21-23 July 2014
College Park, MD, USA

1st International Satellite Snow Products Intercomparison Workshop

SCIENTIFIC COMMITTEE

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

FACILITY

NOAA Center for Weather and Climate Prediction – Conference Center
5830 University Research Court
College Park, MD 20740, USA

DATE

21 - 23 July 2014

SNOWPEX PROJECT AND WORKSHOP WEBSITE

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

LOCAL ORGANIZER

Sean Helfrich / NOAA

CONTACTS

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PROGRAM

MONDAY, 21 July 2014 - 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) / Sean Helfrich / NOAA
Mon1.2	09:10	09:30	The Satellite Snow Product Intercomparison and Evaluation Experiment SnowPEx – Motivation, Objectives and Expected Results	Thomas Nagler
Mon1.3	09:30	09:50	Uncertainty in Snow Cover Datasets – Guidance for SnowPEx	Ross Brown and Chris Derksen
MON-2			**ORAL SESSION: PROTOCOLS FOR PRODUCT VALIDATION AND INTERCOMPARISON**	
Mon-2.1	09:50	10:10	A Validation Protocol for Continental Scale Snow Extent Products that Incorporates Product and Reference Uncertainty	Richard Fernandes, Sari Metsämäki, Gabriele Bippus, Rune Solberg, Chris Derksen, Thomas Nagler, Bojan, Bojkov
Mon-2.2	10:10	10:30	The Satellite Snow Products Intercomparison and Evaluation Experiment: Protocols, Metrics, and Open Issues	Chris Derksen, Ross Brown, Lawrence Mudryk, Kari Luojus, Richard Kelly, Marco Tedesco, Shengli Wu

	10:30	**11:00**	**COFFEE BREAK**	

MON-3			**ORAL SESSION: SNOW EXTENT PRODUCTS – 1**	**Chair: Richard Fernandes David Robinson**
Mon-3.1	11:00	11:20	A Summary of NOAA Satellite-Derived Snow Products	Sean Helfrich; Christopher Grassotti; Peter Romanov; Jeff Key; David Robinson
Mon-3.2	11:20	11:40	NESDIS Global Automated Satellite Snow Product: Current Status and Recent Results	Peter Romanov
Mon-3.3	11:40	12:00	Influence of Grid Resolution on the NOAA Historical Satellite Snow Product	Gina Henderson, David Robinson, Thomas Estilow
Mon-3.4	12:00	12:20	GlobSnow Snow Extent Product	Sari Metsämäki, Kari Luojus, Jouni Pulliainen
Mon-3.5	12:20	12:40	Remote Sensing of Snow Properties from MODIS	Thomas Painter, Karl Rittger, Kat Bormann, Cameron Goodale, Chris Mattmann

	12:40	**14:00**	**LUNCH BREAK**	

MONDAY, 21 July 2014 - AFTERNOON

MON-4			**ORAL SESSION: SNOW EXTENT PRODUCTS - 2**	**Chair: Dorothy Hall Rune Solberg**
Mon-4.1	14:00	14:20	A New Global Snow Cover Product Based on Multi-sensor Multi-temporal Satellite Data	Rune Solberg, Øystein Rudjord, Arnt-Børre Salberg, Mari Anne Killie
Mon-4.2	14:20	14:40	Snow Extent Products of the EC FP7 Project CryoLand	Thomas Nagler; Gabriele Bippus; Sari Metsaemaeki; Rune Solberg
Mon-4.3	14:40	15:00	Enhanced Snow Cover Algorithm Based On 250 m MODIS Images For Monitoring Temporal And Spatial Changes In The Mountain Areas	Claudia Notarnicola, Mattia Callegari, Armin Costa, Giovanni Cuozzo, Ludovica De Gregorio, Antonio Padovano, Bartolomeo Ventura
Mon-4.4	15:00	15:20	A New Snow Product Merging Visible, Near-IR and Passive-Microwave Snow Maps	Dorothy Hall, David A. Robinson, Thomas L. Mote, George A. Riggs, Thomas W. Estilow, Jeffrey A. Miller
Mon-4.5	15:20	15:40	Comparison of Fractional Snow Detection Algorithms for VIIRS Retrievals	Kathryn J. Bormann, Thomas H. Painter
Mon-4.6	15:40	16:00	Prototyping of Hemispherical Snow Cover Extent Products Towards The Japanese Global Change Observation Mission GCOM-C	Masahiro Hori, Konosuke Sugiura, Tomonori Tanikawa, Teruo Aoki, Katsuyuki Kuchiki, Masashi Niwano, Hiroyuki Enomoto

	16:00	**16:20**	**COFFEE BREAK**	

MON-5			**POSTER PRESENTATIONS: 2 Minutes (1-2 Slides)**	**Chair: Gabriele Bippus Lothar Schüller**
Mon-5.1	16:20		EUMETSAT's Network of Satellite Application Facilities (SAF Network): Sustained Development and Operations of Snow Products from Satellites	Lothar Schüller
Mon-5.2			A candidate for the Satellite Snow Product Inter-comparison and Evaluation Experiment	Fabia Hüsler and Stefan Wunderle
Mon-5.3			Taking Advantage of Daily MODIS and VIIRS Data, Time-space Interpolation and Smoothing to Provide Daily Estimates of Snow Surface Properties	Jeff Dozier; Karl Rittger; Thomas H. Painter
Mon-5.4			Scene-specific Approach to Snow Retrieval	Igor Appel
Mon-5.5			Supervised Machine Learning for MODIS Snow Cover Detection	George Bonev, Fazlul Shahriar, Irina Gladkova and Michael Grossberg
Mon-5.6			Evaluation of Assimilation Efforts Using IMS Fractional Snow Cover in the NOAA/NCEP's NAM Operational Product	Jiarui Dong, Mike Ek,Eric Rogers, Brian Cosgrove, Sean Helfrich, George Gayno,Kingtse Mo
Mon-5.7			Fractional Snow Covered Area from Landsat TM and ETM+, a Validation and Application	Karl Rittger, Thomas Painter, Dave Selkowitz, Jeff Dozier
Mon-5.8			The Temporal Variation and Spatial Distribution of Snow Covered Area Over the Tibetan Plateau	Chu Duo, Hongjie Xie, Pengxiang Wang, Jianping Guo, Jia La, Yubao Qiu, Zhaojun Zheng
Mon-5.9			Evaluating the GLOBSNOW and EUMETSAT HSAF SWE Products Over Mountainous Areas in Turkey	Zuhal Akyurek, Kenan Bolat, Kari Luojus, Matias Takala
Mon-5.10			GPS Interferometry Offers New Validation Option for Snow Product Evaluation	Edward Kim and Hemanshu Patel, NASA GSFC

Mon-5.11			Assessing Satellite Snow Products for Assimilation Into the UK Regional Forecasting Model	Samantha Pullen
Mon-5.12		17:00	Global SnowPack – A Set of Snow Cover Parameters Made Available on a Global Scale	Andreas Dietz, Claudia Kunzer, Stefan Dech

