14-16 September 2015
Boulder, Colorado, USA

2nd International Satellite Snow Products Intercomparison Workshop

SCIENTIFIC COMMITTEE

Gabriele Bippus (ENVEO)	Sari Metsämäki (SYKE)
Bojan Bojkov (ESA)	Thomas Nagler (ENVEO) (Chair)
Chris Derksen (EC)	Jouni Pulliainen (FMI)
Richard Fernandes (CCRS)	Dave Robinson (Rutgers University)
Dorothy Hall (NASA)	Helmut Rott (ENVEO)
Sean Helfrich (NOAA)	Rune Solberg (NR)
Kari Luojus (FMI, WMO GCW)	Marco Tedesco (CCNY/CUNY)

VENUE

Aspen Room

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

DATE

14 - 16 September 2015

SNOWPEX PROJECT AND WORKSHOP WEBSITE

Updated information and outcome of the workshop is made available at http://calvalportal.ceos.org/projects/snowpex.

LOCAL ORGANIZER

Cindy Brekke / NSIDC

CONTACTS

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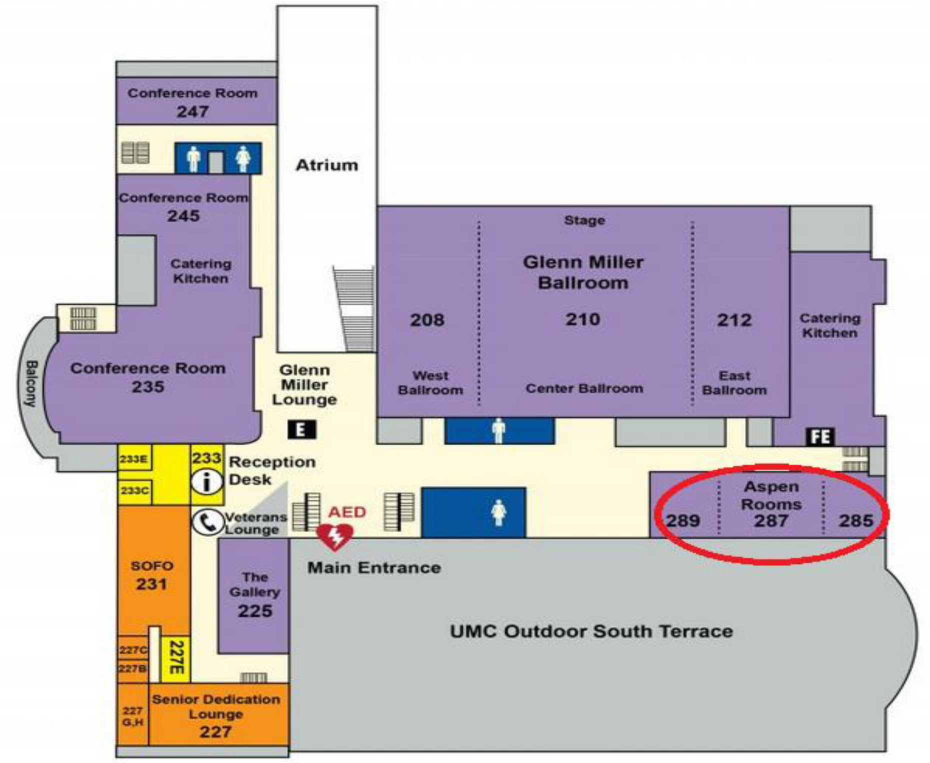
DIRECTIONS

Venue:

Aspen Room

University Memorial Center (UMC)

University of Colorado Boulder 80302

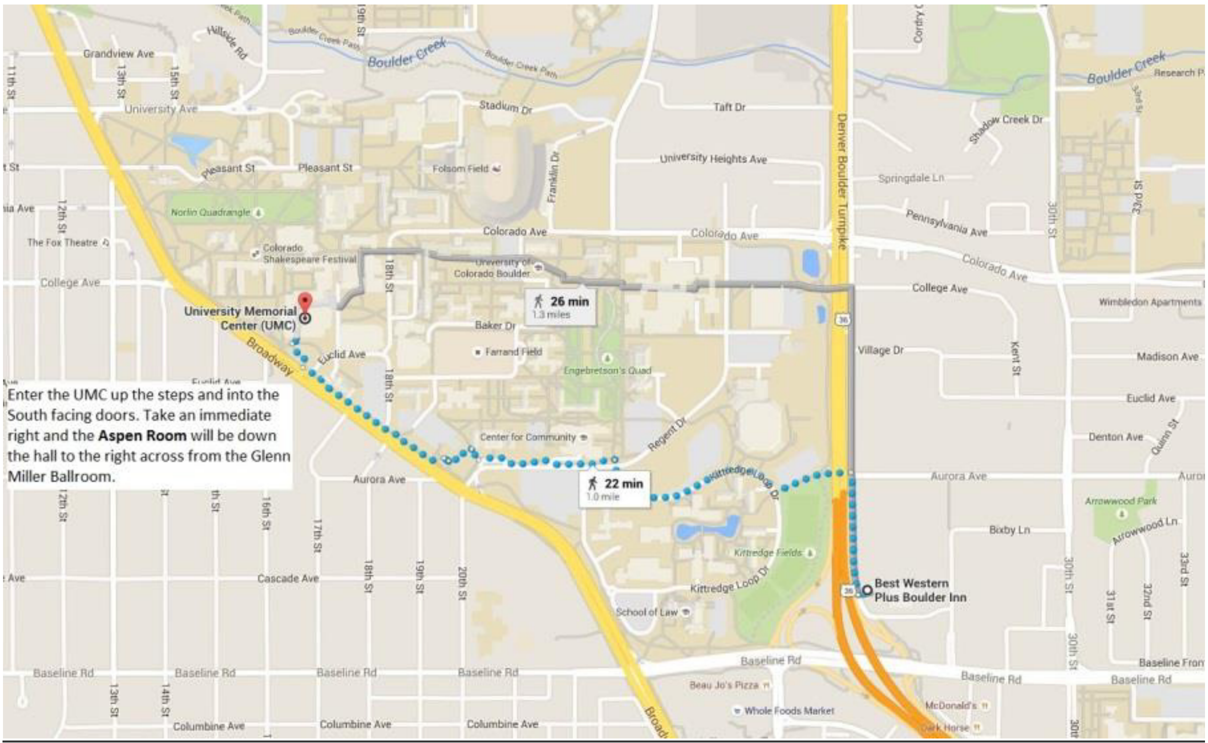


We recommend that participants walk to the facility rather than drive.

If you do wish to drive there is parking available to the east of the UMC at the Euclid AutoPark lot. You will need to have your license plate number to pay at any of the pay-stations located at each pedestrian exit.

The EAP parking rate is $2.00 per hour up to three hours, during the hours of 7:30 AM - 5:00 PM. After three hours, the rate is $4.00 per hour. The parking fee is $4.00 from 5:00 p.m. until 7:30 a.m. each weeknight and all day Saturday and Sunday. EAP pay-stations accept payment by credit card, coin and Parkmobile (Zone 6334.)

Walking Directions from the Boulder Inn to the UMC



PROGRAM

MONDAY, 14 September 2015 - MORNING

	08:30	09:00	RECEPTION	

MON-1			**ORAL SESSION: OPENING**	**Chair: Thomas Nagler Chris Derksen**
Mon 1.1	09:00	09:10	Welcome Housekeeping and organisation	Thomas Nagler (ENVEO), Bojan Bojkov (ESA) / Cindy Brekke / NSIDC
Mon 1.2	09:10	09:30	The Satellite Snow Product Intercomparison and Evaluation Experiment SnowPEx: Objectives, status and expected results	Thomas Nagler
Mon 1.3	09:30	09:50	On the importance of fiducial reference measurements for EO satellite characterisation and traceability	Bojan Bojkov
			ORAL SESSION: SNOW EXTENT PRODUCTS - 1	**Chair: Thomas Nagler Chris Derksen**
Mon 1.4	09:50	10:10	Overview of snow extent products participating at SnowPEx and pre-processing steps for intercomparison	Gabriele Bippus, Thomas Nagler, Elisabeth Ripper, Richard Fernandes, Sari Metsämäki
Mon 1.5	10:10	10:30	Intercomparison of snow extent products - CCRS method and first results	Richard Fernandes, Gabriele Bippus, Sari Metsämäki, Elisabeth Ripper, Thomas Nagler

	10:30	11:00	COFFEE BREAK

MON-2			**ORAL SESSION: SNOW EXTENT PRODUCTS – 2**	**Chair: Richard Fernandes David Robinson**
Mon-2.1	11:00	11:20	Intercomparison of snow extent products - ENVEO method and first results	Gabriele Bippus, Elisabeth Ripper, Thomas Nagler
Mon-2.2	11:20	11:40	Landsat based snow extent reference data set and first validation results	Elisabeth Ripper, Gabriele Bippus, Thomas Nagler, Christopher J. Crawford, Sari Metsämäki, Rune Solberg, and Karl Rittger
Mon-2.3	11:40	12:00	SnowPEx in-situ data sets and first validation results	Sari Metsämäki, Gabriele Bippus, Kari Luojus, Chris Derksen, et al.
Mon-2.4	12:00	12:20	NESDIS Global Automated Satellite Snow Product: current status and planned upgrades	Peter Romanov
Mon-2.5	12:20	12:40	Recent advancements to the Interactive Multisensor Snow and Ice Mapping System	Sean Helfrich

