The Satellite Snow Product Intercomparison and Evaluation Exercise

REPORT ON

2nd International Satellite Snow Products Intercomparison workshop (ISSPI-2)

Monday, 14 September 2015 to Wednesday, 16 September 2015

University Memorial Center (UMC)
University of Colorado, Boulder 80302, CO, USA

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The ISSPI-2 Workshop took place at University Memorial Center (UMC) at University of Colorado, Boulder, US, from 14-16 September 2015. Overall 36 scientists from institutions working in seasonal snow pack monitoring met to discuss plans to assess the preliminary results of the intercomparison and validation of snow products and work out guidelines for improvements.

The Workshop was organized in 3 parts. Part 1 and Part 2 were sessions on Monday and Tuesday morning. Part 1 provided the motivation for performing this exercise, an overview of the SnowPEx project, pre-processing of the data and proposed protocols, selected reference data, methods and protocols for validation and intercomparison of global/hemispheric snow extent (SE), and preliminary intercomparison and validation results for snow extent products. Further, presentations on status and updates in participating products were given by the scientists responsible for each product. Part 2 included presentations on protocols and methods for validation and intercomparison of global/hemispheric snow water equivalent (SWE) products and first results, and presentations on the characteristics of participating products, including period of availability, sensors used, current status of validation, etc., given by the scientists responsible for each SWE product.

On Tuesday afternoon and Wednesday morning, Splinter Sessions (Part 3) on Snow Extent and Snow Water Equivalent were carried out, discussing the tested methods, protocols and selected reference data sets for validating SE and SWE products, and the illustration of the results. Approaches for performing trend analyses were also discussed.

On Tuesday afternoon, products, protocols, methods and design of the snow product intercomparison as well as trend analyses were openly discussed. The discussions were summarized by the Splinter Session Chairs in the second part of the splinter sessions on Wednesday morning.

The summary and outcome Splinter Sessions were presented by the SE and SWE Splinter Session chairs Thomas Nagler (SE) and Chris Derksen (SWE) and the actions were defined. The result of the splinter sessions is the main outcome of the WS and is described in detail in the following sections.

The workshop agenda, as well as all presentations given at the ISSPI-2 workshop are available for download as PDF on the SnowPEx website:

https://earth.esa.int/web/sppa/activities/qa4eo/snowpex/meetings-workshops/isspi2/programme.

1. SUMMARY AND OUTCOME OF SNOW EXTENT SPLINTER SESSION

The chair and rapporteur of the splinter session for SE were T. Nagler and R. Fernandes. The following items were discussed in the splinter session:

- Reference data (Landsat and in-situ) and validation
- Pre-processing of products and ancillary data
- Protocols of product intercomparison and validation
- Trend analysis

1.1. Reference data (Landsat and in-situ) and validation

As validation we understand the comparison of the global / hemispheric SE products with reference data. Based on the agreements and decisions made in ISSPI-1 a set of reference data was compiled by the SnowPEx team. Reference data include

- networks of in-situ snow measurements
- high resolution snow cover maps of high quality and preferably with attached uncertainty information

1.1.1. In-situ reference data

Validation with in-situ measurements is carried out in key regions. Table 1.1 summarizes the in-situ data sets available for SnowPEx validation activities. The participants of the ISSPI-2 workshop agreed that the spatial and temporal availability of the in-situ data is sufficient for SnowPEx validation. Most of the in-situ data are available on request at the data provider. After some discussion it was agreed that the in-situ reference data, at least of the SnowPEx periods, should be made available to the public in order to support future algorithm development and validation. It is also required to attach metadata and reference the data providers.

It was also decided to separate the validation of SE products with in-situ stations located in forests and in open land, respectively, in order to avoid issues of products providing viewable snow / snow on ground.

***ACTION:* Chris Derksen (US, Canada data sets) and Sari Metsämäki (other data sets):** *The team will contact the in-situ data owners and check if it would be possible to include their data set as a publicly available SnowPEx reference data set. Datasets will be made available through the SnowPEx websites. A written agreement of the data owners for including their data in the SnowPEx data set is recommended (email, PDF letter).*

Table 1.1:
In-situ data sets for SnowPEx SE and SWE validation.