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

TUESDAY, 22 July 2014 - MORNING

TUE-1			**ORAL SESSION: SNOW WATER EQUIVALENT**	**Chair: Chris Derksen Marco Tedesco**
Tue-1.1	09:00	09:20	The GlobSnow Snow Water Equivalent Product	Kari Luojus, Jouni Pulliainen, Matias Takala, Juha Lemmetyinen, Tuomo Smolander, Chris Derksen
Tue-1.2	09:20	09:40	NASA Operational Approaches and Exploratory Activities for Improving SWE Estimates And Snowmelt Detection From Passive Microwave Observations	Marco Tedesco
Tue-1.3	09:40	10:00	Snow Water Equivalent Estimation From GCOM-W1 AMSR2 Observations	Richard Kelly, Nastaran Saberi, Qinghuan Li
TUE-2			**ORAL SESSION: REFERENCE DATA 1**	**Chair: Bojan Bojkov Carrie Vuyovich (TBC)**
Tue-2.1	10:00	10:20	On the importance of accessible reference datasets for the evaluation of satellite snow products	Bojan Bojkov
Tue-2.2	10:20	10:30	In situ Snow and Vegetation Properties Along a Latitudinal Transect in North-Eastern Canada: A Reference Data Set to Assess Satellite SWE Products	L. Brucker, A. Langlois, A. Royer, A. Arnaud, P. Clinche, K. Goïta, G. Picard, A. Roy, C. Derksen
Tue-2.3	10:30	10:50	Snow Course Observations in the Mountainous Regions of the North Pacific Rim	Konosuke Sugiura, Tetsuo Ohata, Gombo Davaa, Larry Hinzman, Vladimir Makarov,Trofim Maximov, Masahiro Hori

	10:50	**11:10**	**COFFEE BREAK**

TUE-3			**ORAL SESSION: REFERENCE DATA 2**	**Chair: Sari Metsämaki, L. Brucker**
Tue-3.1	11:10	11:30	Reference Data for Assessing Satellite Snow Products in Europe and Canada	Gabriele Bippus, Thomas Nagler, Sari Metsämäki, Chris Derksen, Richard Fernandes, Kari Luojus, Rune Solberg
Tue-3.2	11:30	11:50	Accuracy Standards for Partially Cloudy Landsat Visible/Infrared Snow Maps	Christopher Crawford, Dorothy K. Hall
Tue-3.3	11:50	12:10	SNODAS Assimilation from 2003-2014: Qualifications as a Reference Analysis	Greg Fall, Carrie Olheiser, Logan Karsten, Andy Rost
Tue-3.4	12:10	12:30	Evaluation of Satellite-based Snow Data For Estimating SWE and SCA for Water Resource Applications	Carrie M. Vuyovich, Jennifer M. Jacobs, Steven F. Daly, Elias J. Deeb, Steven F. Newman, Blaine F. Morris, Elke Ochs

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

TUESDAY, 22 July 2014 - AFTERNOON

TUE-4			**SESSION: SPLINTER-1 SE & SWE**	
	14:00	15:30	Snow Extent	Chair: Thomas Nagler Rapporteur: Richard Fernandes
	14:00	15:30	Snow Water Equivalent	Chair: Chris Derksen Rapporteur: Kari Luojus

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

TUE-5			**SESSION: SPLINTER-2 SE & SWE**	
	16:00	17:30	Snow Extent	Chair: Thomas Nagler Rapporteur: Richard Fernandes
	16:00	17:30	Snow Water Equivalent	Chair: Chris Derksen Rapporteur: Kari Luojus

WEDNESDAY, 23 July 2014 - MORNING

	09:00	9:30	Global Cryosphere Watch and SnowPEx	Barry Goodison and Jeff Key
WED-1			**SESSION: SPLINTER-3 SE & SWE Separately**	
	09:30	10:30	Snow Extent	Chair: Thomas Nagler Rapporteur: Richard Fernandes
	09:30	10:30	Snow Water Equivalent	Chair: Chris Derksen Rapporteur: Kari Luojus

	10:30	**11:00**	**COFFEE BREAK**

WED-2			**ORAL SESSION: SUMMARY**	**Chair: Thomas Nagler Chris Derksen**
Wed2.1	11:00	11:20	Summary of SE Splinter Session	Rapporteur SE
Wed2.1	11:20	11:40	Summary of SWE Splinter Session	Rapporteur SWE
Wed2.1	11:40	12:30	Discussion	Chris Derksen / Thomas Nagler
Wed2.1	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, 21 JULY 2014 OPENING

Mon-1.1 The Satellite Snow Product Intercomparison and Evaluation Experiment SnowPEx – Motivation, Objectives and Expected Results

Thomas Nagler

ENVEO
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This presentation will introduce the SnowPEx Initiative to the Workshop participants. The motivation and the overall objectives of the project are presented. We will explain the design of the project and the working steps to perform the international intercomparison of the project, including an intercomparison of algorithms, products (spatially and temporal), and the generation a reference data set for validation of global / hemispheric / continental snow products. Finally, the expected outcome of the project is outlined.

Mon-1.2 Uncertainty in Snow Cover Datasets – Guidance for SnowPEx

Ross Brown and Chris Derksen

Climate Processes Section, Environment Canada
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Experience has shown that the uncertainty between snow datasets varies with snow cover variable, season and location. Knowledge of the spatial and temporal character of these relative uncertainties provides valuable guidance to SnowPEx on two levels: first it identifies regions where we have relatively high confidence in snow cover that can be used for evaluating new satellite products; second, it highlights areas where additional efforts are needed to reduce uncertainties. This presentation will evaluate the between-dataset agreement of snow in a number of commonly used datasets (e.g. NOAA IMS, CMC, Liston and Hiemstra, ERA-interim, MERRA) for key snow cover variables including monthly SWE and snow cover extent, snow-on date, snow-off date, and annual maximum SWE.

MON-2 PROTOCOLS FOR PRODUCT VALIDATION AND INTERCOMPARISON

Mon-2.1 A Validation Protocol for Continental Scale Snow Extent Products that Incorporates Product and Reference Uncertainty

Richard Fernandes (1), Sari Metsaemaeki (2), Gabriele Bippus (3), Rune Solberg (4), Chris Derksen (5), Thomas Nagler (3), Bojan Bojkov (6)

CCRS(1) SYKE(2), ENVEO (3), Norwegian Computing Center (4), Environmental Canada (4), ESA (6)
Contact: richard.fernandes@nrcan.gc.ca

GCOS requires global daily snow extent maps meeting specified threshold and ideal targets for accuracy, precision, stability and completeness. Previous validation studies have evaluated either snow cover fraction (SCF) or binary snow extent (SE) validation versus localized in-situ measurements or spatial maps from higher resolution satellite data. Some studies have attempted to incorporate product and reference uncertainties in the validation but not in a manner universal across product types. Here we present a protocol for validating SCF and SE products against both spatial and point reference data that:

- incorporates product uncertainty , especially for SE products that use differing thresholds and for unmapped areas due to clouds
- incorporates reference uncertainty, especially for relating snow depth to SCF and
- allows for flexible spatial aggregation is capable of both product intercomparison and direct validation.

