measurements, particularly North of 50.
    - Low-elevation bias in the daily snow depth-observing network.
    - Strength of the GlobSnow validation was the use of large sample sizes over many seasons.
    - RMSE ~32 mm for SWE <150 mm; ~40 for SWE >150 mm.
    - Stable algorithm performance between 1980 and 2009.
    - GlobSnow validation in (sub) Arctic tundra regions challenged by the impacts of sub-grid heterogeneity.
    - GlobSnow retrievals are consistent with the centre of the SWE probability distribution function.
    - Close agreement at Eureka is a function of proximity to weather station, at which measurements reasonably approximate the regional average
    - Higher uncertainty at Baker Lake could be a function of snow depth first guess from the weather station and/or emission model performance.
    - Underline the importance of the SMAP mission for ground measurements (freeze thaw)
- **Introduction of SnowPEX**: bringing together scientists and institutions active in seasonal snow cover monitoring, in order to assess the quality of current satellite-based snow products and to define guidelines for improvement.
    - Activities and challenges for SnowPEX are covered in the presentation of Thomas Nagler (ENVEO, Austria).

Kari Luojus (FMI), Finland) presented the CAL-VAL opportunities for terrestrial cryosphere products at the Sodankylä Supersite, Northern Finland.
He summarized the challenges as follow:

- He first introduced the capabilities of the Sodankylä Super Site Pallas *in-situ* monitoring programme relevant to terrestrial cryosphere, vegetation and atmosphere with examples.
- **Needs:**
    - Optical instruments including MODIS, NPP-VIIRS, FY-3 und upcoming.
    - Sentinels (2 and 3).
    - Planned (but not selected for ESA Earth Explorer) ESA CoReH2O (SAR radar): global SWE mapping at high spatial resolution (terrestrial areas and sea ice regions).
    - Satellite data accompanied with extensive monitoring of soil, vegetation and atmospheric processes (distributed measurements).
    - Primary station in WMO Global Atmosphere Watch (CO2, aerosols etc.).
    - Primary (*Integrated)* station in the WMO Global Cryosphere Watch.
    - Participation in WMO GRUAN network, TCCON network, EU-ICOS, NDACC, GEWEX
    - Linking ground-based observations with satellite data: airborne campaigns (Airborne campaigns support interpretation of in situ reference to satellite scale (1) HUT2D (SMOS reference radiometer) (2) HUTRAD system (AMSR frequencies))
    - Spaceborne: Prototype retrieval algorithm for space-borne L-band observations have been successfully demonstrated, discrimination into thawed, frozen and partially frozen states, SMOS – ESA's Soil Moisture and Ocean Salinity –mission
    - Coverage: whole Northern Hemisphere.
    - Methodology also applicable to NASA SMAP.

Pia Eriksson (Stockholm University, Sweden) presented the error estimation in snow density sampling and its effect on validation of remotely sensed snow cover products.
She summarized the challenges as follow with opening her talk with a key question: **Does field data accurately represent reality?**

- Several operational products exist for SWE and SCA.
- Products typically offer high temporal resolution but low spatial resolution.
- Not all products are validated for all types of landscapes due to paucity of *in situ* data.
- Remote sensing attempts to estimate physical snowpack parameters based on *in situ* observations.
- Hypotheses: (1) Higher spatial resolution gives better measurement accuracy and (2) Field data are more representative than remotely sensed data.
- **Remote sensing methods rely on a miscellany of validation datasets and methods - Recommendations:**
    - Always (additionally) measure bulk density, this reduces the number of factors influencing.
    - Multi-year and spatial analysis: Group samples by methodology and build validation data sets.
    - Always report metadata.
    - Statistical estimation of errors.

Kari Luojus (FMI, Finland) presented on behalf of Jouni Pulliainen (FMI) a view from hemispheric snow cover products towards an integrated view on the land cryosphere" - Remote sensing & snow & carbon cycle.

He summarized the challenges as follow, in the context of the ESA GlobSnow-1 and -2:

- **Way forward:** Combined products to monitor the seasonal cycle of carbon exchange related phenomena.
    - Relevant microwave and optical satellite instruments/missions - SSMI/I, AMSR-E (2), SMOS, Envisat ASAR, TerraSAR-X, MODIS, AATSR, MERIS, Sentinel-1, Radarsat-1/2, Chinese FY-series, etc.
    - Future missions: Sentinels 2 and 3, NASA SMAP.
- **Combination of snow, soil and vegetation products:**
    - Monitoring of all C-relevant processes of the land cryosphere.
- **Combined use with *in situ* data and assimilation with models:**
    - Proxy indicators (developed with *in situ* data).
    - Use with LSM.

Thomas Nagler (ENVEO, Austria) presented the Satellite Snow Product Intercomparison and Evaluation Experiment – SnowPEX.