	12:40	14:00	LUNCH BREAK

MONDAY, 14 September 2015 - AFTERNOON

MON-3			**ORAL SESSION: SNOW EXTENT PRODUCTS – 3**	**Chair: George Riggs Rune Solberg**
Mon-3.1	14:00	14:20	Standard MODIS snow cover products	George A. Riggs, Dorothy K. Hall, Christopher A. Crawford, and Nicolo E. DiGirolamo
Mon-3.2	14:20	14:40	Evaluation of JXAM5 snow cover extent product using ground based snow depth information and Landsat images	Masahiro Hori, Konosuke Sugiura, Tomonori Tanikawa, Teruo Aoki, Masashi Niwano, and Hiroyuki Enomoto
Mon-3.3	14:40	15:00	Assessment of H-SAF MSG/SEVIRI snow cover product over the UK	Samantha Pullen
Mon-3.4	15:00	15:20	Assessment of the stability of a satellite snow extent CDR from station snow depth observations	David Robinson, Thomas Mote, and Kim Love-Myers
Mon-3.5	15:20	15:40	Time series analysis of mountain snow cover from MODSCAG and VIIRSCAG	Kathryn Bormann, Karl Rittger, Thomas. H. Painter

	15:40	**16:10**	**COFFEE BREAK**	

MON-4			**ORAL SESSION: SNOW EXTENT PRODUCTS - 4**	**Chair: Gabriele Bippus Karl Rittger**
Mon-4.1	16:10	16:30	Advancements and validation of the global CryoClim snow cover extent product	Rune Solberg, Øystein Rudjord, Arnt-Børre Salberg, Mari Anne Killie
MON-5			**POSTER PRESENTATIONS: 2 Minutes (1-2 Slides)**	**Chair: Gabriele Bippus Karl Rittger**
Mon-5.1	16:30		Validating a new snow cover extent mapping algorithm over Eastern Canada	Sophie Roberge, Karem Chokmani, and Danielle De Sève
Mon-5.2			Satellite based probabilistic snow cover extent mapping (SCE) at Hydro-Québec	Danielle De Seve, Teasdale Mylène, Jean-Francois Anger, and Luc Perreault
Mon-5.3			Fractional snow cover for Landsat OLI, MODIS, and VIIRS from spectral mixture analysis	Karl Rittger, Kathryn Bormann, Richard, Armstrong, Thomas, Painter, and Jeff Dozier
Mon-5.4			Scene-specific fractional snow cover algorithms for optical remote sensing	Igor Appel
Mon-5.5			The seasonality of snow/cloud discrimination in Landsat imagery across the Northern Hemisphere	Chris Crawford
Mon-5.6			Evaluating multi-spectral snowpack reflectivity with changing snow grain sizes	Do Hyuk Kang, Ana Barros, and Edward Kim
Mon-5.7			Optimal linear relationships of fractional snow cover with visible reflectance and NDSI	Igor Appel
Mon-5.8			Snow monitoring in mountain areas from medium to high resolution images: towards Sentinel 2 data	Carlo Marin, Edoardo Cremonese, Ludovica De Gregorio, Mattia Callegari, and Claudia Notarnicola

Mon-5.9			Updated JAXA GCOM-W/AMSR2 snow depth standard product and its validation	Hiroyuki Tsutsui, Keiji Imaoka, Richard Kelly, and Takashi Maeda
Mon-5.10			Using image reconstruction to enhance spatial resolution of a reprocessed satellite passive microwave historical record	Mary J. Brodzik, David L. Long, Molly A. Hardman, Aaron Paget, and Richard L. Armstrong
Mon-5.11		17:00	COST Action ES1404: A European network for a harmonised monitoring of snow for the benefit of climate change scenarios, hydrology and numerical weather prediction	Samantha Pullen

	17:00	**19:00**	**ICEBREAKER AND POSTER SESSION**

TUESDAY, 15 September 2015 - MORNING

TUE-1			**ORAL SESSION: SNOW WATER EQUIVALENT-1**	**Chair: Chris Derksen Carrie Vuyovich**
Tue-1.1	09:00	09:20	The Satellite Snow Product Intercomparison and Evaluation Experiment: overview of progress for snow water equivalent	Chris Derksen, Lawrence Mudryk, Kari Luojus, Ross Brown, and Carrie Vuyovich
Tue-1.2	09:20	09:40	Assessment of the satellite-based SWE datasets with snow transect data	Kari Luojus, Jouni Pulliainen, Chris Derksen, Ross Brown
Tue-1.3	09:40	10:00	Evaluating the consistency and accuracy of several Northern Hemisphere snow water equivalent datasets	Lawrence Mudryk, Chris Derksen, Paul Kushner, and Ross Brown
Tue-1.4	10:00	10:20	Development of a 10-km gridded SWE dataset over south-western Quebec for SnowPEx validation	Ross Brown and Dominique Tapsoba
Tue-1.5	10:20	10:40	Watershed-based comparison of global SWE algorithms to SNODAS modelled SWE across the United States	Carrie Vuyovich, Jennifer Jacobs, Timothy Baldwin, and Steven Daly

	10:40	**11:10**	**COFFEE BREAK**

TUE-2			**ORAL SESSION: SNOW WATER EQUIVALENT-2**	**Chair: Kari Luojus Lawrence Mudryk**
Tue-2.1	11:10	11:30	An Overview of the current NASA operational AMSR-E/AMSR2 snow science team activities	Marco Tedesco, Mattia Sartori, and Jeyavinoth Jeyaratnam
Tue-2.2	11:30	11:50	The GCOM-W1 AMSR2 snow depth and snow water equivalent product	Richard Kelly, Nastaran Saberi, and Qinghuan Li
Tue-2.3	11:50	12:10	Contributions of SnowPEx to Global Climate Modeling Initiatives	Chris Derksen, with contributions from the LS3MIP and ESM-SnowMIP steering committees
Tue-2.4	12:10	12:30	The NASA SnowEx airborne snow campaign: an upcoming opportunity for SnowPEx	Edward Kim, Charles Gatebe, Dorothy Hall, and Matthew Sturm

	12:30	**14:00**	**LUNCH BREAK**

TUESDAY, 15 September 2015 - AFTERNOON

TUE-3			**SESSION: SPLINTER-1 SE & SWE Separately**	
	14:00	15:30	Snow Extent: Topic: Review of generation of reference data / Pre-processing for Intercomparisons	Chair: Thomas Nagler Rapporteur: Richard Fernandes
	14:00	15:30	Snow Water Equivalent: Review of results; upcoming comparisons with in situ data	Chair: Chris Derksen Rapporteur: Kari Luojus

	15:30	**16:00**	**COFFEE BREAK**

TUE-4			**SESSION: SPLINTER-2 SE & SWE Separately**	
	16:00	17:30	Snow Extent: Intercomparison and validation protocols: discussion, trend analysis, and next steps	Chair: Thomas Nagler Rapporteur: Richard Fernandes
	16:00	17:30	Snow Water Equivalent: plans for trend analysis	Chair: Chris Derksen Rapporteur: Kari Luojus

WEDNESDAY, 16 September 2015 - MORNING

WED1.1	09:00	9:40	The role of product intercomparisons in the Global Cryosphere Watch	Jeff Key
WED-1			**SESSION: SPLINTER-3 SE & SWE Separately**	
	09:40	11:00	Snow Extent (continued)	Chair: Thomas Nagler Rapporteur: Richard Fernandes
	09:40	11:00	Snow Water Equivalent (continued)	Chair: Chris Derksen Rapporteur: Kari Luojus

	11:00	**11:30**	**COFFEE BREAK**

WED-2			**ORAL SESSION: SUMMARY**	**Chair: Thomas Nagler Chris Derksen**
WED2.1	11:30	11:50	Summary of SE Splinter Session	Thomas Nagler, Richard Fernandes
WED2.2	11:50	12:10	Summary of SWE Splinter Session	Chris Derksen, Kari Luojus
WED2.3	12:10	12:30	Discussion	Chris Derksen / Thomas Nagler
WED2.4	12:30	13:00	Action Items, Next Steps	Thomas Nagler / Chris Derksen

WED-3	**13:00**		**Closing of Workshop**	**Thomas Nagler (ENVEO), Bojan Bojkov (ESA)**

A B S T R A C T S

MON-1 MONDAY, 14 SEPTEMBER 2015
ORAL SESSION: OPENING

Mon-1.2 The Satellite Snow Product Intercomparison and Evaluation Experiment SnowPEx: Objectives, status and expected results

Thomas Nagler

ENVEO IT GmbH, Austria

This presentation will provide an overview and current status of the SnowPEx Initiative to the Workshop participants. The motivation and the primary objectives of the project will be presented and the overall design of the project will be explained. The progress of the 1st year of the SnowPEx project will be summarized. An overview on the protocols and validation methods for snow extent and snow water equivalent methods including selected examples will be given pointing to the detailed presentations at the WS. The available reference data set consisting of in-situ snow maps and Landsat data will be summarized. The expected results from the second international snow product intercomparison workshop will be presented as well as the overall outcome of the project.

Mon-1.3 On the importance of fiducial reference measurements for EO satellite characterisation and traceability

Bojan R. Bojkov

European Space Agency (ESA), Italy

Earth observation (EO) from satellites has revolutionised our view of the Earth's atmosphere, oceans, land and the cryosphere. Due to these advances, EO offers an enormous potential for continuous monitoring the state of the environment and for examining the planet's response to the changes in the climate. As such, satellite instruments and their measurements are playing an increasingly important role in supporting the formulation, management and stewardship of environmental policies.

Starting with the first Earth Observation (EO) satellite TIROS-1 in 1960, a rigorous instrument calibration, a continuous monitoring of sensor performance and an extensive validation of the derived products, using independent high-quality in-situ measurements, or Fiducial Reference Measurements (FRM), have been key to any successful mission. Long-term data quality requirements, such as for climate change or for data preservation, have added to the importance of the continuous characterization of sensors and the validation of products across missions using FRM. In addition, the development in recent years of downstream services using space-borne data have increased the need for documented end-to-end characterization of the EO sensors and their derived products.