The protocol will be reviewed and a sample application to a regional dataset will be presented.

Mon-2.2 The Satellite Snow Products Intercomparison and Evaluation Experiment: Protocols, Metrics, and Open Issues

Chris Derksen, Ross Brown, Lawrence Mudryk, Kari Luojus, Richard Kelly, Marco Tedesco, Shengli Wu

Contact: Chris.Derksen@ec.gc.ca

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 the participating SnowPEx SWE datasets, and outline the draft SnowPEx strategy for the assessment of gridded, satellite derived SWE products, including:

- the use of high quality networks of independent ground reference measurements,
- 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.

An additional objective is to raise open issues related to these three areas, and develop consensus from workshop participants on how best to proceed. These issues include:

- How to best perform a comparison with ground measurements (particularly in alpine areas) at the 25 km resolution of the SWE products? Should the comparison be limited to dense ground reference networks that provide multiple sub-grid measurements?
- What will be the standard time periods (golden years) and temporal resolution (daily versus weekly)?
- What is the most meaningful way to utilize the reference gridded SWE products given that some share common reanalysis meteorology and precipitation forcing, and these products have their own uncertainties and biases?

MON-3 SNOW EXTENT PRODUCTS - 1

Mon-3.1 A Summary of NOAA Satellite-Derived Snow Products

Sean Helfrich; Christopher Grassotti; Peter Romanov; Jeff Key; David Robinson

Contact: sean.helfrich@noaa.gov

Satellite-derived snow products have been a key element for National Oceanic and Atmospheric Administration (NOAA) operations for several decades. Proper mapping from space offers a unique and broad evaluation of snow conditions for meteorology, hydrology, commerce, and transportation applications. National Environmental Satellite, Data, and Information Service (NESDIS) has generated operational hemispheric snow maps since 1966, with ever expanding capabilities to determine snow conditions at regional and global scales. Northern Hemispheric snow cover climatology can be constructed by careful management and merging of NESDIS snow extent maps that have underwent improvements over time. Snow products offered by NESDIS are currently in a state of rapid expansion. Highlighted improved and emergent products for this presentation include the third version of the Blended Snow/Interactive Multisensor Snow and Ice Mapping System (IMS) snow cover and depth, binary snow cover from Visible Infrared Imaging Radiometer Suite (VIIRS), snow depth and snow water equivalent (SWE) from the Advanced Technology Microwave Sounder (ATMS) using the Microwave Integrated Retrieval System (MIRS), and snow depth/SWE from the Advanced Microwave Scanning Radiometer 2 (AMSR2). Additional snow characterization and blended snow products are in development in an effort to meet NOAA user requirements.

Mon-3.2 NESDIS Global Automated Satellite Snow Product: Current Status and Recent Results

Peter Romanov

NOAA-CREST Center at City University of New York and NOAA/NESDIS Center for Satellite Applications and Research (STAR)
Contact: peter.romanov@noaa.gov

NESDIS Global Automated Multisensor Snow/Ice Mapping System was implemented into operations at NOAA in 2006 and has successfully operated since that time. The system combines information on the snow and ice cover derived 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. The primary input to the system consists of the data from AVHRR instrument onboard METOP satellites and from SSMIS data onboard DMSP satellites. The nominal spatial resolution of the current product is about 4 km however the effective spatial resolution may degrade if snow and/or ice were mapped solely with coarser resolution microwave data. Daily maps of the snow cover distribution are further processed to estimate hemisphere-wide and continental-scale snow cover extent as well as corresponding anomalies in the snow extent.

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 illustrating the agreement of the two products on the seasonal duration of the snow cover in the Northern Hemisphere will also be presented and analysed. Preliminary estimates show an over 95% yearly mean agreement on the daily continental-scale snow cover distribution between the two products. The mean difference in the estimated daily, monthly and yearly Northern Hemisphere and continental -scale snow extent stays correspondingly within 4%, 2% and 1%.

The focus of the near-future modifications of the automated system will be on increasing the spatial resolution of snow and ice maps. The Southern Hemisphere portion of the product was upgraded to 2 km resolution in 2013. This year a similar improvement will be made to the Northern Hemisphere maps. Potentials to improve snow and ice retrievals in the microwave by using combined observations from multiple SSMIS instruments in the microwave will be discussed.

Mon-3.3 Influence of Grid Resolution on the NOAA Historical Satellite Snow Product

Gina Henderson, David Robinson, Thomas Estilow

Contact: ghenders@usna.edu

Continuous mapping of Northern Hemisphere snow and ice cover by NOAA and the National Ice Center (NIC) has resulted in a snow cover extent (SCE) dataset that is now long enough to be considered a climate data record (CDR). Since the beginning of this dataset in 1966 however, changes in mapping methodologies have occurred over time. With the advancement of satellite technology in spatial and temporal resolution specifically, the once weekly coarse resolution product is now available daily on a much finer scale.

This SCE CDR was generated using a low-resolution, long-term SCE record available on a weekly timescale derived from a thorough reanalysis of NOAA satellite-derived maps of NH continental SCE was integrated with a newly generated 1979-present microwave SCE and melting snow product. A 100 km Equal-Area Scalable Earth version 2 grid (EASE2) developed at the National Snow and Ice Data Center was used for this CDR. A shorter-term integrated dataset with a higher spatial resolution (25km EASE2) and at daily resolution was also for the period 2000-present.

To assess the effects of grid resolution and land mask changes specifically, we present analysis comparing the SCE climatology derived from such different grid resolutions. This analysis will aid in evaluating how sensor improvement, dataset quality control and standardization has affected the SCE representation through the history of this product.

Mon-3.4 GlobSnow Snow Extent Product

Sari Metsämäki, Kari Luojus, Jouni Pulliainen

Contact: sari.metsamaki@environment.fi

European Space Agency's Data User Element (DUE) project GlobSnow was established to create a global database of Snow Extent and Snow Water Equivalent. GlobSnow-1 was launched in 2008 and candidates for Climate Data Record (CDR) on SE and SWE were introduced in 2011. These prototype versions were further developed in the sequel project GlobSnow-2 (2012-2014). The GlobSnow SE product portfolio includes maps on Fractional Snow Cover (FSC, range 0-100 % or 0-1) in $0.01^0 \times 0.01^0$ geographical grid and they cover the Northern Hemisphere in latitudes 25^0N - 84^0N and longitudes 168^0W-192^0E. GlobSnow SE products are based on data provided by ERS-2/ATSR-2 (1995-2003) and Envisat/AATSR (2002-2012), so that a contiguous dataset spanning for 17 year is obtained. The GlobSnow SE method development has been particularly focused on fractional snow retrievals in forested areas. The semi-empirical reflectance model-based method SCAmod by Metsämäki et al., (2005, 2012) is applied. The apparent forest transmissivity is a key element in SCAmod. The Northern Hemisphere transmissivity in $0.01^0 \times 0.01^0$ resolution was derived from MODIS 500m reflectance (550nm) data and GlobCover classification. Besides the transmissivity, SCAmod parameters include generally applicable values of snow, forest canopy and snow-free ground reflectances. In the latest v2.0 SE, spatially varying snow-free ground reflectance map was determined, while the other two are static values.