Dataset	Region	Snow Class	Method	Available Time Period	Temp. Resolu tion	Contact	Param.	Data Policy	Samples @ FTP
Pointwise data									
ECMWF Weather stations	Europe/ North America	All	Sonic snow depth, Manual surveys	1978-2014	Daily	ECMWF in SnowPEx K. Luojus, FMI	SD	Restricted	
RIHMI Weather stations	Russia and former USSR	All	Manual surveys	1966-2011	Daily	O. Bulygina, RIHMI	SD, FSC	Open (registration at RIHMI web page)	All seasons from RIHMI database
FMI Weather stations (Finland)	Finland	All	Sonic snow depth, Manual surveys	1978-2014	Daily	K. Luojus, FMI	SD	Restricted (sample data available on FTP)	2003-2004 2011-2012
ECA&D Weather stations (Germany)	Germany (+ Europe)	All	Sonic snow depth, Manual surveys	2000-2012	Daily	ECA&D in SnowPEx, S. Metsämäki, SYKE	SD	Open	All seasons*
SMHI Weather station data (Sweden)	Sweden	Mountains, taiga	Sonic snow depth, Manual surveys	1980-2015	Daily	SMHI in SnowPEx, S. Metsämäki, SYKE	SD	Open	All seasons*
NVE snow stations (Norway)	Norway	All	Automated stations	1967-2015	Hourly/ Daily	Rune Solberg, NR	SD, SWE	Open	Not yet but will be, season has to be checked
Environment Canada, Olympics 2010	Southern coast mountains	Alpine	Sonic snow depth	2008-2010	Daily	C. Derksen, Environment Canada	SD	On request	
Environment Canada, Bratt's Lake	Saskatchewan	Prairie	Manual surveys	2002-2005	Bi-weekly	C. Smith, Environment Canada	SWE, SD, Density	On request	
Environment Canada, Trail Valley Creek	Northwest Territories	Tundra	Manual surveys	1991-2014	End of season	P. Marsh, Wilfrid Laurier Univ.	SWE, SD, Density	On request	
University of Saskatchewan, Boreal Ecosystem Research and Monitoring Sites	Saskatchewan	Taiga	Sonic snow depth	1997-2011	Daily	H Wheater, Univ. Saskatchewan	SD	On request	
University of Saskatchewan, Boreal Ecosystem Research and Monitoring Sites	Saskatchewan	Taiga	Manual surveys	1995-2011	Monthly	H Wheater, Univ. Saskatchewan	SWE, SD, Density	On request	
University of Alaska, Kuparuk Basin snow surveys	Alaska	Tundra	Snow surveys	2006-2013	Snap-shot	S. Stueffer, Univ. of Alaska – Fairbanks	SWE max	On request	

Dataset	Region	Snow Class	Method	Available Time Period	Temp. Resolution	Contact	Param.	Data Policy	Samples @ FTP
Snow course data									
SYKE Snow Surveys	Finland	Taiga	Manual snow course	2002-2014	Monthly	S. Metsämäki SYKE	SD, FSC (course mean)	Restricted (sample data available on FTP)	10/2003-05/2004 10/2007-05/2008
RIHMI Snow Surveys	Russia	Taiga and tundra	Manual snow course	1966-2014	Bi-weekly	O. Bulygina, RIHMI	SD, SWE, FSC, Density	Open** (registration at RIHMI web page)	All seasons from RIHMI database
Interpolated data									
Hydro-Quebec Krigged SWE	Southern Quebec	Agricul-tural, forest	Interpolated snow course	1999-2010	Bi-weekly	R. Brown, Environment Canada	SWE	Restricted	
WSL Institute for Snow and Avalanche Research SLF	Switzer-land	Mountains	Interpolated snow observations using distributed hydrological model	1998-2014	Daily	T. Jonas, SLF	SWE	Restricted	
SNOWGRID	Alps	Mountains	Gridded snow cover model	2011-2012	Daily	M. Olefs, ZAMG	SWE, SD	Restricted	10/2011-05/2012

* All seasons: 2000-2001, 2003-2004, 2005-2006, 2007-2008, 2011-2012

** RIHMI web page: http://meteo.ru/english/climate/cl_data.php

1.1.2. Reference Snow Maps from Landsat data

Based on the decisions made in ISSPI-1, a set of 459 Landsat scenes from Landsat-5 (188), Landsat-7 SLC-ON (255) and Landsat 8 (16) over the Northern Hemisphere was identified by the SnowPEx team in collaboration with external Landsat experts (Figure 1.1). ENVEO will cross-check if these Landsat scenes are distributed with respect to the selected land cover categories.