It is essential for all space agencies to ensure that an uninterrupted stream of high quality, well-calibrated FRM are available to scientists and policy makers to address strategic issues of national and global significance. As far as calibration and validation (Cal/Val), and data quality are concerned, many issues such as interoperability between EO sensors and products have led to coordinated efforts in the Cal/Val methodologies through the Committee on Earth Observation Satellites Working Group Cal/Val (CEOS/WGCV) and World Meteorological Organization's Global Space-based Inter-Calibration System (WMO/GSICS), leading to the establishment of QA4EO guidelines by CEOS/WGCV and their subsequent adoption by the Group on Earth Observation (GEO). These efforts need improved coordination across the space agencies and international bodies, especially in regards to the Fiducial Reference Measurements infrastructure, measurement planning and the use of best practises across common activities, such as in the SnowPEx project.

ORAL SESSION: SNOW EXTENT PRODUCTS-1

Mon-1.4 Overview of snow extent products participating at SnowPEx and pre-processing steps for intercomparison

Gabriele Bippus[a], Thomas Nagler[a], Elisabeth Ripper[a], Richard Fernandes[b], Sari Metsämäki[c]

[a]ENVEO IT GmbH, Austria

[b]CCRS, Canada

[c] Finnish Environment Institute, Finland

For the SnowPEx Snow Extent (SE) products intercomparison the methods and protocols defined at the 1st ISSPI Workshop in July 2014 are applied. So far, 9 global/hemispheric/continental SE products provided by the contributing product providers for selected periods are included in the intercomparison exercise. The SE intercomparison performed by ENVEO is based on a pixel by pixel moving window approach, using statistical measures to describe the comparison results.

The intercomparison exercises include the total land cover, and additionally analyses of product performances for particular surface classes, such as forest, mountain areas, etc. The SE product intercomparison is done for all products aggregated to 5 km and 25 km grid size, using the map projection EASE-GRID 2.0.

In this presentation we explain the pre-processing steps applied to the various SE products, following the methods and guidelines defined at the 1st ISSPI Workshop.

Mon-1.5 Intercomparison of snow extent products - CCRS method and first results

Richard Fernandes [a], Gabriele Bippus[b], Sari Metsämäki[c], Elisabeth Ripper[b], Thomas Nagler[b]

[a]*CCRS, Canada*

[b]*ENVEO IT GmbH, Austria*

[c]*Finnish Environment Institute, Finland*

Intercomparison of global and continental scale satellite based snow extent (SE) product is required to identify outlier products and to identify areas with low agreement for further assessment. SE intercomparison is complicated by differences in: i) product definition as either binary snow extent (SEB) or snow cover fraction (SCF) ii) in map projection and grid resolution and iii) in the area mapped on any given date. Previous work (e.g. GLOBSNOW) has identified suitable comparison metrics for comparing either SEB or SCF. Here we provide a probabilistic framework for translating between SEB and SCF to allow for the metrics to be applied to all products. The probabilistic framework also allows for comparing large (e.g. 25km square) grid cells with multiple product pixels. Finally, the framework is extended to model the uncertainty of SEB or SCF over a grid cell due to missing retrievals in the cell. The approach is applied to all provided SNOWPEX SE products for two annual cycles and results are reported. Additionally results based on a non-probabilistic framework using only completely mapped grid cells are reported for comparison.

MON-2 ORAL SESSION: SNOW EXTENT PRODUCTS-2

Mon-2.1 Intercomparison of snow extent products - ENVEO method and first results

Gabriele Bippus, Elisabeth Ripper, and Thomas Nagler

ENVEO IT GmbH, Austria

Intercomparisons of global / hemispheric snow extent products are important for quality assessment of the products and for interpretation of the climate trends of seasonal snow cover. In this presentation we introduce a protocol for intercomparison of medium resolution snow products using statistical parameters to characterize the agreement/disagreement between the snow products. The protocol is based on previous validation and intercomparison of ENVEO within the ESA GlobSnow-2 and the EU FP 7 CryoLand projects, and has been further improved for SnowPEx. Input to the procedure are pre-processed snow extent products in EASE-GRID 2.0 projection aggregated to 5 km and 25 km. The procedure calculates various statistical parameters from a pixel-by-pixel intercomparison, excluding all regions where one of the products shows clouds, open water, polar night or invalid pixels. The protocol is applied to the overall area, but also to specific land surface classes to investigate the performance of the products in different environments. Beside statistical parameters we calculate the mean spatial distribution of the differences between 2 snow products over a certain time period. We will present first results of the intercomparison of 9 global / hemispheric snow extent products available for SnowPEX and will discuss the various methods for presenting the results.

Mon-2.2 Landsat based snow extent reference data set and first validation results

Elisabeth Ripper[a], Gabriele Bippus[a], Thomas Nagler[a], Christopher J. Crawford[b],
Sari Metsämäki[c], Rune Solberg[d], and Karl Rittger[e]

[a] ENVEO IT GmbH, Austria
[b] Cryospheric Sciences Laboratory, NASA/GSFC, USA
[c] Finnish Environment Institute, SYKE, Finland
[d] Norwegian Computing Center, Norway
[e] National Snow and Ice Data Center, USA

At the 1st ISSPI workshop it was decided to validate the medium and low resolution snow extent (SE) products participating in SnowPEx with high resolution snow maps from Landsat (LS) data. A data set of 459, predominately cloud free, scenes from Landsat-5, Landsat-7 (SLC-ON) and Landsat-8 was selected and compiled by the SnowPEx team. The scenes are acquired in different environments and climate zones at different seasons and solar illumination over the northern hemisphere. They cover different land cover types like forest, mountainous regions or areas with different amount of open water bodies. In order to avoid a bias in the snow detection by using only one algorithm, we selected 4 published algorithms for generating the Landsat snow reference data set: The algorithms from Dozier and Painter (2004) and Klein et al (1989) result in binary snow extent maps and the algorithms of Salomonson and Appel (2006) and the TMSCAG (Painter et al.) provide fractional snow extent. The TMSCAG algorithm is based on Landsat surface reflectance products from USGS, whereas the other 3 algorithms use Landsat L1T raw data provided by USGS as input. The pre-processing steps radiometric calibration and topographic correction are applied on the L1T scenes. .The Landsat snow products from the various algorithms are intercompared at full resolution to investigate the performance in snow detection. The high resolution Landsat snow products are reprojected and aggregated to each of the map projection and resolution of the coarser resolution global/hemispheric snow extent products. We will present the method and first results of the intercomparison of Landsat snow maps from different algorithms and the validation of global/hemispheric SE products using aggregated Landsat snow maps for selected regions.

Mon-2.3 SnowPEx in-situ data sets and first validation results

Sari Metsämäki[a], Gabriele Bippus[b], Kari Luojus[c], Chris Derksen[d], and others

[a] Finnish Environment Institute, SYKE, Finland

[b] ENVEO IT GmbH, Austria

[c] Finnish Meteorological Institute, Finland

[d] Environmental Canada, Canada

The vast majority of the data represents point-wise observations made at weather stations but also path data (snow transects) are available to some extent. The snow parameters include Snow Depth, Snow water equivalent and Snow Cover Fraction, depending on a dataset. An overview of the available data sets is given.

Comparison of snow-extent (SE) products vs. in-situ observation follows the SnowPEx validation protocol. In the protocol, the validation method is defined separately for SCF-products (CSF 0-100%) and binary (snow/non-snow) products. The validation activity started with SCF products i.e. AVHRR Pathfinder (PATHF), GlobSnow SE (GLSSE), MOD10_C5 (M10C05), CryoLand Pan-European SE product (CRYOL) and finally, SCAG. According to the protocol, Snow Cover Fraction from in-situ observations are derived either by i) direct CSF observations (these data are available only from Finnish snow course network and from RIHMI snow transects) or ii) from Snow Depth observations converted to CSF based on a statistical correspondence derived from Finnish snow course data where both CSF and SD are observed. Most SE-products to be validated in SnowPEx are binary snow/no-snow products. The validation protocol differs from that used for direct SCF-products, so that the data provider-defined SCF threshold for judging a pixel as 'snow' is applied to generate the approximate SCF. In both cases, instead of pixel-to-pixel comparison of single SCF-values, probability functions of SCF are employed to generate of random sample of for the validation window. These samples are the input to the calculation of numerical validation measures. The first results for the validation are presented, the emphasis being in the fractional snow products.

Mon-2.4 NESDIS global automated satellite snow product: current status and planned upgrades

Peter Romanov

NOAA, USA

NESDIS Global Multi-sensor Automated Snow/Ice Maps (GMASI) have been operationally produced at NOAA since 2006. The system combines information inferred from satellite observations in the visible/infrared spectral bands and from microwave sensors to generate continuous, gap-free daily global maps of snow and ice cover distribution at the spatial resolution of 4 km. In the current configuration the primary input to the system consists of the data from AVHRR instrument onboard METOP satellites and SSMIS data onboard DMSP satellites. Daily automated maps of the snow cover distribution are further processed to monitor hemisphere-wide and continental-scale snow cover extent as well as corresponding anomalies in the snow extent. The GMASI product is routinely used as one of the primary inputs to NOAA Interactive Multisensor Snow and Ice Mapping System (IMS) and to the retrieval system processing data from VIIRS and OMPS sensors onboard SNPP satellite.

In the presentation we discuss the results obtained during the last years of the system exploitation, identify issues affecting the accuracy of the product and outline the directions of the future system development. We compare the snow cover distribution and snow extent estimates generated with the automated algorithm with similar estimates based on the NOAA interactive snow and ice product. The results of comparison of satellite-based snow cover retrievals with observations of snow depth at ground-based meteorological stations will be presented and discussed.