The Daily Fractional Snow Cover (DFSC) product provides fractional snow cover in percentage (%) per grid cell for all satellite overpasses of a given day. FSC is provided only for observations at sun zenith angle < 74^0. The Weekly Aggregated Fractional Snow Cover (WFSC) provides the last available estimate within past seven days. The Monthly Aggregated Fractional Snow Cover (MFSC) product provides FSC as an average of all available daily FSC estimates within the calendar month. The corresponding FSC maps categorized in four classes are also provided. In addition to information on fractional snow cover, a statistical uncertainty based on observed/estimated variations in SCAmod parameters is provided for each FSC estimate. The dataset is available at http://www.globsnow.info/se/archive_v2.0/

GlobSnow validation has been focused on daily products. Validation data includes in situ measurements on Snow Depth and Snow Coverage, using data from Finland, Germany, Austria and Switzerland. In Northern Hemisphere scale, validation has been based on Landsat TM/ETM+ data.

References:

Metsämäki, S., Anttila, S., Huttunen, M., Vepsäläinen, J. (2005). A feasible method for fractional snow cover mapping in boreal zone based on a reflectance model. Remote Sensing of Environment, 95, 77–95.

Metsämäki, S., Mattila, O.-P., Pulliainen, J., Niemi, K., Luojus, K., Böttcher, K. (2012). An optical reflectance model-based method for fractional snow cover mapping applicable to continental scale. Remote Sensing of Environment, 123, 508-521.

Mon-3.5 Remote Sensing of Snow Properties from MODIS

Thomas Painter, Karl Rittger, Kat Bormann, Cameron Goodale, Chris Mattmann

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The response of the cryosphere to climate forcings largely determines Earth's climate sensitivity. However, our understanding of the strength of the simulated snow albedo feedback varies by a factor of three in the GCMs used in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, mainly caused by uncertainties in snow extent and the albedo of snow-covered areas from imprecise remote sensing retrievals. Additionally, the Western US and other regions of the globe depend predominantly on snowmelt for their water supply to agriculture, industry and cities, hydroelectric power, and recreation, against rising demand from increasing population. With growing capabilities to model climate at meso-scale, constraining and validating data for snow state and response must be accurate at the per-pixel basis.

To provide the per-pixel accuracy needed for mapping snow properties, we have developed and validated the suite of physically based MODIS snow products that provide accurate per-pixel fractional snow covered area and radiative forcing of dust and carbonaceous aerosols in snow. The MODIS Snow Covered Area and Grain size (MODSCAG) and MODIS Dust Radiative Forcing in Snow (MODDRFS) algorithms, developed and transferred from imaging spectroscopy techniques, leverage the complete MODIS surface reflectance spectrum. The MODSCAG snow cover products are strikingly more accurate than the current MOD10A1/MYD10A1 products and the MODDRFS product fills a gap in our remote sensing retrievals at a time when the modelling of the impacts of light absorbing impurities on snow and ice melt is starved of validation data.

Here we present ongoing analyses of MODSCAG and MODDRFS products against high-resolution fractional snow covered area retrievals from Landsat 5 Thematic Mapper, Landsat 7 Thematic Mapper, and Landsat 8 Operational Land Imager (OLI). We also present the implementation of the near-real time MODSCAG products in the operations of the National Weather Service Colorado Basin River Forecast Center (CBRFC), validation with MODSCAG of the Weather Research and Forecasting/Noah-MP snow simulations, the National Climate Assessment of snow covered area and dust radiative forcing, and the use of MODSCAG time series to map annual minimum exposed snow and ice.

MON-4 SNOW EXTENT PRODUCTS – 2

Mon-4.1 A New Global Snow Cover Product Based on Multi-sensor Multi-temporal Satellite Data

Rune Solberg, Øystein Rudjord, Arnt-Børre Salberg, Mari Anne Killie

Contact: rune.solberg@nr.no

Changes in the snow cover over time are a sensitive indicator of climate change at the global, continental and local scale. The temporal seasonal snow cover pattern has changed significantly over the last few decades, mostly 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 be used only 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 snow depths are 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.

The basic algorithm idea is to estimate the states the snow surface goes through during the snow season. We have chosen a Hidden Markov Model (HMM) to model the states and their relation to the observations. A HMM is established for each grid cell (pixel) in the snow product. We model six basic state types: 1) Snow, a seasonal snowpack consisting of a persisting snow layer; 2) Temporary snow, a thin layer of new snow; 3) Wet snow, a state that may occur any time with a snowpack present; 4) Cloud shadow; 5) Patchy snow; and 6) Snow free. For validation we applied SYNOP snow depth data records, and an overall accuracy of 92.4% was obtained.

The resulting product time series represent daily cloud-free snow maps of full geographical coverage, covering both the Southern and the Northern Hemisphere.

Mon-4.2 Snow Extent Products of the EC FP7 Project CryoLand

Thomas Nagler; Gabriele Bippus; Sari Metsaemaeki; Rune Solberg

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The project “CryoLand – Copernicus Service Snow and Land Ice” deals with the development and delivery of customized snow, glacier and lake and river ice products for a Downstream Service within the Copernicus program of the European Commission. CryoLand exploits Earth Observation data from current optical and microwave sensors and prepares for the Copernicus Sentinel satellite family. The project addresses the cryospheric component of Copernicus Land Monitoring services. The CryoLand project team consists of 10 partner organisations from Austria, Finland, Norway, Sweden, Switzerland and Romania and is funded by the 7th Framework Program of the European Commission.

The operational near-real-time snow service includes monitoring of daily fractional snow cover on regional and continental scale from optical satellite data, of daily snow water equivalent on continental scale and mapping of daily wet snow cover for selected regions during the melting season based on radar satellite data. Snow products at continental coverage are generated for a homogenized snow service for the pan-European area from 72°N/11°W to 35°N/50°E using MODIS data as input. The product with 500 m pixel spacing is based on the SCAMOD algorithm developed by SYKE and re-implemented by ENVEO including some additional classification rules for near real time processing. Additionally to the near-real-time snow services archived MODIS satellite data are reprocessed in order to build a long-term, homogenous satellite based archive of daily snow extent products starting from December 2000 until present.

Quality assessment of the products and services is an important part of the CryoLand project. Reference data include in-situ snow measurements in Finland and snow products from high resolution snow maps. The very-high-resolution satellite including SPOT5, Quickbird, and WorldView data were ordered through and provided by the Copernicus Data Warehouse, and are used for product evaluation at specific test sites all over Europe. This data set was supplemented by Landsat TM / ETM+ / LDCM images. The fractional snow extent products are also intercompared with the MODIS (MOD10_L2) and GlobSnow fractional Snow Extent product.