He summarized the challenges as follow:

- **Main tasks:**
    - Review of algorithms and products focusing on Snow Extent (SE) and Snow Water Equivalent (SWE).
    - Definition of protocols and methods for validation and intercomparison of SE / SWE products.
    - Definition and compilation of reference data sets for quality assessment of SE and SWE products.
    - Intercomparison of SE/SWE products from various institutions and the quality assessment against reference data base.
    - Analysis of Hemispheric/Global SE and Snow Mass Trends and its uncertainty and
    - Study the synergy of SE and SWE products.
    - Conclusion and recommendations for satellite snow monitoring.
- **Summary of next steps:**
    - Protocols for intercomparing and validating snow extent and snow water equivalent products have been defined, and are available at the project website http://calvalportal.ceos.org/projects/snowpex. The methods are implemented and are currently tested using various data sets.
    - Participating products are converted to SnowPEx format. Overall 2 (+3) years of daily snow maps from 15 products.
    - Snow reference data set, including in-situ data and information from high resolution sensors, need to be handled carefully when they are intercompared
    - With medium resolution products because of scale issues and their own uncertainty. The generation of the data set is on-going.
    - First intercomparison and validation results and trend analysis of snow products planned for March 2015.
    - 2nd International Satellite Snow Product Intercomparison (ISSPI) WS is planned for Q2/Q3 2015, will be announced in February 2015.

Lake and coastal session

The lake and coastal session chaired by Claude Duguay (University of Waterloo, Canada) includes presentations from himself, and his research team: Homa Kheyrollah, Cristina Surdu and Kevin Kang – and from Emmanuel Devred (Takuvik, Canada) and Kerri Ann Warner (on behalf of David Barber, University of Manitoba).

Claude Duguay (University of Waterloo, Canada) presented the Arctic Lake Ice Algorithms and Products: Progress and Prospects.

He summarized the challenges as follow:

- **Ice concentration/extent and ice phenology (freeze-up/break-up and ice cover duration):**
  - MODIS 500 m snow product is limited due to cloud cover and polar darkness. The retrieval algorithm needs to be improved even under clear-sky conditions.
  - Multi-frequency/-polarization/polarimetric daily data at 10-100 m (lakes of various sizes) with emphasis on SAR would meet most requirements.
- **Ice thickness (and snow depth on ice):**
  - A retrieval algorithm has been developed from passive microwave data (AMSR-E): provides high temporal (daily) but spatial resolution too coarse for all but the largest lakes of the northern hemisphere. It also needs to be evaluated on other lakes.
  - Multi-frequency SAR data remains to be evaluated to estimate ice thickness (variations in ice types present a challenge).
  - No on-ice snow depth algorithm has yet been developed. Radar altimeter data (Jason-2, Cryosat, and follow-up missions) need to be examined.
- **Areal extent of floating and grounded ice in shallow lakes:**
  - Need to ensure continuity of same SAR configuration for long-term monitoring (1991-beyond) in lake-rich coastal regions of the Arctic.
- **Snow/ice surface temperature and albedo:**
  - The continued production of unified, consistent time series maps of surface temperature is recommended to add to the time series of surface skin temperature and broadband albedo from NOAA AVHRR that extend back to the early 1980s.
  - Methods for estimating the spectral albedo of snow and ice from satellite should continue to be developed.
- **Others:**
  - Need to establish Super (lake) Sites for algorithm development/validation and for long-term monitoring.
  - Need to intensify the development of lake ice products for data assimilation into Numerical Weather Prediction (NWP) models.

Homa Kheyrollah (University of Waterloo, Canada) presented the Pan-Arctic Land and lake surface temperature from AATSR and MODIS: Products development and evaluation.

She summarized the challenges as follow:

- More frequent satellite observations is a must and will be available (e.g. Sentinel-3 SLSTR, GCOM-C1 SGLI) with 1-km and 500-m spatial resolutions respectively.

Cristina Surdu (University of Waterloo, Canada) presented the Multi-sensor monitoring of ice regimes of High Arctic Lakes.
She summarized the challenges as follow:

- **Main limitations:**
    - Spatial resolution of the SAR beam modes (100-150 m) – does not capture melt onset for (small) lake.
    - Melt onset observed with Landsat.
    - Temporal resolution of both SAR and optical sensors.
    - Transition from minimum ice to open water can occur within 1-2 days.
    - Optical and SAR acquisitions are at times 5 days apart.

Kevin Kang (University of Waterloo, Canada) presented Improvement of MODIS snow products for Arctic lake ice.
He summarized the challenges as follow:

- There are issues for current MODIS snow products to discriminate cloud cover (or open water) from snow (or lake ice) in the land/inland water mask (MOD03/MYD03) and in the cloud mask (MOD35_L2/MYD35_L2) products.

Emmanuel Devred (Takuvik, Canada) presented color remote sensing for the study of Arctic marine ecosystems: II - Algorithm development and data processing platforms
He summarized the challenges as follow:

- Remote sensing of Ocean color remains the only mean to obtain a detailed description of carbon cycle at the pan-arctic scale, including, phytoplankton production, export of particulate and dissolved organic matter.
- Limitation of Ocean Color observations in the Arctic Ocean, as a result of cloud cover, remains a challenging problem.