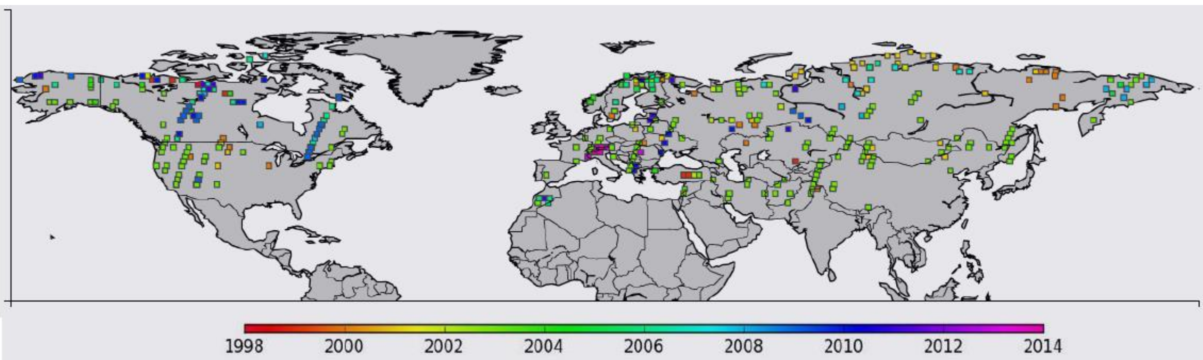

Figure 1.1: Availability of Landsat scenes for reference snow maps generation. The applied colour code shows the temporal distribution of the scene acquisitions.

At the ISSPI-2 workshop the participants in the SE splinter session agreed that this Landsat data set is sufficient to cover different snow zones, surface cover types, topography. It was mentioned that the available data set could be extended to cover the following regions:

- Himalaya (2010)
- South of Hudson Bay (2004, and time series)
- Tibetan plateau (2004)
- Canadian forested areas (2004)
- and with a set of multiple LS acquisitions of the same path/row of different years

ACTION: ***ENVEO***: *check the availability of suitable Landsat scenes in the regions listed above.*

For the snow detection from Landsat scenes 4 algorithms are applied on each of the selected scenes:

- Dozier and Painter (2004): binary snow on ground
- Klein et al. (1998): binary snow on ground
- Salomonson and Appel (2006): viewable fractional snow cover
- Painter et al. (2009) – TMSCAG: viewable fractional snow cover and snow on ground

1.2. Pre-processing of SE products and ancillary data

The products participating in the SnowPEx intercomparison and validation exercise were prepared by the product providers according to the SnowPEx product coding document, keeping the original map projection and grid sizes. These products, re-coded and renamed according to the SnowPEx standards, were uploaded by the product providers to the FTP installed at ENVEO. In order to make these products comparable all data sets need to be harmonized regarding map projection and grid sizes. It was decided after the ISSPI-1 workshop that the equal-area map projection WGS84 / NSIDC EASE-GRID 2.0 North (EPSG: 3973) and 5 km and 25 km grid sizes will be used for all product intercomparisons. Additionally to the products, ancillary data are required for distinguishing different land categories for the products intercomparisons and validation, which also have to be prepared to match exactly the geometry of the products.

Thus, before starting the SE products intercomparison activities the following pre-processing steps were executed by ENVEO:

1. Collect products from product providers for a pre-defined period
2. Collect and prepare all required geo-spatial ancillary data
    - Digital Elevation Model
    - Surface classification, including at least water and forest

- Any other ancillary data, e.g. climate zones
- Prepare static masks of ancillary data including water, forest, mountains used for partitioning the intercomparison and validation exercises

3. Prepare products and used geo-spatial ancillary data
    - Transform products and ancillary data sets to a common projection and aggregate the data to a common grid size
    - Account for thematic differences between products
4. Prepare masks for products intercomparison
    - Mapped area (MAA) and valid area (VAA) masks for CCRS intercomparison
    - Intercomparison masks of all valid pixels and snow pixels for ENVEO intercomparison

These pre-processing steps were explained in detail at the ISSPI-2 workshop (Mon1.4), and were accepted by all participants.

ACTION: ***SnowPEx Team:*** *The SnowPEx snow products of the 5 years will be made available in original and EASE-GRID2 projection to the community.*

ACTION: ***Kat Bormann:*** *The current MODSCAG products are Viewable Snow product; Kat will apply a canopy correction to the MODSCAG products, and provide the new products to ENVEO.*

1.3. Product Intercomparison and Validation Protocols

1.3.1. Refinements of SE Product Intercomparison Protocols

This exercise includes the intercomparison of snow extent product. All products (independent of resolution, binary or fractional snow extent) can participate in the intercomparison. In the first intercomparison round the focus was on global and hemispheric snow extent products.

Two approaches (developed by CCRS and ENVEO) were presented at the ISSPI-2 workshop. The community agreed to apply the proposed CCRS and ENVEO protocols for SE intercomparisons.