The focus of the near-future modifications of the automated system will be on increasing the spatial resolution of snow and ice maps. This will be achieved by replacing AVHRR observations in the system by VIIRS data. Improvements in the snow and ice mapping under cloudy conditions are associated with the use of AMSR2 data in addition to SSMIS.

Mon-2.5 Recent Advancements to the Interactive Multisensor Snow and Ice Mapping System

Sean Helfrich

United States Department of Commerce, NOAA, USA

Environmental awareness of snow is a key input to NOAA's National Centers for Environmental Prediction (NCEP) numerical weather prediction (NWP) models. Current NCEP NWP models rely on the Interactive Multi-Sensor Snow and Ice Mapping System (IMS) snow cover area and the US Airforce snow depth products as the primary source of information on snow cover. Recent innovations in the IMS have added a 1km resolution output, new imagery and in-situ data sources, new formats, and additional fields (snow depth, sea ice concentrations, sea ice thickness, and a date of last observation). All historical formats were retained to promote continuity through time, while adding capacities required by NCEP and NOAA's Arctic Action Plan. The new snow depth, ice thickness, and ice concentrations apply a weighted blending of derived and analysed data sources from satellites and in-situ observations. Downscaling and interpolation techniques are applied to refine observations to a 4km scale. The release of this data has demonstrated improved utility, but remains in needs of improvements that will be forthcoming in the late 2015. Examples of snow applications and assessment of the analyses will be provided and reviewed.

MON-3 ORAL SESSION: SNOW EXTENT PRODUCTS-3

Mon-3.1 Standard MODIS snow cover products

George A. Riggs[a], Dorothy K. Hall[b], Christopher A. Crawford[c], Nicolo E. DiGirolamo[a]

[a] SSAI & NASA, USA
[b] NASA, USA
[c] ORAU & NASA, USA

Satellite Snow Products intercomparison and evaluation Exercise (SnowPEX) consists of an international team that will evaluate and compare current global / hemispheric snow-cover products to quantify uncertainty of long-term trends in snow-cover extent (SCE) and snow-water equivalent (SWE). This ESA-initiated project is a high priority for the Global Cryosphere Watch. The MODIS Snow and Ice Mapping Project has contributed five years of MOD10A1 snow-cover extent products in the format required by SnowPEX. Following receipt of the data files, a daily hemispheric product was mosaicked by SnowPEx personnel to create a Climate Modeling Grid (CMG) – like product for the Northern Hemisphere at 500-m resolution for a single day. This is an extraordinarily detailed snow map of the Northern Hemisphere and the first available at such a high resolution. Validation will be accomplished using Landsat and other high-resolution imagery.

Mon-3.2 Evaluation of JXAM5 snow cover extent product using ground based snow depth information and Landsat images

Masahiro Hori[a], Konosuke Sugiura[b], Tomonori Tanikawa[a], Teruo Aoki[c], Masashi Niwano[c], and Hiroyuki Enomoto[d]

[a] Japan Aerospace Exploration Agency, Japan
[b] University of Toyama , Japan
[c] Meteorological Research Institute, Japan
[d] National Institute of Polar Research, Japan

JXAM5 snow cover extent (SCE) product includes global snow cover extent at 5km spatial resolution at weekly or half-monthly intervals from 1979 to 2014 (except for some months in 1980, 1981, 1994, 1995 and 2001) derived from the data acquired with polar orbiting satellite optical sensor series of AVHRR and MODIS. The long-term SCE products will be connected to SCE to be derived from the data of SGLI onboard JAXA's Earth observing satellite GCOM-C to be launched in around early 2017. The accuracies of the snow cover extent product were evaluated using snow depth stored in Global Historical Climate Network-Daily (GHCND) provided by NOAA/NCDC. As the precedent studies have indicated, omission errors of the JXAM5 SCE tend to increase in spring melting season at dense forest areas such as closed broadleaved deciduous forest and needle-leaved evergreen forest and so on which are identified using the GlobCover land cover product. For the improvement of the SCE in such dense vegetation cover regions, capability of snow cover detection in dense forest area is under evaluation for domestic snow sites (Hokkaido in Japan) using in-situ snow depth, UAV photos, and high resolution Landsat imageries. In addition, long-term trends of annual snow cover duration period derived from the JXAM5 half-monthly SCE product are being evaluated and compared with those derived from the GHCND data at around the ground station sites.

Mon-3.3 Assessment of H-SAF MSG/SEVIRI snow cover product over the UK

Samantha Pullen

Met Office UK, United Kingdom

At the Met Office, a snow assimilation scheme is under development for implementation in the high resolution UK forecasting model. Both ground station snow depth reports and satellite-derived snow cover data will be used to produce an improved analysis of model snow extent and amount. Assessment of the snow cover product from the EUMETSAT H-SAF suggests that it would be a suitable source of UK snow cover data in the new assimilation scheme. This paper will describe the assessment of the H-SAF snow cover product for potential assimilation over the UK, and introduce the new assimilation scheme under development.

The lack of widespread persistent snowy conditions in the UK makes validation of observational and model snow data hard. Validation of satellite-derived snow cover data depends upon there being sufficient ground station reports, and cloud-free satellite observations for meaningful analysis. Validation must, therefore, be performed using data from exceptionally snowy winters. The UK experienced two episodes of severe winter weather between late November and late December 2010. Significant snowfalls on both occasions, and persistently low temperatures, led to much of the UK spending considerable time under lying snow, making this a particularly useful study period for assessment of modelled and observed snow in the UK.

For evaluation of the H-SAF snow cover product, comparisons of snow presence have been performed between the H-SAF product, short-range forecast fields of snow amount from the UK NWP model, and ground-based observations of snow from the UK Synoptic network, during December 2010. Representation of snow cover compared well between satellite product and model, with an overall rate of agreement of over 80%. An estimate of the relative accuracies of the remotely sensed and modelled snow cover was found by comparing both datasets with a common set of ground-based snow observations. Rates of agreement with ground station observations were very high for both datasets, but the H-SAF product performed better overall, with an agreement rate of over 89%. These results, along with qualitative studies of the snow cover in each dataset on individual days, indicate the added value that the H-SAF data could provide by assimilation into the forecasting model.

This paper will present full results of the assessment study, noting examples of particularly good, or poorer, performance. Some of the difficulties of validating satellite snow products are well illustrated in this study, and these will be discussed, along with some of the current activities underway to address them.

Mon-3.4 Assessment of the stability of a satellite snow extent CDR from station snow depth observations

David Robinson[a], Thomas Mote[b], and Kim Love-Myers[b]

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Station and satellite-based measures of snow cover extent produce complementary, but occasionally conflicting, climate data records (CDRs). A record of snow cover extent from visible satellite data is available on a weekly basis since the late 1960s, while a gridded station product for North America is available on a daily basis for the past century. Several changes in the visible satellite record have been documented by the Rutgers Global Snow Lab. The effects of these discontinuities in the satellite CDR — such as different sensors, overpass times, or mapping methodologies — have not been fully assessed. Here the gridded North American snow depth record is compared to the visible satellite record for different epochs within the satellite CDR. The average snow depths in the station product are identified for the 50th percentile probability of snow identification in the satellite product. The data set was broken into three different time periods, 1965 to 1980 (Period 1), 1981 to 1998 (Period 2), and 1999 to 2009 (Period 3), corresponding roughly to periods of technological and processing changes in the NOAA snow charts used to generate the CDR. A logistic regression modeled the probability of snow cover detection in any satellite cell based on two variables: average snow depth reported from weather stations, and fraction of reporting stations reporting at least 1 cm of snow. The modeled results were used to adjust the earlier two periods based on the most recent period, and the adjustment indicated that most recent period shows 5.23% greater snow extent Period 1, and 2.75% more than Period 2.

Mon-3.5 Time series analysis of mountain snow cover from MODSCAG and VIIRSCAG

Kathryn Bormann[a], Karl Rittger[b], and Thomas. H., Painter[a]

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The continuation of existing large-scale snow cover records into the future is crucial for monitoring the impacts of global pressures such as climate change, weather variability and dust deposition on the cryosphere. With daily MODIS records since 2000 from a now ageing MODIS constellation (Terra & Aqua) and daily VIIRS records since 2012 from the Suomi-NPP platform, the coherence of information between the two optical sensors for long-term monitoring must be reconciled. Daily fractional snow and vegetation cover data from SCAG (Snow Cover and Gran Size) algorithms were collected for both MODIS (Terra) and VIIRS retrievals and used to derive long-term estimates of regional snowline elevation and intra-season anomalies in snow covered area in mountainous terrain. The study focuses on snowline elevation in an attempt to capture changes in the rain/snow transition zone where climate change pressures may be enhanced. We also focus on snow cover area anomalies to both expand examination of snow cover metrics beyond the typical snow cover area and snow cover duration, with the expectation that we can start to capture extreme events (as the spatial datasets become of sufficient length). Where intra-seasonal snowfall extremes are important at the regional scale and may have implications for avalanche and flooding risk. Despite the large inter-annual variability often observed in snow metrics, we expect that over the 15-year time series we will see a rise in elevation of the snowline and the rain/snow transition boundary. However, the 15-year record is not expected to be sufficient to capture maximum snowfall extremes amidst significant inter-annual variability further demonstrating the importance of maintaining our earth observing records into the long-term. This work combines recent advances in snowline detection algorithms and the application of existing spectral unmixing techniques for fractional snow detection from VIIRS retrievals to create multi-sensor time series for long-term trend analysis.