Kerri Ann Warner on behalf of David Barber (University of Manitoba) presented the validation of Earth Observation Data for snow covered sea ice: Challenges and Opportunities.
She summarized the challenges as follow:

- **Focus on SAR: Geophysical and the thermodynamic parameter retrieval:**
    - Understand what drives the signatures.
    - Multi scale roughness, dielectrics.
    - Connect signature with snow/ice physical data.

Day 2: 13 November 2014:

Land session (2/2)

The land session (2/2) session chaired by Alexander Trishchenko (CCRS, NRCAN, Canada) includes presentations from himself, Donald McLennan/Katherine Wilson (CHARS, Canada), Bahram Salhei (C-CORE, Canada), Wenjun Chen (CCRS, NRCAN, Canada) and Elizabeth Hoy (NASA, US).

Alexander Trishchenko (CCRS) presented using VIIRS to extend MODIS long-term clear-sky composites over Canada.
He summarized the challenges as follow:

- **MODIS processing at CCRS:**
  - They would like to make the best use of MODIS data over Canada and to generate products compatible with other LTSDR time series (AVHRR, etc.).
  - **Different projections**: LCC (CCRS) vs sinusoidal (MODIS). Need to minimize distortions due to multiple re- projections.
  - **Different compositing intervals**: 10-day CCRS vs 8 & 16-day MODIS: **250m** is a requirement for spatial resolution for several terrestrial ECVs: GCOS-154 (2011). "*Systematic observation requirements for satellite-based data products for climate. 2011 Update. Supplemental details to the satellite-based component of the "Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (2010 Update)*".
  - **Enhance spatial resolution** of 500m bands to 250m.
- **Uncertainties in Global Land Cover Data Related to Arctic Perennial Snow and Ice Map:**
  - GLC-2000 and GLC-2005 PSI area in Canada North overestimated by 128% (59,000km2) and 129% (52,000km2) relative to CCRS 250m MODIS data! Errors for other regions span the range from -73% to +115%.
- **VIIRS Image Discontinuities to be addressed, e.g. Lambert Conic Conformal Projection (LCC) compatible with MODIS and other CCRS products.**
- **Further plans:**
  - Testing and analysis of various components Improving Scene ID and compositing schemes.
  - Start developing new BRDF/Albedo scheme based on "all clear-sky data points" rather than two-value compositing as implemented in MODIS processing.
  - Atmospheric correction.
  - Operational production of VIIRS products compatible with CCRS MODIS series.

Katherine Wilson and Donald McLennan (CHARS, Canada) presented CHARS as a science partner for coordinated northern EO/RS.
They summarized the challenges as follow:

- **CHARS RS/EO needs:**
  - Terrestrial/Freshwater Ecosystems: (1) Terrestrial ecosystems, land use, vegetation physiognomy, focal habitats, permafrost, snow, growing season, surface water, wetlands, lake/river ice, (2) Scaling up plot based measures to landscapes and the whole Arctic, e.g., snow, shrub cover, biomass, C sequestration.

- Coastal/Marine Ecosystems (1) Coastal landform dynamics (erosion and sedimentation), (2) Marine/coastal productivity (chlorophyll-a, surface temperature), (3) Ice changes and ecosystem/habitat/community effects.
- Cryosphere Research: (1) Marine and terrestrial components, (2) Important EO/RS contribution – linked to ground observations permafrost, sea/river/lake ice, snow, glaciers ecosystems, habitats, disturbance.
- Baseline Information Preparedness for Development (1) Work with regulators, industry, science community and Northerners to develop baseline monitoring and cumulative effects tools for guiding development, (2) Habitats, connectivity, roads and infrastructure
- Infrastructure for Development: (1) soil stability, flooding/mass wasting, coastal erosion risk, (2) community and industrial infrastructure
- Would like CHARS to become a "supersite"

Bahram Salehi (LOOKNorth, Canada) presented the object-based land cover classification of Torngat Caribou Habitat in Quebec and Labrador, Canada using SPOT imagery and DTM data.
He summarized the challenges as follow: **No Cal/Val or EO/RS needs identified.**

Wenjun Chen (CCRS, NRCAN, Canada) presented the challenges in monitoring Arctic plant growth and phenology using long-term remote datasets.
He summarized the challenges as follow:

- **Challenges:**
  - Plant productivity trend analysis trendy, easy to do using a VI, yet problem without proper evaluation/validation.
  - Cause of the challenge: Selection of plant productivity indicator: Is NDVI the proper plant productivity indicator for trend analysis? (1) Error analysis: if estimation error > productivity trend, then the trend is not detectable and meaningless, (2) Method for computing the trends: given these errors, what is the best way to calculate the productivity trend?
- **Trend analysis is popular under global change, yet one has to address 3 related questions:**
  - What's proper plant productivity indicator? NDVI vs. leaf biomass.
  - Are the magnitudes of trends detectable? Trend vs. detectable error threshold.
  - At which scale should the trend analysis performed? Region/circumpolar vs. classes in a biogeo/climatic- region.
- **Question?**
  - How to make remote sensing more relevant to decision making on key issues in the Arctic, e.g., resource development vs. caribou habitat?