As further refinements the viewable snow / snow on ground products (cf. Table 1.2) will be discriminated for intercomparisons in forests. This discrimination is not needed for open land. Additionally, the climate categorization of Sturm et al. (1995) will be considered for partitioning the product intercomparisons. Instead of the intercomparison of products with the maximum snow extent derived from all products it was decided to compare the products with the climatological mean data set. For reporting the intercomparison results for presentation in journals and conferences the product versus product matrix showing RMSE and Bias will be used. Regression metrics for SCF intercomparisons will be avoided since the SCF 0 % and SCF 100 % comparisons dominate these results. The SnowPEx team will continue working on finding the best way for illustrating key results.

Table 1.2:
Overview of SE products participating in the intercomparison (INTEXE) and validation (VALEXE) exercise, and the reported quantity to be considered for the product intercomparisons and validations. Products providing information on "snow on ground" are marked bold.

SnowPEx PROD. ID	**Product Name**	**Pixel size**	**Organisation**	**Thematic Parameter**	***Quantity***	***Precision of products ****	***Exercise***
ASNOW	Autosnow	4 km	NESDIS (P. Romanov)	Binary, Global	Viewable Snow		VALEXE INTEXE
CRCLIM	**CryoClim**	**5km**	**NR,METNO (R. Solberg et al.)**	**Binary, Global**	**Snow on Ground**	**≥ 50 %**	VALEXE INTEXE
CRYOL	**CryoLand**	**0.5 km**	**ENVEO / SYKE (T. Nagler et al.)**	**Fractional, PanEU**	**Snow on Ground**		VALEXE INTEXE
EURAC	**EURACSnow**	**0.25 km**	**EURAC (C. Notarnicola)**	**Binary, Alps**	**Snow on Ground**		VALEXE INTEXE
GLSSE	**GlobSnow v2.1**	**1 km**	**SYKE (S. Metsämäki)**	**Fractional, NH**	**Snow on Ground**		VALEXE INTEXE
HSAF10	HSAF H10	5km	FMI / EUMETSAT (M. Takala)	Binary, PanEU	?		VALEXE INTEXE
IMS01	**IMS**	**1 km**	**NOAA (S. Helfrich et al.)**	**Binary, NH**	**Snow on Ground**		VALEXE INTEXE
IMS04	**NOAA IMS**	**4 km**	**NOAA (S. Helfrich et al.)**	**Binary, NH**	**Snow on Ground**		VALEX INTEXE
IMS24	**NOAA IMS**	**24km**	**NOAA (S. Helfrich et al.)**	**Binary, NH**	**Snow on Ground**		INTEXE
JXAM5	JASMES GHRM5C	5km	JAXA (M. Hori et al)	Binary, Global	Viewable Snow		VALEXE INTEXE
JXM10	JASMES MDS10C	5km	JAXA (M. Hori et al)	Binary, Global	Viewable Snow		VALEXE INTEXE
M10C05	MOD10_C5	0.5 km	NASA (D. Hall et al.)	Fractional, Global	Viewable Snow		VALEXE INTEXE
MEASU	**MEaSUREs**	**25km**	**NASA (D. Hall et al.)**	**Binary, Global**	**Snow on Ground**		INTEXE
PATHF	**AVHRR Pathfinder**	**5km**	**CCRS (R. Fernandes, Zhao et al)**	**Fractional, NH**	**Snow on Ground**		VALEXE INTEXE
SCAG	SCAG	0.5 km	JPL, NSIDC (T. Painter et al.)	Fractional, NH	Viewable Snow		VALEXE INTEXE

SnowPEx PROD. ID	Product Name	Pixel size	Organisation	Thematic Parameter	*Quantity*	*Precision of products **	*Exercise*
					conversion to Snow on Ground TBC		

*** ***ACTION:*** ***PROVIDERS OF BINARY SNOW EXTENT PRODUCTS:*** *Please specify the probability of a given SCF: for mapping a pixel as snow covered in your binary product.*
PROVIDERS OF FRACTIONAL SNOW EXTENT PRODUCTS: *Please specify the uncertainty of your SCF product using the RMSE.*

ACTION: ***Gabriele Bippus and Richard Fernandes:*** *update the SE intercomparison protocol, and improve options for illustrating SE intercomparison and validation results.*

1.3.2. Refinements of Validation Protocols

The protocol for validation with in-situ data and Landsat Snow Maps was presented and discussed.

A) Protocol for SE products validation with Landsat reference snow maps:

The general validation protocol with reference snow maps from Landsat data was accepted by the community.