MON-4 ORAL SESSION: SNOW EXTENT PRODUCTS-4

Mon-4.1 Advancements and validation of the global CryoClim snow cover extent product

Rune Solberg[a], Øystein Rudjord[a], Arnt-Børre Salberg[a], and Mari Anne Killie[b]

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Changes in the snow cover over time are a sensitive indicator of climate change at the global, continental and local scale. The Arctic region is warming faster than the Earth in general, and the corresponding part of the cryosphere is significantly affected. This includes the seasonal snow cover resulting in shorter snow seasons.

There are rather long time series (> 30 years) of daily optical and passive microwave radiometer (PMR) data of global coverage available. However, both sensor types are sensitive to weather conditions. Optical data can only be used under cloud-free conditions and with the sun sufficiently high above the horizon. With PMR it is difficult to retrieve the snow cover accurately when the snow is wet or when the snow depth is shallow.

To mitigate such effects we have in the CryoClim project (www.cryoclim.net) developed a multi-sensor multi-temporal algorithm for retrieval of snow cover extent (SCE) at the global scale from AVHRR GAC plus SMMR and SSM/I satellite data. The data from the two sensor types are fused in a multi-sensor model and analysed in a time series of observations. The resulting product is a binary SCE map of 5 km resolution. The algorithm is applied for generating a ~30-year time series of daily snow maps that will be updated regularly with new observations.

While the initial validation showed high accuracy in general (92.4%), there were a few known weaknesses that needed to be mitigated, as the accuracy requirements for a climate product are strict. Additionally, a more comprehensive validation was needed as to better characterise the temporal and land-cover dependent accuracy. In situ data from the former Soviet Union is by several authors in the snow research community regard as the data of highest quality available, in particular the HSDSD Version 2 and the FSUHSS data sets. HSDSD has two major advantages: its quality control and the fact that snow depth is recorded year-round, even during the warm season when snow is absent. This makes it possible to accurately and unambiguously identify the onset and end of the periods with snow on the ground, in contrast to the regular WMO synoptic observations, which are affected by occasional coding errors and sometimes do not distinguish between lack of snow and missing observations. The HSDSD data set starts in 1881 with a few stations and ends in 1995. The FSUHSS dataset includes snow density, snow depth and SWE observations generally collected within one day, 3 times per month, along transects.

The presentation will explain the algorithm and the characteristics of the CryoClim snow product, the new improvements implemented and the validation analysis and results.

MON-5 POSTER PRESENTATIONS (ORAL, 2 MINUTES PER POSTER)

Mon-5.1 Validating a new snow cover extent mapping algorithm over Eastern Canada

Sophie Roberge[a], Karem Chokmani[a], Danielle De Sève[b]

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[b] Institut de Recherche d'Hydro-Québec, Canada

Snow cover is a key element in the hydrological cycle of Eastern Canada. Being the leader in electricity supply, monitoring daily snow cover extent (SCE) and snow water equivalent (SWE) is one of the highest priorities for Hydro-Quebec to predict snowmelt water incomes. In the last five years, an operational procedure have been developed by both INRS and IREQ's remote sensing research teams to maps daily SCE over the provinces of Quebec and Labrador (Eastern Canada). The SCE mapping procedure is made of six thresholds to detect snow-covered areas, snow-free areas and clouds from 1-km daily NOAA-AVHRR images (visible and thermal infrared) taken during onset of snow cover and snowmelt periods, over the years 1988 to 2013. Snow maps have been compared with ground-truth snow measurements. The preliminary validating results have shown an overall accuracy of 95%. SCE has been identified in 90% of the time over Eastern Canada. However, SCE has been identified in 65% of the time only in forested areas. The SCE mapping procedure needs to be improved.

The objective of this study is to develop and validate a new procedure to improve monitoring of daily snow cover extent over Eastern Canada, more precisely in dense forest areas located in the southern part of the study area. Data included in the procedure are: (1) 1985-2005 AVHRR-1km and 2000-2011 MODIS-250m land cover products, both developed by CCRS (Canada Center for Remote Sensing), and (2) 32km NARR reanalysis of surface air temperature. Unlike the previous SCE mapping procedure, this one includes threshold values depending on air temperature, and for land cover classes. Validation includes various datasets: (1) a set of high resolution LANDSAT images covering 18 locations in various land cover over the study area, most of them are in the boreal forest; (2) 1988-2013 daily snow depth measurements from 20 stations of Environment Canada snow depth network over the study area; (3) 2005-2009 daily snow depth measurements from 16 stations of Hydro-Québec snow depth network located in the Gatineau basin; (4) 2007-2011 near-real time snow water equivalent from 7 stations of Hydro-Québec GMON network located in the Cascades basin.

Mon-5.2 Satellite based probabilistic snow cover extent mapping (SCE) at Hydro-Québec

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Over 40% of Canada's water resources are in Quebec and Hydro-Quebec has developed potential to become one of the largest producers of hydroelectricity in the world, with a total installed capacity of 36,643 MW. The Hydro-Québec fleet park includes 27 large reservoirs with a combined storage capacity of 176 TWh, and 668 dams and 98 controls. Thus, over 98% of all electricity used to supply the domestic market comes from water resources and the excess output is sold on the wholesale markets.

In this perspective the efficient management of water resources is needed and it is based primarily on a good river flow estimation including appropriate hydrological data. Snow on ground is one of the significant variables representing 30% to 40% of its annual energy reserve. More specifically, information on snow cover extent (SCE) and snow water equivalent (SWE) is crucial for hydrological forecasting, particularly in northern regions since the snowmelt provides the water that fills the reservoirs and is subsequently used for hydropower generation.

For several years Hydro Quebec's research institute (IREQ) developed several algorithms to map SCE and SWE. So far all the methods were deterministic. However, given the need to maximize the efficient use of all resources while ensuring reliability, the electrical systems must now be managed taking into account all risks. Since snow cover estimation is based on limited spatial information, it is important to quantify and handle its uncertainty in the hydrological forecasting system.

This paper presents the first results of a probabilistic algorithm for mapping SCE by combining Bayesian mixture of probability distributions and multiple logistic regression models applied to passive microwave data. This approach allows to assign for each grid point, probabilities to the set of the mutually exclusive discrete outcomes: "snow" and "no snow". Its performance was evaluated using the Brier score since it is particularly appropriate to measure the accuracy of probabilistic discrete predictions. The scores were measured by comparing the snow probabilities produced by our models with the Hydro-Québec's snow ground data.

Mon-5.3 Fractional snow cover for Landsat OLI, MODIS, and VIIRS from spectral mixture analysis

Karl Rittger[a], Kathryn Bormann[b], Richard, Armstrong[c], Thomas, Painter[b], and Jeff Dozier[d]

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Maps of snow from MODIS have seen growing use in investigations of climate, hydrology, and glaciology. Some of these snow cover maps have been validated with ground measurements that represent points, not areal extents. Alternatively the snow cover maps have been compared to higher spatial resolution satellite sensors such as Landsat 5, TM and Landsat 7, ETM+ that saturate in visible wavelengths over snow where models need information to separate snow from other land surfaces. In addition, cubic convolution used in processing satellite data has made identifying saturated pixels virtually impossible and it mixes saturated pixels with unsaturated ones. Snow mapping models can have errors in either the positive or negative direction depending on assumptions and performance with lowered visible reflectance (ie saturation). Snow cover estimates from Landsat TM/ETM+ using spectral mixture analysis assume 100% snow cover when bands 1, 2, and 3 saturate, so it likely overestimates snow cover fraction systematically whereas a band ratio would likely underestimate snow cover for saturated pixels. Fortunately, the recently launched Landsat 8 OLI sensor can provide an areal estimate of fractional snow cover at 30m and has a dynamic range that does not saturate in the visible wavelengths, increasing the accuracy of the model above implementations used for previous comparisons and providing an opportunity to better understand MODIS snow cover maps as well as newer VIIRS snow cover maps.

We apply spectral mixture analysis to satellite data from Landsat OLI, MODIS, and VIIRS. Fractional snow cover maps from MODIS and VIIRS have similar spatial resolution of 500m and 1km respectively. We compare these maps to the 30m spatial resolution fractional snow maps from Landsat OLI. For the comparison we coarsen the 30m maps as well as the 500m and 1km maps to the half the spatial resolution to account for geolocation errors and calculate binary and fractional statistics. The comparison of MODIS to OLI shows that underestimates of snow cover from MODIS (-2%) are smaller than previously estimated using Landsat TM/ETM+ (-7%). The smaller difference in the negative direction supports the hypothesis that saturation in Landsat TM/ETM+ overestimated snow cover and reveals that the biases from MODIS fractional snow cover at ~500m are smaller then previously thought. The comparison of VIIRS to OLI shows slightly higher biases of -5% and larger root mean squared errors of 16% compared to 11% from MODIS. The difference is largely driven by lower recall or probability of detection likely associated with the coarser 1km VIIRS data.

Mon-5.4 Scene-specific fractional snow cover algorithms for optical remote sensing

Igor Appel[a]

[a] *NOAA/STAR IMSG, USA*

The future snow applications of satellite data to a great degree depend on using the Visible Infrared Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (SNPP) platform. Because of an original scanning and aggregation scheme, VIIRS observations providing the spectral coverage from 412 nm to 12 µm are characterized by a pixel growth factor of only two both along a track and along a scan giving the opportunity of getting snow distribution globally at 800 m resolution and 375 m at nadir.

The information from visible and near-infrared bands is very useful to distinguish snow from non-snow since snow is among the brightest of natural substances in the visible part of the spectrum, but it is also often the darkest in the short wave infrared. At the same time, the snow and background reflectance spectra exhibit significant variability changing in time and from one place to other.

The distinction between the reflectance in the visible wavelengths and the reflectance in the near infrared wavelengths is characterized by the Normalized Difference Snow Index (NDSI) widely considered as an indicator of the presence of snow on the ground.