Elizabeth E. Hoy (NASA, US) presented the Spaceborne Remote Sensing Requirements for the Arctic-Boreal Vulnerability Experiment (ABoVE).
She summarized the challenges as follow:

- Satellite and airborne remote sensing data will be critical to the spatial and temporal scaling of observations made from field studies, and provide the basis for improving terrestrial biosphere models.
- **RS for ABoVE:**
  - Use of existing or planned spaceborne information products (Landsat, MODIS).

- Refinement, development, validation, and use of new information products from airborne and spaceborne remote sensors (OCO-2, SMAP, ICESat-2, NISAR, HyspIRI).
- Generation of information products for specific end users (e.g., for wildlife managers, transportation planners).
- Potential ABoVE-related products identified and maturity determined in the ACEP: (A): Research grade, needs further development and validation – Stage 1 validation products (B): Validation needed to assess product for Arctic and boreal regions – Stage 2-4 validation products (C): Accuracy is known and products can be used without further refinement and validation

- **High Importance Airborne Sensing Products**
  - Biomass/canopy structure: small footprint LiDAR, InSAR.
  - Deep substrate properties: Electromagnetic resonance imager, SAR.
  - Vegetation composition: Hyperspectral imager.
  - Atmospheric CO2, CH4, CO: CARVE Payload, Airborne Fourier Transform.
  - Season surface deformation: Small footprint LiDAR, InSAR.

Atmosphere session

The atmosphere session chaired by James Drummond (Dalhousie University, Canada) includes presentations from Kaley Walker (University of Toronto, Canada), Ray Nassar (EC, Canada), Zahra Vaziri (York University, Canada), Stella Melo (EC, Canada) and Ralf Bennartz (University of Wisconsin)

Kaley Walker (University of Toronto) presented the validation capacity in the Canadian High Arctic: The Polar Environment Atmospheric Research Laboratory (PEARL).
She summarized the challenges as follow opening with a key question: **Why Satellite Validation at PEARL?**

- *Eureka is at the "sweet spot" for polar orbiting satellites* - ***More overpasses at this latitude than any other location on the planet.***
- **Needs:**
  - Need to find methods for sustained support of validation stations.
  - Often "assumed" that stations will be there when needed. Currently funded by national science, environmental, space agencies in piecemeal manner.

Ray Nassar (EC, Canada) presented the observing CO_2 from a highly elliptical orbit for studies of the carbon cycle in the Arctic and boreal regions.
He summarized the challenges as follow:

- **CO2 and CH4 Validation:**
  - Validation of column-average CO2 and CH4 mole fractions (XCO2, XCH4) requires column measurements by ground-based remote sensing.
  - The Total Carbon Column Observing Network (TCCON) is the only widely accepted method.
  - TCCON instrumentation and retrievals are standardized and data are calibrated to the WMO scale by in situ profile measurements from aircraft over flights. Additional high latitude TCCON sites (~50-80 N) in North America and Asia are needed.

- **Cross Validation for GEO Missions:**
    - LEO, GEO and HEO missions could be used to validate each other, but sun-synchronous LEO only give one point in the diurnal cycle. HEO would provide overlap with GEO observations in some regions and thus an opportunity to validate throughout the diurnal cycle.

Zahra Vaziri (York University, Canada) presented the Balloon demonstrator Imaging Fourier Transform Spectrometer for the measurement of methane and carbon dioxide over the Arctic.
She summarized the challenges as follow:

- **Note: No Cal/Val or ES/RS needs identified.**

Stella Melo (EC) presented the Validation/Verification of the microphysical and dynamic characteristics of Arctic Cloud systems: what infrastructure is required to meet the challenge?
She summarized the challenges as follow:

- **To meet the challenge:**
    - Move towards a view of an integrated observing system where satellite data is integrated by conception to other observing platforms towards generation of products that addresses the user needs.
    - Bridge with applications need to be an integral part of the observing system design: it supports optimization of requirements and guide the system implementation.
    - International collaborative approach is a must.

Ralf Bennartz (University of Wisconsin, US) presented the measuring High-Latitude precipitation and falling snow from space.
He summarized the challenges as follow:

- **Validation (surface snow accumulation):**
    - Mission Goals: – radiometric calibration validation over cold clear scenes.
    - Resolve CrIS and IASI differences– assess satellite T/q profile retrievals for cold scenes.
    - Mission Dates and Location: – Flights out of Keflavik from March 3-23, 2015 (Dates are tentative, it may change slightly).
- **Needs:**
    - High latitude precipitation is a major gap with current satellite missions but progress is being made with experimental missions (CloudSat, EarthCare).
    - There is much to gain by the precipitation and snow on the ground communities working together to outline priorities for future missions and address retrieval issues.
    - If we want to observe climate signals, we need to have long- term records. Need for stable, well-calibrated long-term satellite datasets.
    - ICECAPS provides an excellent validation site/testbed EO satellites (CloudSat, EarthCare, etc.)

Cryosphere session (2/2)

The cryopshere (2/2) session chaired by Chris Derksen (EC, Canada) includes presentations from Barry Goodison (GCW Steering Committee Group, Canada), Yi Luo/Lynn Pogson (CSI, EC, Canada), Kaan Ersashin (ASL Environmental Science Inc., Canada, Naomi Short (CCRS, NRCAN, Canada) and Thomas Puestow (C-CORE, Canada).