In order to exploit the 4 snow algorithms applied on Landsat scenes for validation it has been decided to check how the snow maps generated by these LS algorithms differ from each other after aggregation to 1 km and 5 km according to following methodology:

- Aggregate Landsat snow maps (30 m pixel size in UTM/WGS) to 1 km and 5 km pixel sizes
- Calculate the average of FSC, use spreading as uncertainty measure

For each of the Landsat scenes information on the forest content from GlobCover in geographic coordinates on WGS84 ellipsoid with 0.01 deg grid size will be provided by the SnowPEx team.

Note: The different **thematic information** provided by the 4 algorithms applied on the Landsat scenes has to be considered for the validation of the global/hemispheric snow extent products **in forested areas**. Algorithms of Dozier and Klein provide information on **snow on ground**, while TMSCAG and algorithm of Salomonson provide information on **viewable snow**. **All 4 Landsat algorithms are applied on all non-forested areas**.

ACTION: Karl Rittger: *The current TMSCAG products are Viewable Snow product; Karl will apply a canopy correction to the TMSCAG products. Karl will process some more Landsat images (clear sky)* *applying the TMSCAG (viewable snow and snow on ground). Elisabeth Ripper will send him the list of Landsat images.*

***ACTION:* Chris Crawford:** *Chris volunteered to run his cloud screening algorithm on all remaining Landsat scenes to generate cloud masks.*

***ACTION:* Elisabeth Ripper and Gabriele Bippus:** *update protocol for validation with reference snow maps from Landsat imagery.*

B) Protocol for SE products validation with in-situ observations:

In many areas where in-situ measurements are carried out information on snow depth is available. Thus, the focus for the validation of hemispheric snow extent products with in-situ data will be on snow depth measurements converted to binary snow information using the following conversion conditions:

- SD > 0 cm → 'snow', otherwise 'no-snow'
- SD ≥ 2 cm → 'snow', otherwise 'no-snow'
- 0 cm ≤ SD < 15 cm → 'no-snow', SD ≥ 15 cm → 'snow'
- 0 cm < SD ≤1 cm → trace snow (for RIHMI Stations where SCF information can be utilized to discriminate between thin full snow cover and trace snow (very low snow fractions))

Validation with in-situ observations will be made in the original map projection and grid size of the global/hemispheric snow extent products. ENVEO will provide SYKE the required pixel information of the original products for each observation day and location.

a) Validation of fractional snow cover products

Hemispheric fractional snow cover products are each converted to binary snow information (snow/no-snow).

For hemispheric SCF products the following conversion factors are applied:

- SCF<50% → 'snow'
- SCF≥ 50% → 'no-snow'

It is planned to test also other thresholds (40%, 60%) for converting SCF products to binary snow information. A 2 x 2 contingency table is created, and binary statistical measures are provided (accuracy, precision, hit-rate, f etc.) to describe the validation results.

The CCRS approach for intercomparing unchanged SCF products with in-situ observations will only be used for Finland where in-situ measurements of Finnish snow courses (up to 4 km transects) are available. The Cumulative Distribution Function (cdf) will be used to convert in-situ snow depth (SD) measurements to Snow Cover Fraction. The resulting 100 comparison pairs for each sampling time/location will be binned into four SCF categories, and a 4 x 4 contingency table is produced. Only binary measures will be reported, but no fractional measures (like RMSE and Bias).

b) Validation of binary snow cover products

Binary hemispheric snow products are used as they are. For reporting the validation results with the in-situ snow depth measurements converted to binary snow information, a 2 x 2 contingency table is created, and binary statistical measures are provided (accuracy, precision, hit-rate, f etc.).

***ACTION:* Sari Metsämäki:** *Update protocol of validation with in-situ data and perform validation with in-situ data.*

1.4. Design of SE Trend Analysis Exercise

The selected global and hemispheric snow extent products to be used for trend analyses and their temporal availability are shown in Figure 1.2. Although five years are not enough to make a trend analysis the SE community clearly stated that it is important to exploit the available SE products participating in SnowPEx to develop procedures for adding uncertainty information to the temporal trends. As a starting point to assess the uncertainty range in the temporal trend of the SE products the minimum and maximum monthly snow extent of each hemispheric SE product available for the five selected periods will be used.