It has been previously established that NDSI has the following advantages

- NDSI is sensitive enough to provide the snow fraction
- NDSI presenting relative ratio of reflectances to a large degree suppresses the influence of varying illumination conditions

A linear relationship between snow fraction (SF) and observed NDSI proposed by Salomonson and Appel is equivalent to a linear interpolation between snow and non-snow NDSI:

SFNDSI = (NDSI - NDSInon-snow) / (NDSIsnow - NDSInon-snow) Changes in pixel reflectances should not be ascribed exclusively to variable fraction, because they depend also on the variability in spectral signatures of the endmembers. The quality of snow retrieval could be improved if the variability of reflective properties characterizing snow and underlying non-snow states is taken into account.

Allowing for the variability in spectral signatures of endmembers is a key requirement to snow algorithms. When a scene-specific approach detects local endmembers (on the fly) the comparison of fractional snow retrieval with ground truth is characterized by high quality. Average correlation coefficient is 94% despite a couple of low magnitudes. Typical intercept of linear regression line is on the order of 1%. Average slope of linear regression line is more than 0.9. Average bias of data is 2 %. Average standard deviation (uncertainty) is 10%.

The adjustment of the parameters in snow algorithms to specific local conditions is a promising improvement leading to better quality of the VIIRS snow products.

Mon-5.5 The seasonality of snow/cloud discrimination in Landsat imagery across the Northern Hemisphere

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Snow/cloud discrimination in optical satellite imagery is well understood across the solar spectrum. Even so, frequent cloud obstruction of the visible snow surface across geographic regions with persistent atmospheric instability requires a steadfast commitment to characterize automated cloud-screening errors during the snow season. Imagery from the Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) are playing a fundamental role in Satellite Snow Product Intercomparison and Evaluation Experiment (SnowPEx) validation activities. While most of the Landsat validation images have either minimal cloud contamination or are cloud-free, a number of images require pixel-based cloud screening prior to snow cover classification. In this work, a seasonally representative subsample of SnowPEx Landsat images are selected from the Northern Hemisphere domain, and three different Landsat cloud/cloud shadow algorithms, Function of Mask, Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS), and heritage automated cloud cover assessment (ACCA) are evaluated for their performance. Seasonal biases and the challenges of differentiating between liquid, mixed-phase, and ice cloud types are identified for Landsat-type spectral and seasonal resolutions, and trade-offs of cloud/cloud shadow mask choice are discussed. Several physically based improvements in Landsat cloud screening are explored using thermal brightness temperatures, the water vapour spectral band carried on OLI, and hyperspectral cloud retrievals from the EO-1 Hyperion imaging spectrometer.

Mon-5.6 Evaluating multi-spectral snowpack reflectivity with changing snow grain sizes

Do Hyuk Kang[a], Ana Barros[b], and Edward Kim[a]

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This study investigates the sensitivity of multi-spectral reflectivity to changing snow grain size. To this end, this paper implements and tests Mätzler's Ice-lamellae model to evaluate the reflectivity of snow grain sizes at multiple frequencies from the ultraviolet (UV) to the microwave bands. The model reveals that the reflectivity is inversely proportional to increasing grain size in the UV to infrared (IR) frequency range. On the other hand, in the microwave frequency range, the reflectivity increases with snow grain size. The model further shows that the reflectivity behaviour can be mainly attributed to scattering rather than absorption. The largest scattering coefficients and reflectivity occur with very small grain sizes (~10-5 m) at high frequencies above the IR band. At microwave frequencies, the largest scattering coefficients are found at mm wavelengths. For validation purposes, the Ice-lamellae model is coupled with a multi-layer snow physics model to match reflectivity responses with realistic snow hydrological processes. Simulated reflectivities from the coupled model in both the visible and the microwave bands are consistent with satellite-based reflectivity data. The model results are also compared with co-located in-situ snow grain size measurements (Cold Land Processes Field Experiment 2002-2003). This coupled modelling system to cover multiple frequencies can provide a critical tool to improve a forward operator in a data assimilation framework to predict the status of snow physical properties including snow grain size.

Mon-5.7 Optimal linear relationships of fractional snow cover with visible reflectance and NDSI

Igor Appel[a]

[a] *NOAA/STAR IMSG, USA*

It is considered a standard approach to apply high-resolution observations to validate moderate resolution retrieval of the fractional snow cover using the aggregation of high-resolution pixels binary classified as snow / non-snow. It is also typical that the algorithms to retrieve fractional snow cover are based on processing visible and near infrared reflectances.

The quality of remote sensing observations is comparable for different sensors including both high-resolution and moderate resolution. It means that there is no principal difference between reflectances calculated from different sensors. However, the estimates of moderate resolution fractional snow cover retrieval quality are influenced to a large degree by varying viewing geometry and the observations from nadir are therefore preferable. Since moderate-resolution observations on reflectances are approximately equal to aggregated high-resolution data, the latter (reflectances and ground truth snow fraction) are quite sufficient to validate and improve fractional snow cover algorithms.

16 Landsat scenes characterized by a wide variety of surface types and solar illumination conditions were taken into consideration to implement proposed methodology. The quality of two algorithms based on assumptions of linear relationships of visible reflectance and the Normalized Difference Snow Index (NDSI) with snow fraction was estimated using the regressions of ground truth fraction on both visible reflectance and NDSI.

The comparison of two algorithms demonstrates obvious advantages of the regression on NDSI (characterized by correlation coefficients of 0.95) when compared to the linear regression on the visible reflectance (characterized by correlation coefficients of 0.85).

Further analysis indicates approximately 60% increase in the standard deviation for the regression of the fractional snow cover on visible reflectance in comparison with the standard deviation for the regression on NDSI in the case when the intercept for the regression lines is set to zero. It means that the variance for the regression on the visible reflectance is twice larger than the variance for the regression on NDSI.

The uncertainty of the relationships under consideration is less than 0.1 in most cases for the regression on NDSI, but only in two Landsat scenes for the regression on visible reflectance. The worst quality of the regression on NDSI is characterized by the standard deviation of less than 0.12, but more than 0.20 for the regression on visible reflectance.

The comparison above has been made for optimal linear relationships of fractional snow cover with visible reflectance and NDSI. However it is not clear how the realization of the visible band algorithm could be optimized and therefore practically the retrieval based on the visible reflectance provides much poorer quality of snow fraction than described above. The scene-specific realization of the NDSI algorithm on the contrary is close to its optimal version and could meet requirement to the VIIRS snow fraction retrieval.

Mon-5.8 Snow monitoring in mountain areas from medium to high resolution images: towards Sentinel 2 data

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This paper presents two snow cover products derived from the 250 meters MODIS and the 30 meters LANDSAT-8 data. An extensive validation have been carried out that considers: i) ground data; ii) a cross-comparison between the two proposed products; and iii) a cross-comparison with the standard MODIS product MOD10-MYD 10. The proposed 250 meters resolution snow cover product comes from an improved version of the EURAC snow cover algorithm based on 250 m MODIS satellite images, which was specifically designed for mountain areas (Notarnicola et al., 2013). In the improved version of the algorithm, a specific module for the proper detection of snow in forest has been introduced. This module automatically downscales the information derived from NDSI index and keeps the resolution of the final map at 250 m. The agreement between standard MODIS snow cover product (i.e. MOD10-MYD 10) and the snow maps obtained by the proposed methods considering a pool of dates from 2003 to 2013 increases of around 7-8% inside forests, meanwhile the misclassification decreases of around 3-4% outside forests. Additionally, in order to have a further and thorough validation, the snow maps from 2005 to 2009 have been compared with ground data, which have been collected by 83 snow depth sensors located in Valle d'Aosta and Piemonte (Northern Italy). Elevation, forest cover and morphology (i.e. 3 categories: ridges, slopes and valley floor) has been considered for each validation point, in order to understand the impact of these parameters on the accuracy of the snow maps. Differently from the MODIS data, in LANDSAT 8 images more spatial details are visible. From one hand this allows the discrimination among a higher number of land cover types, nonetheless on the other hand it increases the complexity of the detection among the classes. Indeed, if standard strategies based on static thresholds are applied the generated decision trees may become complex (i.e., large) and the correct evaluation of uncertain values may fail. For this reason in this work we propose to use a supervised support vector machine (SVM) classifier. SVM has the intrinsic potentiality to find non-linear discriminant functions in a multi-dimensional feature space (Camps-Valls&Bruzzone, 2005). The main features used for the classification are: i) the LANDSAT 8 spectral bands; ii) the physically inspired features extracted as combination of bands (e.g., NDSI) that model the proprieties of snow, clouds and vegetation; and iii) the topographic characteristics of the investigated mountain region. The obtained results have been compared with the results obtained by standard approaches based on static thresholds showing that the proposed method is more accurate especially when similar classes (e.g., clouds and snow) or mixed classes (e.g., snow under forest) have to be identified. It is finally worth noting that the capability to extract information from medium and high resolution data is of great importance in view of the availability of free-of-charge Sentinel 2 data. In this context LANDSAT 8 can be considered a precursor of Sentinel 2 and their data can be used in order to explore the potentially of the upcoming Sentinel 2 images.