Barry Goodison (GCW Steering Group, WMO) presented the Global Cryosphere Watch (GCW): A Contribution to Arctic Products Validation and Evolution (APVE).
He summarized the challenges as follow:

- **Recommendations from Sea Ice Thickness Intercomparison:**
  - Intercomparison: A formal, robust, international intercomparison project should be undertaken to clearly identify strengths and weaknesses of each product, and to better characterize errors.
  - Blending: Evaluate the feasibility of blending multiple data products to provide a single picture of sea ice thickness over time.
  - Assimilation: There is very little use of ice thickness observations in models. Model impact studies should be undertaken. How often do we need thickness estimates? At what spatial scale?
  - Synergy: Continue to explore the combination of laser and radar altimeters to solve the problem of unknown snow depth on ice. Are there other space-based solutions?
  - Validation: In situ observations of ice thickness and snow depth should be expanded, standardized, and freely available.
- **Product Intercomparison and Assessment:**
  - Intercomparison required to assess product quality (uncertainty, bias, error correlation), and to isolate algorithm/methodological weaknesses
  - Intercomparison of satellite products within dependent external reference measurements (in-situ, airborne, etc.).
  - Validation, characterization of errors, estimate of absolute biases, sources of uncertainty etc.
  - Intercomparisons amongst different satellite products – to establish relative biases and range of uncertainty.
  - Intercomparison must be continuous process – (1) to evaluate spectral content of errors, (2) Evaluate rate of change of product uncertainties (e.g. contributed by instrument ageing, orbit degradation, switch to redundant instrument chains, etc.).
- **A Recipe for Intercomparison:**
  - Generate Level playing field (agreed best practices/intercomparison standards or guidelines).
  - Establish Temporal/Spatial coincidence of different products.
  - Select key Areas for Intercomparison, based on locations of GCW Reference Sites, or other independent validation datasets (e.g. airborne data).
  - Assemble knowledge on spatial resolution limitations (e.g. impact of product gridding).
  - Assemble knowledge on spectral content of time-series of temporally averaged products (e.g. impact of temporal averaging, impact of illumination geometry from successive orbits).

- Assemble necessary ancillary data for common use by all participants (e.g. DEMs, land cover maps; and common land/snow/ ice masks).

Yi Luo and Lynn Pogson (CSI, EC, Canada) presented the Canadian Ice Service Satellite-based Ice Monitoring: Optical Data Applications and t he Regional Ice Prediction System (RIPS) version 2.1.
They summarized the challenges as follow:

- **CIS Remote Sensing R&D Priorities:**
  - Improved short term and seasonal ice forecasting – Assimilation of satellite data to sea ice model.
  - Investigation, support for development of future sensors for ice & marine applications – RADARSAT Constellation, Sentinel-1, GOES-R, PCW.
- **Quality control / filtering:**
  - Conversion from satellite measurement to ice concentration is not straightforward/ foolproof.
  - Data assimilation does not aim to include all parts of the imagery – with multiple data sources; only the areas that can be confidentially analysed are used.
  - Use of quality control conditions and filtering of data.

Kaan Ersahin (ASL Environmental Sciences Inc., Canada) presented the characterization of Hazardous Ice using Spaceborne SAR and Ice Profiling Sonar: Preliminary Results.
He summarized the challenges as follow:

- **Needs:**
  - Developing validated information products by combining the "view from above" with the "view from below".
  - Fine scale analysis from RS-2 (classification, ice draft estimation) with comparison to ULS data
  - Validation sites needed.
- **Outlook:**
  - Other complementary data sources considered for validation: other space-borne sensors, airborne EM data, and ship-based observations.
  - Need to support future validation activities and continue satellite data acquisitions to build an extensive archive.

Naomi Short (CCRS, NRCAN, Canada) presented the validation of DInSAR displacement measurements in permafrost environments.
She summarized the challenges as follow:

- **Note:**
  - Validation methods are largely qualitative, and simply confirm that the satellite displacement trend is realistic.
  - Quantitative methods are possible, but tend to be point only and difficult to extract to large areas.

Thomas Puestow (C-CORE/ Canada) presented the Polar View – Lessons Learned for the Validation and Evaluation of Operational Arctic Monitoring Services.
He summarized the challenges as follow:

- **Needs:**

- Emphasis on user needs rather than technology-push.
- Reliable access to free data is key

Closing Session

This workshop confirmed the importance of all contributors in the value chain in order to make sense out of the space-based data and succeeded in stimulating the networking on activities (science driven, products driven, requirements driven, etc.) It provided a framework for exploring opportunities for partnership with Space Agencies and contributions to EO.

The presentations covered cross-sectorial approaches to common Arctic issues with impressive contributions ranging from new research to services, all with a clear focus on EO science trends on high-latitude and Arctic issues.

The usefulness of the meeting was recognised by all participants in bringing together representatives from different communities to discuss and share common validation and calibration topics.