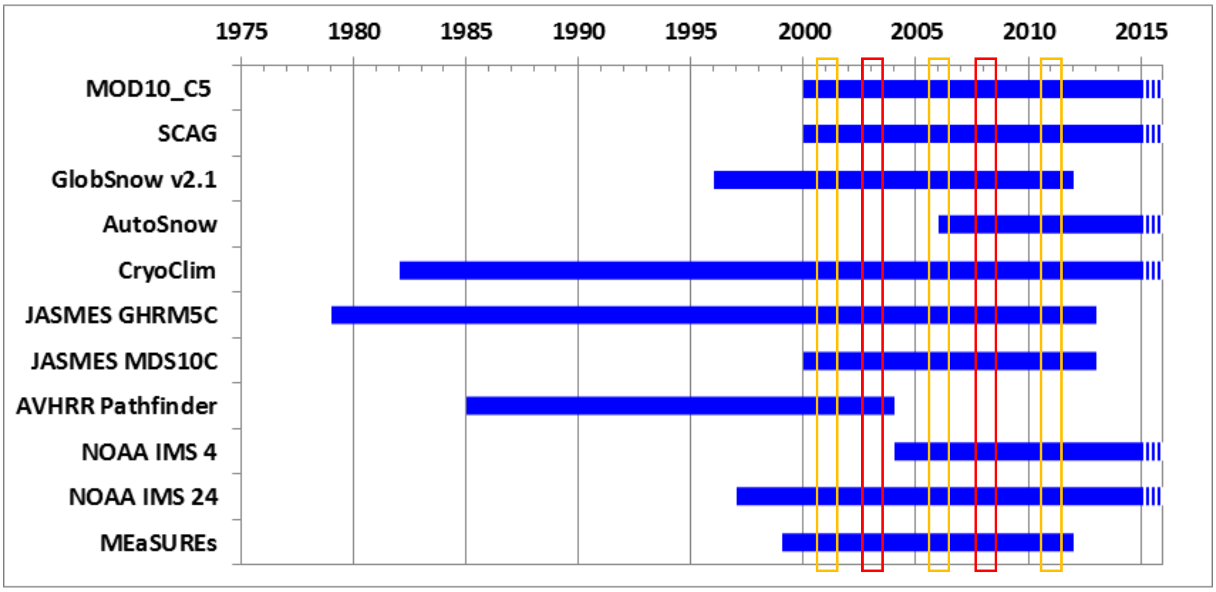

Figure 1.2: Periods for SE products participating in intercomparison exercise, and selected periods for intercomparisons. Red outlines mark the periods for which the first intercomparison results are presented at this ISSPI-2 workshop, orange outlines indicate periods with ongoing intercomparison activities.

2. SUMMARY AND OUTCOME OF SNOW WATER EQUIVALENT SPLINTER SESSION

The chair and rapporteur of the splinter session for SWE were C. Derksen and K. Luojus, respectively.

The discussion covered the following areas:

- participating SnowPEx SWE datasets
- summary of reference datasets and potential new additions
- refinement of analysis protocol
- project documentation
- publishing plan
- SnowPEx timeline in the context of other international snow initiatives

2.1. Participating SnowPEx SWE datasets

The datasets in Table 2.1 have been acquired and processed to a standard grid for inter-comparison.

Table 2.1: SnowPEx SWE datasets.

Dataset	Method	Ancillary/ Forcing Data	Resolution	Time Series	Reference
GlobSnow	Passive microwave + in situ	Weather station snow depth measurements	25 km	1979-2015	Takala et al (2011)
NASA AMSR-E standard	Standalone passive microwave		25 km	2002-2011	Kelly (2009)
NASA AMSR-E prototype	Microwave + ground station climatology	Weather station snow depth climatology	25 km	2002-2011	TBD
ERAint-Land	HTESSEL land surface model	ERA-interim	0.75° x 0.75°	1981-2010	Balsamo et al (2013)
MERRA	Catchment land surface model	MERRA	0.5° x 0.67°	1981-2010	Rienecker et al (2011)
Crocus	ISBA land surface + Crocus snow model	ERA-interim	1° x 1°	1981-2010	Brun et al (2013)
GLDAS-2	Noah 3.3 land surface model	Princeton Met.	1° x 1°	1981-2010	Rodell et al (2004)

The addition of the SSM/I SWE product from the National Snow and Ice Data Center was discussed. While no longer supported as an official product by NSIDC, Mary-Jo Brodzik agreed to provide 3 years of data for evaluation (2004-2007). Additional years may be provided by Mary-Jo in 2016.

2.2. Summary of Reference Datasets and Potential New Additions

Table 2.2 provides a summary of reference datasets in place for evaluation of the SWE products.

Table 2.2: Summary of reference data sets for evaluation of SWE products.