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Mon-5.9 Updated JAXA GCOM-W/AMSR2 snow depth standard product and its validation

Hiroyuki Tsutsui[a], Keiji Imaoka[a], Richard Kelly[b], and Takashi Maeda[a]

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The JAXA GCOM-W/AMSR2 standard products were updated in Japan fiscal year 2014, and the following products were opened to the public: 1) water vapour, 2) cloud liquid water, 3) precipitation, 4) SST, 5) sea surface wind speed, 6) sea ice concentration, 7) snow depth, and 8) soil moisture content. Among these products, the AMSR2 snow depth standard product was improved by Dr. Richard Kelly at University of Waterloo. This improvement is scientifically-important in order to achieve the AMSR2 goal accuracy of ±10cm snow depth. The following major improvement was implemented in this product: (a) correction of the brightness temperature based on a forest transmissivity, (b) application of an estimation methodology for a realistic snow depth distribution over the Tibetan Plateau and (c) update of spatial water fraction data. In the improvement (a), a forest correction expression is derived using the MODIS reflectance data to estimate forest transmissivity according to the work of Metsämaki et al (2005). The forest correction factor for each frequency is applied to correct for forest attenuation. This is a significant improvement because the impact of forest affects the estimation of snow depth by the microwave remote sensing strongly. In the improvement (b), the microwave estimation methodology, which can estimate the sparse snow distribution over the Tibetan Plateau, was applied and was evaluated by snow cover area based on ALOS/AVNIR-2 with 10 m high spatial resolution. Furthermore, the water fraction data was updated using the WWF GIS dataset and the product also detects the presence of frozen or liquid water state. Thereafter, the estimated snow depth from this product was compared with in situ snow depth observations from the WMO GSOD data set consisting of 1007 stations in the northern hemisphere. The mean average error (MAE) is calculated for spatially and temporally-matched stations within a 30 km diameter of the AMSR2 snow depth estimate. Validation period is from July 23, 2012 to September 30, 2014. The AMSR2 snow depth standard product achieved the release and standard accuracies, which are 20 cm in MAE. In the workshop, further detail for these improvements and validations and future subject will be presented.

Mon-5.10 Using image reconstruction to enhance spatial resolution of a reprocessed satellite passive microwave historical record

Mary J. Brodzik[a], David L. Long[b], Molly A. Hardman[c], Aaron Paget[b], and Richard L. Armstrong[c]

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Currently available global gridded passive microwave data sets serve a diverse community of hundreds of data users, but do not meet many requirements of modern Earth System Data Records (ESDRs) or Climate Data Records (CDRs), most notably in the areas of intersensor calibration and consistent processing methods. The original gridding techniques were relatively primitive and were produced on 25 km grids using the original EASE-Grid definition that is not easily accommodated in modern software packages. Further, since the first Level 3 data sets were produced, the Level 2 passive microwave data on which they were based have been reprocessed as Fundamental CDRs (FCDRs) with improved calibration and documentation. We are funded by NASA MEaSUREs to reprocess the historical gridded data sets as EASE-Grid 2.0 ESDRs, using the most mature available Level 2 satellite passive microwave (SMMR, SSM/I-SSMIS, AMSR-E) records from 1978 to the present. We are currently producing prototype data from SSM/I and AMSR-E for the year 2003, for review and feedback from our Early Adopter user community. The prototype data set includes grids derived from the two candidate image reconstruction techniques we are evaluating: 1) Backus-Gilbert (BG) interpolation and 2) a radiometer version of Scatterometer Image Reconstruction (SIR). We discuss our rationale for the respective algorithm tuning parameters we have selected, compare results and computational costs, and include prototype sample images at enhanced resolutions of up to 3 km. We anticipate that using our new brightness temperature ESDR may improve current snow water equivalent products in at least three ways: 1) we are using the latest intersensor calibration from Level 2 input data sets, 2) we are tuning image reconstruction parameters to enhance gridded spatial resolution, and 3) we will be producing consistently gridded image products for the complete sensor record (SMMR, AMSR-E, 6 SSM/Is and at least 2 SSMISs).

Mon-5.11 COST Action ES1404: A European network for a harmonised monitoring of snow for the benefit of climate change scenarios, hydrology and numerical weather prediction

Samantha Pullen

Met Office UK, United Kingdom

A new COST Action on snow was initiated in November 2014 and will run for four years. The Action is chaired by Dr Ali Nadir Arslan, from FMI, and has a Management Committee made up of representatives from 24 European countries. The Action brings together snow scientists from diverse applications in participating countries and will achieve its aims by networking activities including working groups, workshops, and training opportunities, focusing on three main issues: (1) Physical characterisation of snow properties, (2) Instrument and method evaluation, and (3) Snow data assimilation and validation methods for NWP and hydrological models. The primary objective of the Action is to enhance the capability of the research community and operational services to provide and exploit quality-assured regional and global observation-based data on the variability of the state and extent of snow. Secondary objectives are:

- Establish a European-wide science network on snow measurements and their optimum use and applications, by direct inclusion and interactions across disciplines and expertise.
- Assess and harmonise practices, standards and retrieval algorithms applied to ground, air-borne and space-borne snow measurements and foster their acceptance by key snow network operators at the international level.
- Develop a rationale and long-term strategy for snow measurements, their dissemination and archiving.
- Advance the application of snow data assimilation in European NWP and hydrological models and show its benefit for weather and hydrological forecasting as well as other applications.
- Establish a validation strategy for NWP, hydrological and climate models against snow observations and advance its implementation within the European modelling communities.
- Training of a new generation of scientists on snow science and measuring techniques with a broader and more holistic perspective linked with the various applications.

This presentation will give an overview of the Action, explaining its structure, goals and how these will be achieved over the four year period.

TUE-1 TUESDAY, 15 SEPTEMBER 2015
ORAL SESSION: SNOW WATER EQUIVALENT-1

Tue-1.1 The Satellite Snow Product Intercomparison and Evaluation Experiment: overview of progress for snow water equivalent

Chris Derksen[a], Lawrence Mudryk[b], Kari Luojus[c], Ross Brown[a], Carrie Vuyovich[d]

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Reliable information on snow water equivalent (SWE) at regional to continental scales is required for studies of freshwater and energy budgets, the evaluation and initialization of land surface models for both short term weather and seasonal forecasts, and the assessment of coupled climate model simulations. While multiple independent passive microwave derived SWE products are available, their full potential has not been realized because of poorly constrained error budgets due to the challenges related to the physical processes underpinning the SWE retrievals, and the extensive snow covered regions of the world without adequate surface observations for algorithm validation. The purpose of SnowPex is to obtain a quantitative understanding of the uncertainty in remotely sensed SWE products through an internationally coordinated and consistent evaluation exercise.

This presentation will provide an overview of initial SnowPEx progress related to the inter-comparison and evaluation of SWE products, including:

- the use of high quality networks of independent ground reference measurements,
- the methods for scaling surface observations and for taking account of sampling biases e.g. open areas and lower elevations,
- the role of gridded SWE products from reanalysis and land surface models,
- the calculation of SWE trends over the passive microwave satellite record, and comparison with the reference gridded products.

Open issues related to these three areas will also be discussed, in order to develop consensus from workshop participants on how best to proceed.

Tue-1.2 Assessment of the satellite-based SWE datasets with snow transect data

Kari Luojus[a], Jouni Pulliainen[a], Chris Derksen[b], Ross Brown[b]

[a] Finnish Meteorological Institute, Finland
[b] Environment Canada, Canada

The SnowPEx team has acquired the currently available satellite-based SWE datasets and performed the preliminary intercomparison of the different products. The inter-comparison has been carried out for the 1) GlobSnow SWE, 2) the NASA Standard SWE, 3) NASA prototype SWE and 4) HSAF SWE products.

The intercomparisons have been carried out by using ground-based snow course observations as the reference. The evaluations have been carried out using Finnish Snow Course data, available for 1979-2014, covering Finland and distributed snow transect data collected from the former Soviet Union and Russia covering the period 1979–2012. The reference dataset contains snow path measurements carried out within 517 different snow path locations, ranging from 35° to 85° northern latitude and 14° to 179° of eastern longitude. The preliminary results will be shown at the SnowPEx ISSPI-2 workshop.

Tue-1.3 Evaluating the consistency and accuracy of several northern hemisphere snow water equivalent datasets

Lawrence Mudryk[a], Chris Derksen[b], Paul Kushner[a], and Ross Brown[b]

[a] *University of Toronto, Canada*

[b] *Environment Canada, Canada*

We analyse spatial and temporal consistency and accuracy within and between two classes of daily, gridded Northern Hemisphere snow water equivalent (SWE) datasets over two recent periods.

We first present a completed analysis of several reanalysis-based SWE products over the 1981-2010 period: 1) the Global Land Data Assimilation System (GLDAS); 2) the Crocus distributed physical snow model driven by meteorology from ERA-Interim reanalysis; 3) ERA-Interim/Land reanalysis; and 4) Modern Era Retrospective Analysis for Research and Applications (MERRA reanalysis). We find that the climatologies of total Northern Hemisphere snow water mass (SWM) vary among the datasets by as much as 50%, but their interannual variability and daily anomalies are comparable, showing moderate to good temporal correlations (between 60% and 85%) on both interannual and intraseasonal time scales. Examining spatial patterns of SWE indicates that the datasets are most consistent with one another over boreal forest regions compared to Arctic and alpine regions. Wintertime trends of total Northern Hemisphere SWM are consistently negative over the 1981-2010 period among the datasets but vary in strength by a factor of 2-3. We also highlight temporal inhomogeneities present in other prominent SWE datasets: the MERRA-Land reanalysis, the Canadian Meteorological Centre Daily Snow Depth Analysis and an earlier version of the GLDAS product. Finally, we provide evidence that while land surface model differences control the majority of spread in the climatological value of SWM, meteorological forcing differences control the majority of the spread in temporal correlations of SWM anomalies.

We will contrast the comparison of reanalysis-based products with that of three satellite-based products over the 2003-2010 period: 1) the GlobSnow combined satellite passive microwave analysis; 2) the standard AMSR-E operational product and 3) a new prototype of the AMSR-E operational product. Where possible we will also provide an initial assessment of accuracy of both the reanalysis- and satellite-based products with recently available high quality in situ observations.