Numerous issues were raised during the two days and were further discussed in the closing session including the following:

Interoperability is a key issue. New approaches, including improved auxiliary data information were noted such as better access to information/documentation (RT, meta data, ATBDs, international peer-reviewed documents and better tools for the end-users that are not as well familiar with working with lower level data). Many participants have raised their concerns about data accessibility.

Intellectual Property issues. General consensus for the need of transparency in EO. Examples given were full access to documentation such as calibration approaches, or avoiding "black-box" processing systems at all data levels.

Identification for existing algorithms and products in the Arctic and High-Latitude and new additional products were not clearly identified, but there were a general agreement from the participants that a new approach should be initiated (e.g. coordinated team to report the community needs to ESA).

The need to formulate requirements for validation of High-Latitude and Arctic products – including proposed improvements to the ground-based observation networks, such as WMO/GCW, National sites, Sustained Arctic Observing Networks (SAONs), or the creation/addition of new measurement capabilities. – are necessary, and ESA will address the issue. ESA is really open about collaboration and helping the Canadian communities in their Cal/Val research activities.

As for defining key EO reference sites/areas targeting specific representativity issues (for example intercomparison best-practices, or targeted studies in mountainous areas, coastal zones, etc.).

Space agencies are currently supporting targeted studies such as SnowPEx for Hemispheric intercomparisons (see T. Nagler presentation) and new activities are being initiated.

Key user issue: need for "data compatibility" for data set/product continuity: While instruments are changing throughout time, there is a clear need to make the transition easier for the end-users. It was recommended to have resources such as training or tools, made available for the end-users to adopt new datasets. Space agencies were also asked to provide detailed information on sensor performance differences, accuracy and uncertainties estimates, etc. so as to facilitate the continuity of products and services.

It was well noted that the Arctic remains a challenge for backscatter-derived products and that the **atmospheric corrections in high-latitudes** need improvements. It was recommended for Space Agencies to initiate atmospheric correction "round-robin" experiments with a focus on the Arctic.

The Space Agencies are interested in formalising cooperation and long-term planning activities for infrastructure in the high-latitudes such as the CHARS initiative by the Canadian Government or sustaining the atmospheric capabilities at the PERAL at Eureka.

In situ data accessibility: How can we have access to them easily? A tool such as a general database was suggested, as a possibility (e.g. as proposed in CHARS). This issue will be re-addressed in the near future.

The recommendations defined during the meeting are tabulated in the next section. These will be treated as action items by the space agencies.

APPENDICES

APPENDIX A: Final Agenda

1St International Arctic and High-Latitude and Evolution Workshop: Lessons learned, Ottawa, Canada, 12-13 November 2014.
Room: Pinnacle, Ottawa Delta Centre Hotel

Programme 29 October 2014			
Day 1: Wednesday, 12 November 2014			
	Introduction		
8:30	Yves Crevier	CSA, Canada	Welcome and introduction
8:40	Bojan Bojkov	ESA, Italy	EO challenges in High-Latitudes and the workshop objectives
9:00	Guy Aubé	CSA, Canada	Downstream EO Products and Services for the Arctic: CSA Support for Canadian Governmental Organizations, Industry & Academia
	User Perspectives - *Chair: T. Puestow*		
9:15	Dennis Nazarenko/ Bill Jefferies	LOOKNorth, Canada	The Growing Importance of Remote Sensing Derived Information to Northern Commercial Activities.
9:35	Ralf Bennartz *(On Behalf of)* Ulrika Willen	SMHI, Sweden	Using Arctic and High-Latitude observational data for process studies and model evaluation at the Swedish Meteorological and Hydrological Institute (SMHI)
9:50	James Snider	WWF, Canada	Use of remote sensing in WWF's Rapid Assessment of Circum-Arctic Ecosystem Resilience (RACER) tool for conservation planning in a rapidly changing Arctic
10:05	Marcel Babin	Takuvik, Canada	Ocean color remote sensing for the study of Arctic marine ecosystems: I- Major research initiatives and scientific results
10:20	**Discussion**		
10:45-11:00	**Coffee Break**		
	Land Session (1/2) - *Chair: D. Peddle*		
11:00	Derek Peddle	ATIC, U.Lethbridge, Canada	Remote Sensing of Northern Forest Tree Species Products and Validation using Spectral Mixture Analysis and Multi-Temporal Satellite Imagery, Northwest Territories, Canada
11:30	Robert H. Fraser	CCMEO, NRCAN, Canada	Detecting Landscape Changes in High Latitude Environments using Landsat Trend Analysis: 1. Visualization