Examples of CryoLand snow products and preliminary results of the validation with reference data sets will be presented.

Mon-4.3 Enhanced Snow Cover Algorithm Based On 250 m MODIS Images For Monitoring Temporal And Spatial Changes In The Mountain Areas

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This paper presents the development and extensive validation of a new algorithm for snow cover monitoring based on 250 m MODIS satellite images and specifically designed for mountain areas. Despite the availability and general performance of the MODIS MOD10 Snow Product, being characterized by a spatial resolution equal to 500 m, obvious limitations affect the monitoring of local environment and stress the need for an adapted and robust algorithm to map snow cover with the highest possible amount of spatial details. They can enable an improved determination of snow as well as more accurate depiction of the winter snowline.

The EURAC snow algorithm has two main characteristics with respect to the NASA algorithm: first, it exploits the bands at 250m in order to have a snow map with improved spatial resolution; second, thanks to a direct broadcast from the EURAC receiving station the snow maps are delivered to the users in quasi real-time i.e. around 4 hours after MODIS image acquisitions (Notarnicola et al., 2013). The algorithm is divided in three main modules. The first module is devoted to snow detection based on the 250m resolution MODIS bands and on NDVI thresholds, the second to the detection of snow in forest and the third to the cloud detection. The snow layer is produced along with four quality layers dedicated to: 1. snow quality flag; 2. cloud quality flag; 3. input data quality flag; 4. satellite viewing geometry quality flag. The algorithm validation was carried out by using high-resolution snow maps derived from LANDSAT images and snow depth data from ground stations of selected test sites in Central Europe. A comparison of MODIS snow cover maps to sixteen snow cover maps derived from LANDSAT showed an overall accuracy of 93.6 %. The residual mismatch area is often linked to forest, presumably due to changes in forest areas. This behaviour can be therefore ascribed to limited abilities of MODIS to accurately detect the snow under forest especially under extreme illumination conditions. For the comparison with ground data, snow depth measurements from 148 ground stations in Germany, Austria, Italy and Slovakia were used. In most of the areas, the overall accuracy is around 95%. It decreases to around 80% in very rugged terrain restricted to in-situ stations along north facing slopes, which lie in shadow in winter during the early TERRA acquisition. The whole 2002-2014 time series of MODIS TERRA and AQUA images is currently being processed over the entire Alpine areas. Moreover, in this reprocessing enhanced snow products will be available where the clouds presence is mitigated applying standard time filters which exploit the time correlation of snow cover under proper assumptions and implementing a novel spatial filter based on the Support Vector Machine (SVM) technique and exploiting topographic information such as altitude, aspect and slope.

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Mon-4.4 A New Snow Product Merging Visible, Near-IR and Passive-Microwave Snow Maps

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As part of a NASA Making Earth System Data Records for Use in Research Environments (MEaSUREs) project, three snow product data records were merged to enable detailed comparisons of snow extent in the Northern Hemisphere. The snow products merged into a 10-year long time series are the: Moderate Resolution Imaging Spectroradiometer (MODIS) cloud-gap filled (CGF) daily, 500-m resolution snow-cover extent (SCE) maps, Interactive Multisensor Snow and Ice Mapping System (IMS) visible satellite SCE climate-data record (CDR) maps and passive-microwave snow maps of SCE on land. The product, MEaSUREs Northern Hemisphere Terrestrial Snow Cover Extent Daily 25km EASE-Grid 2.0, a daily time series of merged-map data products that extends from 1999 – 2012, will be archived and distributed through the National Snow and Ice Data Center (NSIDC). The MODIS snow-cover maps are daily but cloud cover precludes complete snow mapping, so a cloud-gap filling technique is used to derive the MODIS daily cloud-free maps at their inherent resolution of 500 m. The IMS product, at ~4 km resolution, utilizes a variety of satellite and station data to produce a daily, cloud-free map. The passive-microwave maps, at ~25-km spatial resolution and unhindered by cloud cover, are also produced daily. All three datasets are re-gridded to the 25-km resolution EASE-Grid 2.0 map projection. It is now possible to perform detailed studies comparing snow-cover distribution among the three products within the merged dataset. Analysis has focused on determining accuracy of the snow maps under various circumstances using station reports and visible satellite imagery. Evaluation of selected cases of snow map agreement and disagreement will be discussed.

Mon-4.5 Comparison of Fractional Snow Detection Algorithms for VIIRS Retrievals

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Monitoring snowpack dynamics in complex mountainous terrain from space requires retrievals at moderate to high spatial and temporal resolution. With daily near-global coverage and 500m spatial resolution, MODIS-derived (Moderate-resolution Imaging Spectroradiometer) snow cover products from NASA's Earth Observing System satellites have become a workhorse for snow cover monitoring. These satellites have been operating since 2000 and 2002 and have surpassed their expected life span. The Visible Infrared Imager Radiometer Suite (VIIRS) aboard Suomi National Polar-orbiting Partnership (Suomi NPP) was launched in October 2011 and provides data continuity with MODIS data. Moderate band surface reflectance retrievals from the VIIRS sensor are available at 750m resolution and are collected for similar but not identical spectral bandpasses as those from MODIS. The current standard fractional snow cover product that is currently produced from VIIRS data uses the empirically-based Normalized Difference Snow Index (NDSI) algorithm for a binary map and then turned to fractional via a 2x2 averaging operation. As such, the algorithm can only achieve 25% fSCA (fractional snow cover area) increments and cannot meet the existing requirement of per-pixel uncertainty of less than 10%. Linear spectral unmixing techniques such as Snow Cover and Grain size (SCAG) have been previously applied to MODIS data and shown to be more accurate than empirical algorithms. Spectral unmixing algorithms have the capability to detect more fractional snow cover than empirical NDSI-based algorithms, particularly during transitional periods when snow is patchy and grain size is large. In this study we present fSCA data from VSCAG, the mixed pixel SCAG algorithm to the VIIRS Level 2 surface reflectance data. When compared to high-resolution 30m Landsat TM scenes, snow cover mapping using VIIRS surface reflectance data is significantly improved for the SCAG algorithm over the standard VIIRS Snow Cover Product. This work demonstrates the value of spectral unmixing for snow cover detection in mountainous snowfields and has important applications for the continuation of long-term snow cover monitoring.