Dataset	***Region***	***Snow Class***	***Method***	***Time Period***	***Temporal Resolution***	***Contact***
Boreal Ecosystem Research and Monitoring Sites	Saskatchewan	Taiga	Sonic snow depth	1997-2014	Daily	H Wheater, U. Saskatchewan
Environment Canada – Bratt's Lake	Saskatchewan	Prairie	Sonic snow depth; manual surveys	2011-	Daily	C Smith, Environment Canada
FMI – Sodankyla	Finland	Taiga	Sonic snow depth; cosmic	19xx-2014	Daily	J. Pulliainen, FMI
Trail Valley Creek	Northwest Territories	Tundra	Sonic snow depth	2002-2014	Daily (with gaps)	P. Marsh, WLU
Finnish Environment Institute Snow Surveys	Finland	Taiga	Manual snow course	19xx-2014	Monthly	S. Metsämäki, SYKE
RusHydroMet Snow Surveys	Russia	Prairie; Taiga; Tundra	Manual snow course	1966-2009	Bi-weekly	O. Bulygina, RIHMI-WDC)
Hydro-Quebec Snow Survey Network	Quebec	Taiga	Kriged snow course	1999-2013	SWEmax	D. Tapsoba (IREQ)
Kuparuk River Basin Surveys	North Slope	Tundra	Manual	2006-2013	SWEmax	S. Steufer (UAF)
SLF Gridded SWE	Switzerland	Open; Alpine	Observations + distributed snow model	1998-2014	Daily	T. Jonas (SLF)

Potential additional datasets to add were discussed including: NRCS snow surveys (Carrie Vuyovich), the SnoTel network (Chris Derksen /Noah Molotch), and GPS stations (Ed Kim). The persons associated with each dataset above will pursue acquisition of these datasets, and further discussion will occur within the SnowPEx SWE team as to their eventual inclusion in the analysis.

2.3. Refinement of the analysis protocol

Results achieved to date were discussed, with the following objectives set for the next six months:

2.3.1. Interpretation of comparisons with in situ data (led by Kari Luojus; fall 2015/winter 2016):

- ***ACTION:*** *produce summary tables of comparison statistics with Finnish and Russian snow surveys, organized by month/region etc.*
- utilize a standard time period for comparison of model and microwave datasets, although this will reduce the sample size
- test for land cover representativeness of Finnish and Russian snow survey data: ensure the transect land cover matches the dominant EASE-Grid land cover and stratify results by the level of this agreement
- explore whether the Russian snow surveys can be binned to 1x1 degree resolution to facilitate a spatial comparison. Regardless, a spatial visualization of the comparison with the Russian data should be explored
- perform comparison with in situ reference datasets from Canada (L. Mudryk/C. Derksen/R. Brown; fall 2015/winter 2016)

2.3.2. Gridded product comparison: merging spread with bias information (L. Mudryk/C. Derksen/Kari Luojus; fall 2015)

- ***ACTION:*** *recalculate the multi-dataset mean using various ensemble combinations*
- ***ACTION:*** *evaluate these ensemble combinations with in situ data (relying primarily on the Russian data) and determine the optimal ensemble of datasets to minimize RMSE and bias relative to the Russian snow surveys. Perform a similar evaluation with North American reference datasets to ensure consistency at the continental scale*

2.3.3. Watershed analysis (Carrie Vuyovich):

- ***ACTION:*** *conduct watershed evaluation, and evaluate the optimal ensemble dataset delivered by Environment Canada, at the HUC4 scale (fall 2015/winter 2016)*
- ***ACTION:*** *conduct analysis of model, microwave, and optimal ensemble datasets with discharge data at the HUC8 scale (2016)*

2.3.4. Trend analysis (Environment Canada; winter 2016):

- ***ACTION:*** *produce monthly spatial trend maps over the 1981-2010 period at 1x1 deg resolution (ONDJFMAMJ; seasonal trends) using all individual products and the optimal ensemble*

- explore the use of Taylor diagrams to visualize multi-dataset trend agreement
- explore the derivation of SCE from the SWE datasets

2.4. Project Documentation

It was acknowledged that the protocol documentation (Deliverable 4 to ESA) requires updating (to be addressed in Deliverable 7), and the documentation of reference datasets (Deliverable 10 and metadata associated with each dataset) requires refinement (to be addressed by Chris; Kari).

2.5. Publishing Plan

As PI of SnowPEx T. Nagler / ENVEO will lead a joint publication on SnowPEx methods and main result. This will include SnowPEx project partners as co-authors, co-authorship is also offered to all contributing scientists. This joint publication will also serve as Final Report to ESA. In addition, project participants will continue to produce standalone papers on components of the SWE analysis, and make the connection to SnowPEx in these manuscripts.