Programme 29 October 2014			
Day 1: Wednesday, 12 November 2014			
11:50	Ian Olthof	CCMEO, NRCAN, Canada	Detecting Landscape Changes in High Latitude Environments using Landsat Trend Analysis: 2. Classification
12:10	H. Peter White	CCRS, NRCAN, Canada	Hyperspectral Simulation of an Arctic Landscape with ISDASv2
12:30	**Discussion**		
13:00-14:00	**Lunch**		
	Cryosphere Session (1/2) - *Chair: B. Goodison*		
14:00	Chris Derksen	Environment Canada	Validation needs for microwave derived terrestrial cryosphere products
14:20	Kari Luojus	Finnish Meteorological Institute, Finland	CAL-VAL Opportunities for Terrestrial Cryosphere Products at the Sodankylä Supersite, Northern Finland
14:40	Pia Eriksson	Stockholm University, Sweden.	Error estimation in snow density sampling and its effect on validation of remotely sensed snow cover products
15:00	Kari Luojus *(On Behalf of)* Jouni Pulliainen	Finnish Meteorological Institute, Finland	From hemispheric snow cover products towards an integrated view on the land cryosphere" - Remote sensing & snow & carbon cycle
15:20	Thomas Nagler	ENVEO, Austria	The Satellite Snow Product Intercomparison and Evaluation Experiment – SNOWPEX
15:40	**Discussion**		
15:50-16:05	**Coffee Break**		
	Lake and Coastal Session - *Chair: C. Duguay*		
16:05	Claude Duguay	University of Waterloo, Canada	Arctic Lake Ice Algorithms and Products: Progress and Prospects
16:35	Homa Kheyrollah Cristina Surdu Kyung-Kuk (Kevin) Kang	University of Waterloo, Canada	• Pan-Arctic Land and lake surface temperature from AATSR and MODIS: Products development and evaluation • Multi-sensor monitoring of ice regimes of High Arctic Lakes • Improvement of MODIS snow products for Arctic lake ice
17:20	Emmanuel Devred	Takuvik, Canada	Ocean color remote sensing for the study of Arctic marine ecosystems: II - Algorithm development and data processing platforms
17:40	David Barber/Kerri Ann Warner	University of Manitoba, Canada	On the Validation of Earth Observation Data for snow covered sea ice: Challenges and Opportunities

Programme 29 October 2014	
Day 1: Wednesday, 12 November 2014	
18:00	**Discussion**
18:30	**End of day 1**
20:00	*Optional dinner: At the Mills St. Pub*

Day 2: Thursday, 13 November 2014			
	Land Session (2/2) - *Chair: A. Trishchenko*		
8:45	Alexander Trishchenko	CCRS, NRCAN, Canada	Using VIIRS to extend MODIS long-term clear-sky composites over Canada
9:15	Donald McLennan/ Katherine Wilson	CHARS, Canada	CHARS as a Science Partner for Coordinated Northern EO/RS
9:35	Bahram Salehi	C-Core, Canada	Object-based land cover classification of Torngat Caribou Habitat in Quebec and Labrador, Canada using SPOT imagery and DTM data
9:55	Wenjun Chen	CCRS, NRCAN, Canada	Challenges in monitoring Arctic plant growth and phenology using long-term remote datasets
10:10	Elizabeth Hoy	NASA, US	Spaceborne Remote Sensing Requirements for the Arctic-Boreal Vulnerability Experiment (ABoVE)
10:30	**Discussion**		
10:45-11:00	**Coffee Break**		
	Atmosphere Session - *Chairs: J. Drummond*		
11:00	Kaley Walker	University of Toronto	Validation Capacity in the Canadian High Arctic: The Polar Environment Atmospheric Research Laboratory (PEARL)
11:30	Ray Nassar	Environment Canada	Observing CO_2 from a highly elliptical orbit for studies of the carbon cycle in the Arctic and boreal regions
11:50	Zahra Vaziri	York University, Canada	Balloon demonstrator Imaging Fourier Transform Spectrometer for the measurement of methane and carbon dioxide over the Arctic
12:10	Stella Melo	Environment Canada	Validation/Verification of the microphysical and dynamic characteristics of Arctic Cloud systems: what infrastructure is required to meet the challenge?
12:30	Ralf Bennartz	University of Wisconsin, US	Measuring High-Latitude precipitation and falling snow from space
12:50	**Discussion**		
13:00-14:00	**Lunch**		

Day 2: Thursday, 13 November 2014			
	Cryosphere Session (2/2) - *Chair: C. Derksen*		
14:00	Barry Goodison	GCW Steering Group, Canada	Global Cryosphere Watch (GCW): A Contribution to Arctic Products Validation and Evolution (APVE)
14:30	Yi Luo/Lynn Pogson	Canadian Ice Service, Environment Canada	Canadian Ice Service Satellite-based Ice Monitoring: Optical Data Applications/ The Regional Ice Prediction System (RIPS) version 2.1
14:50	Kaan Ersahin	ASL Environmental Sciences Inc., Canada	Characterization of Hazardous Ice using Spaceborne SAR and Ice Profiling Sonar: Preliminary Results
15:10	Naomi Short	CCRS, NRCAN, Canada	(3.10) Validation of DInSAR displacement measurements in permafrost environments
15:30	Thomas Puestow	C-CORE, Canada	Polar View – Lessons Learned for the Validation and Evaluation of Operational Arctic Monitoring Services
15:50	**Discussion**		
16:00-16:15	**Coffee Break**		
16:45	**Conclusions and recommendations – Way forward** *Chairs: B. Bojkov and Y. Crevier*		
18:00	**End**		

APPENDIX B: List of Participants

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APPENDIX C: Acronyms and Abbreviations

This appendix lists all abbreviations and acronyms used within this document.