Mon-4.6 Prototyping of Hemispherical Snow Cover Extent Products Towards The Japanese Global Change Observation Mission GCOM-C

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Japan Aerospace Exploration Agency (JAXA) will launch an Earth observing satellite for climate study named “GCOM-C” in JFY2016 which carries an optical sensor SGLI. The GCOM-C satellite will observe various geophysical targets such as snow cover extent and snow physical parameters including snow grain size, temperature and so on in order to establish long-term satellite data record of those geophysical parameters. As a preparatory data set, JAXA has started to generate satellite products of those climate-related geophysical variables (including snow cover extent) using NASA’s optical sensor MODIS radiance data. Those products have been distributed to the public through the web site named JAXA Satellite Monitoring for Environmental Studies (JASMES, http://kuroshio.eorc.jaxa.jp/JASMES/index.html) since 2008. Currently, the data period of the snow cover extent product are being extended toward the past around 1980’s using NOAA/AVHRR radiance data. Preliminary results indicate that the retrieved long-term snow cover extent in the Northern Hemisphere basically follows the temporal variations of the NOAA/NCDC Climate Data Record of Snow Cover Extent (SCE) products with having some biases seen in spring (negative) and autumn (positive) seasons. The effects of the ascending node drifting of NOAA-series satellites still seem to affect the accuracy of the snow cover identification in some observation years. In this presentation we will introduce our activities on the prototyping of the hemispherical snow cover extent products using MODIS and AVHRR data.

Mon-4.7 Remote Sensing of Snow Properties from MODIS

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The response of the cryosphere to climate forcings largely determines Earth's climate sensitivity. However, our understanding of the strength of the simulated snow albedo feedback varies by a factor of three in the GCMs used in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, mainly caused by uncertainties in snow extent and the albedo of snow-covered areas from imprecise remote sensing retrievals. Additionally, the Western US and other regions of the globe depend predominantly on snowmelt for their water supply to agriculture, industry and cities, hydroelectric power, and recreation, against rising demand from increasing population. With growing capabilities to model climate at meso-scale, constraining and validating data for snow state and response must be accurate at the per-pixel basis.

To provide the per-pixel accuracy needed for mapping snow properties, we have developed and validated the suite of physically based MODIS snow products that provide accurate per-pixel fractional snow covered area and radiative forcing of dust and carbonaceous aerosols in snow. The MODIS Snow Covered Area and Grain size (MODSCAG) and MODIS Dust Radiative Forcing in Snow (MODDRFS) algorithms, developed and transferred from imaging spectroscopy techniques, leverage the complete MODIS surface reflectance spectrum. The MODSCAG snow cover products are strikingly more accurate than the current MOD10A1/MYD10A1 products and the MODDRFS product fills a gap in our remote sensing retrievals at a time when the modelling of the impacts of light absorbing impurities on snow and ice melt is starved of validation data.

Here we present ongoing analyses of MODSCAG and MODDRFS products against high-resolution fractional snow covered area retrievals from Landsat 5 Thematic Mapper, Landsat 7 Thematic Mapper, and Landsat 8 Operational Land Imager (OLI). We also present the implementation of the near-real time MODSCAG products in the operations of the National Weather Service Colorado Basin River Forecast Center (CBRFC), validation with MODSCAG of the Weather Research and Forecasting/Noah-MP snow simulations, the National Climate Assessment of snow covered area and dust radiative forcing, and the use of MODSCAG time series to map annual minimum exposed snow and ice.

MON-5 POSTER PRESENTATIONS

Mon-5.1 EUMETSAT's Network of Satellite Application Facilities (SAF Network): Sustained Development and Operations of Snow Products from Satellites

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Satellite Application Facilities (SAFs) are dedicated centres of excellence for processing satellite data and they form an integral component of EUMETSAT's distributed applications ground segment. Located at National Meteorological Services in Member States, they use the expertise of the EUMETSAT community to process application-specific data from geostationary and polar orbiting satellites for the generation of data products and tools for the meteorological and climate data user communities and beyond.

The SAF Network was created in the late 1990s when EUMETSAT recognised the technological and scientific development during the last decades together with new capabilities arising from the advanced European operational meteorological satellite programmes (Meteosat Second Generation MSG and the EUMETSAT Polar System EPS). These new capabilities offered new possibilities for supporting application areas and disciplines with satellite based data and services appeared and with the sophisticated instrumentation of MSG and EPS (Metop) a wide range of applications and services became feasible. This led to concept of a distributed Application Ground Segment, including the Central Facility in Darmstadt, Germany, and a network of elements, known as Satellite Application Facilities (SAF), as specialised development and processing centres. Each SAF is led by the National Meteorological Service of a EUMETSAT Member State, working with a consortium of cooperating entities.

The current development activities of the SAFs are focussed on providing new products of increased coverage and quality as well as on the preparation for the next generation of EUMETSAT's satellites, namely the Meteosat Third Generation (MTG) and the EPS Second Generation.

The satellite snow product activities of EUMETSAT are concentrated in the SAF on "Support to Operational Hydrology and Water Management (H-SAF)" which is providing products and services related to precipitation, soil moisture and snow properties and makes use for a wide range of different operational satellite sensors in a synergetic approach.

The individual snow products are:

Snowfall intensity from AMSU and MHS observations

- Snow detection (snow mask) from SEVIRI (Meteosat) and later FCI (MTG)
- Snow status (dry/wet) from SSMIS (DMSP)
- Snow detection and Effective snow cover from AVHRR (NOAA and Metop)
- Snow water equivalent from SSMIS (DMSP)

Mon-5.2 A candidate for the Satellite Snow Product Inter-comparison and Evaluation Experiment

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Large-scale systematic snow monitoring is of paramount importance due to its essential influence on climate, water cycle, weather patterns, and socio-economic spheres. Complementary to ground-based station data and model approaches, satellite imagery provides comprehensive snow information, even in remote areas. The relative brevity of satellite records, however, poses a primary disadvantage of the technique. Only AVHRR offers the opportunity to analyse more than 25 years of medium-resolution satellite imagery on a daily basis. Yet, this sensor offers a great opportunity to assess long-term environmental changes on a hemispheric to global scale. However, to serve this purpose, adequate algorithms and careful validation are of essential significance.

We present a new AVHRR SE record covering Europe and dating back to the mid-eighties. Originally developed for the European Alpine Region (Hüsler 2012) the product has recently been expanded to the continental scale. Taking into account the distinct spectral properties of the AVHRR sensors, the snow detection relies on a threshold approach that capitalizes on the spectral properties of snow in the visible and the near infrared spectrum (Khlopenkov 2007). A major asset in comparison to most other AVHRR snow detection schemes is that this detection algorithm is applicable to any kind of AVHRR sensor generation with consistent results, which only then allows for retrieval of homogeneous long-term SE information. The product consists of daily SE charts over Europe at 1-km resolution combining the data from various overpasses of AVHRR payloaded platforms into a maximum composite with minimum cloud coverage. As a quality assessment, a map comes along with each composite that indicates the distinct probability of each pixel of being snow covered as derived from logistic regression. Furthermore, a set of daily cloud-free snow products is provided by applying spatial and temporal gap-filling techniques. Consequently, this allows for the pan-European retrieval of various important parameters such as snow onset day, snow cover duration (SCD), melt-out date (SCMD) and the snow cover area percentage (SCA) to analyse the spatiotemporal snow cover variability of snow cover over the last three decades (Hüsler 2014). A land cover-dependent validation of the record as well as an intercomparison to other European SE products is currently ongoing. Likewise, the temporal consistency and inter-sensor stability of the algorithm will be assessed on the expanded data set.