2.6. SnowPEx Timeline in the Context of Other International Snow Initiatives

SnowPEx will make important contributions to CMIP6, and new snow mission concept studies at CSA, ESA, and JPL. The SWE splinter group produced Table 2.3 in order to summarize the timeline of various snow related initiatives.

Table 2.3: Timeline of international snow initiatives.

	2015				2016												2017		
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
SnowPEx	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
CSA concept study	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
ESA concept study			■	■	■														
ESA EE-9 proposal development					■	■	■												
JPL concept study	■	■	■																
LS3MIP simulations					■	■	■	■	■	■	■	■	■	■	■	■			
ESM-SnowMIP simulations											■	■	■	■	■	■	■	■	■
SnowEx														■	■	■	■	■	■

3. RECOMMENDATIONS OF THE SNOW COMMUNITY

Open Accessible Reference Data Set for Algorithm Development and Intercomparison, extended by 3-5 years

The availability of **regularly updated reference data** for validating snow products is crucial for assessing the quality of the products. Reference data must be spatially and temporarily well distributed over the area and time of interest. The preparation of a harmonized reference data set including high resolution satellite data and quality checked in-situ data which is updated every 3 – 5 years and would be freely made available would be of great benefit for the full snow community.

Continuation of SnowPEx and Follow-on Workshop ISSPI-3

The continuation of SnowPEx activities was discussed by the community. The community stated that that there is a high need for continuation of SnowPEx activities which contribute to WMO GCW and which are also of high interests for WRCP CliC. A follow-on WS of ISSPI-1 and ISSPI-2 was highly recommended by the community. Potential scientific topics for SnowPEx extension or follow project- and of a potential ISSPI-3 WS, such as trend assessments, product provision, synergy SWE/SE, assessing the maturity of products, were discussed.

Publications

Finally, a joint publication of SE and SWE SnowPEx intercomparison protocols and results including all relevant contributors as co-authors in a peer reviewed journal is planned under the lead of ENVEO. Afterwards, further publications with details about products validation with Landsat and in-situ reference data are planned. All participants agreed on these suggestions. Details regarding the publication strategy will be further discussed by the SnowPEx team in the next meetings.

4. SUMMARY OF ACTIONS ITEMS

ID	Item	Responsibility	Due Date	Status
ACTION 01	Extend existing data base with scenes over Himalaya (2010), South of Hudson Bay, Tibetan plateau, Canadian forested areas (2004) and multiple LS acquisitions of same path/row in different years	ENVEO	16 Oct. 2015	Completed
ACTION 02	Final documentation of Protocols	ENVEO, CCRS, SYKE, EC, NR, FMI	30 Oct. 2015	Final Draft
ACTION 03	Make SnowPEx snow products (5 years) available in original and EASE-GRID2 projection to the community	SnowPEx Team	30 Oct. 2015	In progress, data provided on request
ACTION 04	Send information on precision of SE product to ENVEO (see Table 1.2)	Participating SE Product Providers	30 Oct. 2015	PENDING
ACTION 05	Prepare MODSCAG and TMSCAG to correct for canopy to provide snow on ground and provide data to ENVEO	Kat Bormann (MODSCAG), Karl Rittger (TMSCAG)	30 Oct. 2015	TMSCAG in progress
ACTION 06	Finalization of validation data sets (in-situ and LS) for SnowPEx periods	ENVEO, SYKE	31 Dec. 2015	
ACTION 07	Make validation datasets available at snowpex.enveo.at	ENVEO, ESA	1 Feb. 2016	
ACTION 08	Improve options for illustrating SE intercomparison and validation results	ENVEO, SYKE, CCRS, NR	1 Apr. 2016	
ACTION 09	Produce summary tables of comparison statistics with Finnish and Russian snow surveys, organized by month/region etc.	FMI	1 Dec. 2015	
ACTION 10	Recalculate the multi-dataset mean using various ensemble combinations, and evaluate with in situ data to determine the optimal ensemble of datasets to minimize RMSE and bias	EC	1 Apr. 2016	
ACTION 11	Conduct watershed evaluation, including the optimal ensemble dataset at the HUC4 scale; conduct analysis of model, microwave, and optimal ensemble datasets with discharge data at the HUC8 scale	CRREL	1 June 2016	
ACTION 12	Produce monthly spatial trend maps over the 1981-2010 period at 1x1 deg resolution using all individual products and the optimal ensemble	EC	1 June 2016	

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