Tue-1.4 Development of a 10-km gridded SWE dataset over south-western Quebec for SnowPEx validation

Ross Brown[a] and Dominique Tapsoba[b]

[a] Environment Canada, Canada

[b] L'Institut de recherche d'Hydro-Québec (IREQ), Canada

As a contribution to SnowPEX, co-kriged estimates of SWE at a 10-km resolution were generated over a region of south-western Quebec from in situ snow course data collected by Hydro-Québec and partners from 1999 to 2013 for the 1st and 15th of the month over the Jan-April survey period. This particular area was selected because of a relatively even distribution of snow course surveys and the presence of several passive gamma GMON SWE observing systems in the region. The kriging methodology is based on Tapsoba et al (1999) and uses up to five variables to optimize the spatial model (latitude, longitude, elevation, land use, and estimated SWE from the Canadian Meteorological Centre daily snow depth analysis). The talk will outline the datasets and methods used in developing the gridded SWE estimates, present cross-validation results, and compare the new H-Q dataset with SWE estimates from GlobSnow and MERRA. Preliminary results suggest that these products considerably under-estimate SWE over the region.

Tue-1.5 Watershed-based comparison of global SWE algorithms to SNODAS modelled SWE across the United States

Carrie Vuyovich, Jennifer Jacobs, Timothy Baldwin, and Steven Daly

ERDC, USA

The Satellite Snow Product Intercomparison and Evaluation Experiment (SnowPEX) seeks to compare and validate several passive microwave satellite-based snow water equivalent (SWE) algorithms as well as the SWE output from global climate models. Accurate SWE data is essential for water resource applications in many regions that rely on snowmelt for water supply and are susceptible to flood and drought. For this study we evaluate the various SWE products by comparison to the NOAA NOHRSC Snow Data Assimilation System (SNODAS) spatially distributed model estimates. Results are compared for over 2,000 HUC8 watersheds throughout the United States. This watershed comparison allows us to evaluate data across multiple regions and provides an independent means for validation of both the satellite and modelled results by comparison to basin discharge. We use watersheds selected from the Hydro-Climatic Data Network (HCDN), which identifies basins with minimal human impacts to stream flow. A previous comparison of SNODAS to SSM/I and AMSR-E standard algorithms found that lack of observations in the Central Plains region negatively impacts the SNODAS results both on magnitude and timing of SWE and passive microwave data has potential for providing an accurate source of SWE data in this region. In regions with relatively deep snow packs and heavy vegetation, the satellite estimates suffered. This study evaluates the additional SWE products made available from SnowPEx; AMSR-E prototype algorithm and GlobSnow by comparison to SNODAS and the standard algorithms. Results are evaluated by several basin statistics to determine the difference in magnitude. The Spearman's rank-order test is used to compare the relative magnitudes of annual maximum estimates. Weekly SWE data are compared using the Nash-Sutcliffe model efficiency index which measures the fit between predicted and observed values. Global climate model estimates of SWE are similarly compared to SNODAS, but at the HUC4 basin scale because of the coarse resolution of the data.

TUE-2 ORAL SESSION: SNOW WATER EQUIVALENT-2

Tue-2.1 An overview of the current NASA operational AMSR-E/AMSR2 snow science team activities

Marco Tedesco[a], Mattia Sartori[b], and Jeyavinoth Jeyaratnam[a]

[a] *The City College of New York (CCNY), USA*
[b] *CCNY / University of Brescia, Italy*

The knowledge of snow depth (SD) and snow water equivalent (SWE) is fundamental for water resources management and weather and flash flood forecast, among other things. Snow also strongly influences the global energy balance because of its high reflectivity, insulation properties, and the amount of latent heat consumed during melting. Data collected at global scale by space-borne passive microwave sensors have been used to estimate SWE and SD at operational level. Data collected by the Advanced Microwave Scanning Radiometer 2 (AMSR2) and by the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) are routinely used to generate global maps of SWE and SD. In this paper, we focus on providing an overview of some of the activities of the NASA operational AMSR-E/AMSR2 snow science team activities. In particular, we discuss the following tasks:

- Adapting the AMSR-E SWE algorithm to for AMSR2 to ingest L1R brightness temperature provided by JAXA
- Assessing the improvement of dynamic snow density masks on SWE
- Updating the Snow Possible/Snow Impossible mask using the CMC dataset.
- Developing of a research prototype algorithm
- Comparison between current operational algorithm and research prototype algorithm and in-situ/modelled snow depth fields
- Evaluation of an enhanced spatial resolution product with in situ measurements
- Cross-calibration between AMSRE and AMSR2 brightness temperatures

Tue-2.2 The GCOM-W1 AMSR2 snow depth and snow water equivalent product

Richard Kelly, Nastaran Saberi, and Qinghuan Li

University of Waterloo, Canada

Estimates of snow depth (SD) and snow water equivalent (SWE) are presented from recent developments of the standard snow product for the Advanced Microwave Scanning Radiometer – 2 (AMSR2) aboard the Global Change Observation Mission – Water. AMSR2 is designed as a follow-on from the successful Advanced Microwave Scanning Radiometer – EOS that ceased formal operations in 2011. The standard SD product for AMSR2 has been updated in two ways. First, the detection algorithm identifies various observable geophysical targets that can confound SD / SWE estimation (water bodies [including freeze/thaw state], rainfall, high altitude plateau regions [e.g. Tibetan plateau]) before detecting moderate and shallow snow. Second, the implementation of the Dense Media Radiative Transfer model (DMRT) originally developed by Tsang et al. (2000) and more recently adapted by Picard et al. (2011) is used to estimate SWE and SD. The implementation combines snow grain size and density parameterizations originally developed by Kelly et al. (2003). Snow grain size is estimated from the tracking of estimated air temperatures that are used to drive an empirical grain growth model. Snow density is estimated from the Sturm et al. (2010) scheme. Efforts have been made to keep the approach tractable while reducing uncertainty in these input variables. Results are presented from the recent winter seasons to illustrate the performance of the new approach in comparison with the current AMSR2 algorithm.

Tue-2.3 Contributions of SnowPEx to global climate modelling initiatives

Chris Derksen (with contributions from the LS3MIP and ESM-SnowMIP steering committees)

Climate Research Division, Environment Canada, Canada

Model intercomparison projects ('MIPs') provide an important benchmarking opportunity to assess the performance of specific components of climate models, and diagnose sources of uncertainty. Two MIPs which include consideration of terrestrial snow cover are currently under development: the Land Surface, Snow, and Soil Moisture (LS3MIP) proposed to the Coupled Model Intercomparison Project phase 6 (CMIP6), and the Earth System Model Snow MIP (ESM-SnowMIP) endorsed by the World Climate Research Programme (WCRP) Climate and Cryosphere (CliC) initiative. Both of these initiatives require a well validated set of gridded snow cover extent (SCE) and snow water equivalent (SWE) datasets in order to quantify and model biases and support process studies. This presentation will provide an update on the status of LS3MIP and ESM-SnowMIP focusing on an overview of the proposed simulations and corresponding observational requirements. In the case of both SCE and SWE, SnowPEx is poised to provide the observational foundation for the analysis of the model simulations, and will provide a new understanding of observational spread and uncertainty for comparison with the inter- (between model) and intra- (between ensemble member) model spread.

Tue-2.4 The NASA SnowEx airborne snow campaign: an upcoming opportunity for SnowPEx

Edward Kim[a], Charles Gatebe[b], Dorothy Hall[b], Matthew Sturm[c]

[a] NASA, USA

[b] NASA GSFC, USA

[c] UAF, USA

NASA is planning a 3-year airborne snow campaign notionally called “SnowEx,” and planned for the northern hemisphere winters of 2016-2018. The primary goal of SnowEx is the collection of coincident observations with a suite of observation types including active and passive optical and active and passive microwave sensors. Detailed ground truth will also be collected for algorithm verification, accuracy comparisons, and quantitative assessments of SWE, SCA, SCF, and depth measurement uncertainties under a variety of conditions and snow types, etc. Also being discussed are studies to quantitatively assess the distribution of uncertainties between actual measurements vs. models when these are combined in an assimilation framework to produce snow data products.

The objective of this presentation is to inform the SnowPEx community of SnowEx plans, to begin exploring the potential for SnowPEx to exploit SnowEx activities, and to offer the opportunity for SnowPEx lessons-learned concerning validation issues to be incorporated into the design of the SnowEx campaign to the benefit of future global-scale snow satellite data products.

WED-1 WEDNESDAY, 16 SEPTEMBER 2015

WED-1.1 The role of product intercomparisons in the Global Cryosphere Watch

Jeff Key

National Oceanic and Atmospheric Administration (NOAA), Madison, Wisconsin, USA

The World Meteorological Organization (WMO) Global Cryosphere Watch (GCW) is a sustained, robust, end-to-end operational cryosphere observing and monitoring system that encompasses ground-based measurements, satellite remote sensing, aircraft measurements, modelling, and data management. GCW provides authoritative, clear, and useable data, information, and analyses on the past, current and future state of the cryosphere. But what is “authoritative” information? In order to address this question, at least in part, GCW is promoting and engaging in product intercomparisons studies. The goal of a product intercomparison is to evaluate dataset maturity, determine in-depth error characteristics, assess strengths and limitations, resolve discrepancies, provide information on dataset availability, and develop guidelines for product improvement. The GCW Snow Watch Team and the European Space Agency’s (ESA) SnowPEx project are engaged in an intercomparison of snow products, including satellite-derived, in situ, and analysis/reanalysis products. Lessons learned from SnowPEx, as well as from intercomparison projects underway by the International Cloud Working Group and the International Winds Working Group, will help determine the best methodology to employ in intercomparison projects for other cryosphere variables, such as a sea ice thickness.