Finally, the aim is to compile a consistent snow cover climatology for continental Europe based on historical 1-km AVHRR data showing the high year-to-year and regionally influenced snow cover variability. Furthermore, this product is considered a valuable candidate when working towards a satellite product intercomparison experiments.

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Mon-5.3 Taking Advantage of Daily MODIS and VIIRS Data, Time-space Interpolation and Smoothing to Provide Daily Estimates of Snow Surface Properties

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Estimates of spatially distributed snow cover and its albedo are interrupted by clouds, sensor noise, and artefacts cause by off-nadir viewing. We identify sensor noise, discriminate snow from clouds, and account for the increase in the pixel size caused by off-nadir views up to 55 degrees. For any period, say one or two weeks, we weight each pixel for its reliability on a scale from 0 to 1. We can use these weights to pick the "best" pixel for the period, or we can use the weights in a time-space interpolation and smoothing scheme to provide our best estimate for each pixel's snow properties, each day.

Mon-5.4 Scene-specific Approach to Snow Retrieval

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The careful detailed validation of VIIRS snow data on the basis of comparison with the ground truth for a variety of conditions provides valuable information on the reasons of retrieval errors and helps identify the directions to improve the snow products.

The Landsat bands closely correspond to the bands utilized by the VIIRS snow algorithms to calculate NDSI values used to detect snow cover and serving as an indicator of varying snow fraction. Our estimation of ground truth at a high resolution scale is based on the hypothesis that NDSI calculated for Landsat pixels could be used to distinguish snow covered Landsat pixels from snow free pixels.

Good correspondence between maps of binary (snow / non-snow) Landsat pixels classification and coregistered false colour Landsat images for exactly the same projection and resolution demonstrates high quality of the classification based on a predetermined NDSI threshold. The review of NDSI images also confirms that the Landsat pixel classification is reliable and could be used to assess the VIIRS snow products.

The Landsat ground truth and the VIIRS data were made completely spatially comparable after precise coregistration of the Landsat classified pixels with the VIIRS binary snow product and their aggregation for identical 0.05° cells of a regular latitude / longitude grid widely used for hydrologic and climate modelling. Snow Covered Area (SCA) estimated as the percentage of a model cell covered by snow is a major measure of spatial inhomogeneity of snow cover.

The analysis shows that the typical NDSI value separating snow from non-snow is higher than the currently used threshold. It was further found that the magnitude of the optimal NDSI threshold to distinguish snow from non-snow varies considerably - from 0.15 to 0.65 depending on local reflective properties of snow and non-snow surfaces in the VIIRS scenes. The adjustment of the NDSI threshold to specific local conditions leads to better quality of snow products.

The improved snow retrieval can be achieved by an algorithm that takes into account the variability of snow and non-snow reflectances in space and time. The development of a scene-specific approach taking local reflective snow and non-snow properties into account could be considered as a promising way to improve snow retrieval from VIIRS observations.

The comparisons between retrieved and true SCA demonstrate that on average there is no bias between calculated and true values. The statistical comparison of the gridded VIIRS snow product with Landsat ground truth information is characterized by the linear relationships between true and calculated values with negative intercepts and the slopes exceeding 1. Such parameters of a linear regression, typical for the scenes under consideration, demonstrate the need to modify the current VIIRS algorithm significantly and consistently overestimating the frequency of extreme aggregated snow cover area values (0% and 100%) and underestimating the probability of intermediate values (from 10% to 90%).

Since such type of errors is inherent to any binary snow retrieval, we tested different approach and reprocessed VIIRS observations using the fractional snow cover algorithm developed for MODIS by Salomonson and Appel, who demonstrated in their works that NDSI is sensitive enough to provide the snow fraction within a pixel of moderate resolution observations and that a fairly robust determination of the fraction of snow cover within pixels withstands to a certain degree a variability in snow and non-snow properties. As confirmation of such conclusions, the quality of the statistical relationships between aggregated SCA and Landsat ground truth enhances in comparison with the binary VIIRS snow retrieval. Experimental tests of the fractional snow cover algorithm provided noticeable improvement of the VIIRS snow area estimates.

It is important to note that the improvement of the SCA quality was provided by a standard "universal" version of the fractional snow algorithm. The adjustable version of the algorithm can and do vary from region to region and from time to time depending on snow and background surface state as well as the conditions of observations, such as viewing and solar geometry, the state of the atmosphere.

The optimal approach to improve moderate resolution remote sensing information on snow cover will combine allowing for the variability of snow and non-snow properties with snow fraction retrieval within a scene-specific snow algorithm to create unbiased and consistent information on snow cover distribution required for global studies, regional and local scale hydrological applications.

Mon-5.5 Supervised Machine Learning for MODIS Snow Cover Detection

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Snow cover data is used in a wide range of scientific studies, climate, water supply and management applications. The Earth Observation System's (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS), which is an instrument onboard the National Aeronautics and Space Administration's (NASA) Aqua and Terra satellites, captures data in 36 spectral bands. NASA has developed a physics based snow detection algorithm that utilizes a normalized difference snow index (NDSI) which takes advantage of the spectral differences of snow in the short-wave infrared and visible spectral bands. This approach relies on a subset of the spectral information that is available, using only 4 of the 7 MODIS spectral bands available at 500 meter resolution and 2 thermal bands. It relies on a set of precomputed thresholds defined to meet the requirements of global coverage. This work evaluates the performance of NASA Aqua and Terra snow products from 2010/08/15 to 2011/05/29 over the western United States using snow depth data acquired from 798 Snow Telemetry

(SNOTEL) sites provided by the Natural Resources Conservation Service (NRCS). We also evaluate several supervised learning classification methods which were trained on the SNOTEL data and operate on all 7 high-resolution reflectance bands as well as the 2 1-km thermal bands. In addition we compare these learning based classifiers to the NASA products.

Mon-5.6 Evaluation of Assimilation Efforts Using IMS Fractional Snow Cover in the NOAA/NCEP's NAM Operational Product

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NASA's Land Information System (LIS) integrates NOAA operational land surface and hydrological models (NCEP's Noah), high-resolution satellite and observational data, and land data assimilation tools. We first conduct a 5-year spinup run using the recursive one-year production NAM NDAS forcing from July 1, 2012 to June 30, 2013, and the offline LIS Noah run has been conducted with the initial conditions from above spinup serving as an open loop run. The production NAM NDAS has used both the IMS snow cover and AFWA snow depth analyses resetting the snow at the start over every 06z NDAS run. The 4km daily Interactive Multisensor Snow and Ice Mapping System (IMS) became operational in 2004. The IMS product is manually created by a satellite analyst looking at all available satellite imagery, several automated snow mapping algorithms, and other ancillary data. The production NAM/NDAS will serve as an assimilation run. Both open-loop and assimilation runs will be evaluated with ground-based measurements over CONUS to investigate the performance of the production NAM NDAS with assimilated snow product. Currently, the IMS data is served as a 'check' on the NOAA/NCEP global and regional modelling because it has more accurate coverage, especially in mountain ranges. The uncertainty in the IMS snow product will be further examined for successful utilization of snow cover products in advanced assimilation applications (e.g., EnKF).