Acronyms

AATSR	Advanced Along Track Scanning Radiometer
ABoVE	Arctic-Boreal Vulnerability Experiment
AMSR	Advanced Microwave Scanning Radiometer
AMSR-E	Advanced Microwave Scanning Radiometer - Earth Observing System
ASAR	Advanced Synthetic Aperture Radar
APVE	Arctic Products Validation and Evolution
ATIC	Alberta Terrestrial Imaging Centre
AVHRR	Advanced Very High Resolution Radiometer
BRDF	Bidirectional Reflectance Distribution Function
CAA	Canadian Arctic Archipelago
CARVE	Carbon in Arctic Reservoirs Vulnerability Experiment
Cal/Val	Calibration and Validation
CCMEO	Canada Centre for Mapping and Earth Observation
CHARS	Canadian High Arctic Research Station
CrIS	Cross-track Infrared Sounder
CRYOLAND	Copernicus Service Snow and Land Ice
CSA	Canadian Space Agency
CSI	Canadian Ice Service
DEM	Digital Elevation Model
DInSAR	Differential Interferometric Synthetic Aperture Radar
DOCt	Dissolved Organic Carbon
DTM	Digital Terrain Model
EC	Environment Canada
EM	Electro Magnetic
ENVEO	ENVironmental Earth Observation
ENVISAT	ENVIronmental SAtellite
EO	Earth Observation
EOAU	Earth Observation Applications and Utilizations
EOADP	Earth Observation Applications Development Program
ESA	European Space Agency
EU	European Union
FMI	Finnish Meteorological Institute
FY	Feng-Yun
GCM	Global Climate Model
GCOM	Global Change Observation Mission
GCOS	Global Climate Observing System
GCW	Global Cryosphere Watch
GEO	Geosynchronous
GEWEX	Global Energy and Water Cycle Experiment
GHG	Greenhouse Gas

GLC	Global Land Cover
GOES-R	Geostationary Operational Environmental Satellite-R
GRIP	Government Related Initiatives Program
GRUAN	GCOS Reference Upper Air Network
HEO	Highly Elliptical Orbit
HUT2D	Helsinki University of Technology Synthetic Aperture Radiometer
HUTRAD	Helsinki University of Technology RADiometer
HyspIRI	Hyperspectral Infrared Imager
IASI	Infrared Atmospheric Sounding Interferometer
ICECAPS	Integrated Characterization of Energy, Clouds, Atmospheric state, and Precipitation at Summit
ICESat-2	Ice, Cloud, and land Elevation Satellite-2
ICOS	Integrated Carbon Observation System
InSAR	Interferometric Synthetic Aperture Radar
ISDASv2	Imaging Spectrometry Data Analysis System
ISSPI	International Satellite Snow Product Intercomparison
IP	Intellectual Property
KBHs	Key Bird Habitat Areas
LANDSAT	Land Remote-Sensing Satellite
LCC	Lambert Conic Conformal
LEO	Low Earth Orbit
LIDAR	Laser Imaging Detection and Ranging
LOOKNorth	Leading Operational and Observations for the North
LSM	Land Surface Model
MERIS	MEdium Resolution Imaging Spectrometer
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDACC	Network for the Detection of Atmospheric Composition Change
NDVI	Normalized Difference Vegetation Index
NGO	Non-Governmental Organization
NISAR	Nasa-Isro Synthetic Aperture Radar
NOAA	National Oceanic and Atmospheric Administration
NRT	Near Real Time
NRCAN	Natural Resources Canada
NPP	National Polar-orbiting Partnership
NWP	Numerical Weather Prediction
NWT	Northwest Territories of Canada
OCO-2	Orbiting Carbon Observatory-2
PEARL	Polar Environment Atmospheric Research Laboratory
PCW	Polar Communications and Weather
POCt	Particulate Organic Carbon
PP	Primary Production
PSI	Perennial Snow and Ice
RACER	Rapid Assessment of Circum-Arctic Ecosystem Resilience
R&D	Research and Development
RIPS	Regional Ice Prediction System

RMSE	Root-Mean-Square Error
RS	Remote Sensing
RT	Real Time
SAON	Sustained Arctic Observing Network
SAR	Synthetic Aperture Radar
SE	Snow Extent
SGLI	Second generation Global Imager
SLSTR	Sea and Land Surface Temperature Radiometer
SMAP	Soil Moisture Active/Passive
SME	Small-Medium Enterprises
SMHI	Swedish Meteorological and Hydrological Institute
S/N	Signal-to-Noise
SMOS	Soil Moisture and Ocean Salinity
SnowPEX	Satellite Snow Product Intercomparison and Evaluation Exercise
SOAR	Science and Operational Applications Research
SWE	Snow Water Equivalent
TCCON	Total Carbon Column Observing Network
UAV	Unmanned Aerial Vehicle
ULS	Upward Looking Sonar
UNFCC	**U**nited Nations Framework Convention on Climate Change
VIIRS	Visible Infrared Imaging Radiometer Suite
WMO	World Meteorological Organization
WS	Workshop
WWF	World Wide Fund