Mon-5.7 *Fractional Snow Covered Area from Landsat TM and ETM+, a Validation and Application*

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We describe and validate a model that retrieves fractional snow-covered area from Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) at 30m spatial resolution. Planetary reflectance is calculated using the standard equations from the Landsat Handbook and surface reflectance is estimated using the Second Signal in the Solar Spectrum (6S) tailored to incorporate a digital elevation model to vary the atmospheric thickness. We also test data from the Landsat Surface Reflectance Climate Data record (CDR) from the USGS as direct input into our model. The approach uses a spectral mixture analysis with a library of snow endmembers derived for the scene's illumination geometry. Other endmembers such as vegetation, rock and soil were measured. Saturation in bands 1 through 3 results in a spectrum with artificially low apparent reflectance (with 6S) or an artificially high apparent reflectance (with CDR) so when all 3 bands are saturated we assume 100% snow cover. If only band 1 or bands 1 and 3 are saturated we perform spectral mixture analysis on the remaining non-saturated bands.

In bands 1-3 where saturation occurs, the 6S calculation underestimates the surface reflectance compared to in-situ measurements on February 15, 2002 by 12 to 20%, while the CDR calculation overestimates surface reflectance by 26 to 27%. Differences in band 4, 5, and 6 are approximately 1%, 21%, and 25% for both 6S and CDR though the absolute differences are small. Snow, vegetation, and soil/rock outputs from the spectral mixture analysis using the 2 different surface reflectance estimates vary up to 25% but with a mean of 1% across the image.

WorldView 2 scenes at a spatial resolution of 0.4m were acquired from the Digital Globe EnhancedView archive to provide validation for fractional snow covered area. Scenes were classified using the ISODATA unsupervised classification algorithm, with resulting classes manually assigned to snow covered or snow free categories. Resulting binary snow covered area images were reviewed and areas of incorrect classification were corrected via manual editing. These images were coarsened to the spatial resolution 30m and compared to Landsat TM and Landsat ETM+. Our initial comparison with a single validation image shows a mean error of 0.05 and a root mean squared error of 0.21 for the spectral mixing algorithm.

We combine data from a library of 30m Landsat-derived fractional snow cover images with daily fractional snow cover maps from MODIS at 500m to create a downscaled daily time series of 30m fractional snow covered area for the central Sierra Nevada of California. This approach consistently resulted in accurate 30m fractional snow covered area estimates for pixels where at least 30 cloud-free Landsat observations were available. Based on comparison with Landsat scenes not used in the downscaling process, root mean squared error was 0.12 when snow free pixels are considered and 0.22 for the subset of observations where MODIS fractional snow covered area was > 0.

Mon-5.8 The Temporal Variation and Spatial Distribution of Snow Covered Area Over the Tibetan Plateau

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The temporal variation and spatial distribution of snow covered area (SCA) over the Tibetan Plateau (TP) are analysed using MODIS/Terra 8-day snow cover products (MOD10A2) from 2001 to 2013 and SCA is compared with in situ snow cover days (SCD) from meteorological network in the TP. Results show that at monthly level the minimum SCA occurs in July, followed by August, and SCA increases rapidly from September and reaches the maximum in March; on average, 2002, 2005 and 2008 are snowy years, whereas 2001, 2003,2007and 2010 are less-snow years. Apart from strong seasonal variations, the general trend of inter-annual snow cover variations from 2001 to 2013 is not obvious, remaining at a relatively stable status. The snow cover over the TP is characterized by unevenly geographic distribution. In general, snow is abundant with long duration at the high mountains while it is less with short duration in the vast interior of the TP. The inter-annual variations of snow cover over the TP from ground-based meteorological stations using SCD are very consistent with MODIS SCA, with a correlation coefficient of 0.80 (P<0.01), indicating that MOD10A2 data has high accuracy to capture and monitor spatiotemporal variations of snow cover over the TP.

Mon-5.9 *Evaluating the GLOBSNOW and EUMETSAT HSAF SWE Products Over Mountainous Areas in Turkey*

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Monitoring snow parameters (snow depth, density, Snow Water Equivalent (SWE) and cover) at global, continental and regional scale is essential for the management of water generating from snowmelt and climate change studies. In practice, MW radiometers and scatterometer are the only space-borne remote sensing instruments that can supply data for calculation of snow parameters for hydrological applications. The spatial resolution of satellite microwave data is coarser than that of visible and thermal observations. The signal of a microwave radiometer observing a land surface from space is composed of surface and atmospheric contributions, both of which depend on the relief. Relief effects are twofold: First, the path through the atmosphere between the surface and the sensor depends on the altitude of the emitting surface, thus leading to a height-dependent atmospheric influence. The effect can be taken into account by standard atmospheric radiative transfer models if the elevation of the surface and the atmospheric state are known. Second is the variable topography of land surfaces, consisting of slopes, ridges and valleys, sometimes with characteristic alignments, and surfaces surrounded by elevated terrain. These surfaces can interact radiatively, not only with the atmosphere, but also with each other, leading to the tendency to enhance the effective emission. Under such circumstances, deviations occur from the standard hemispheric emission of a horizontal surface. Due to the coarse resolution of passive microwave sensors and the effect of topography over the mountainous areas, monitoring SWE over mountainous areas is still a big challenge.

In this study two daily snow products, namely GlobSnow and EUMETSAT HSAF, are used to evaluate the performance of their snow water equivalent (SWE) products over mountainous areas of Turkey. In situ observations for the years 1980-2013 for the evaluation of GlobSnow SWE product and 2010-2013 for the evaluation of HSAF SWE product are used. 95 ground stations having elevation values between 871 and 2885 m are used in the analyses. Ground stations having elevation values within 400 m varying from the median elevation of the satellite snow products' pixel area are considered in the validation studies. RMSE, bias and correlation coefficient are used as the statistical measures in the comparison of the products. It is observed that Globsnow product is underestimating the ground observation SWE values, whereas EUMETSAT HSAF product makes much better predictions on individual days with respect to RMSE values. For both of the products as snow depth increases negative bias also increases. Though the algorithms used in both SWE products depend on HUT emission model, but they show variation in the assimilation part of the algorithm. The comparison of two products is also done on an aerial basis. It is observed that Globsnow product catches the snow depth temporal variation better than HSAF product. The validation results are discussed according to the differences in the SWE retrieval algorithms of two products.

Mon-5.10 GPS Interferometry Offers New Validation Option for Snow Product Evaluation

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Ground-based GPS offers a relatively new source of snow validation data that is fully independent. The basic technique is well-understood and will be described. There are sites in Europe, the USA, and Japan that are undergoing evaluation for their applicability as snow validation sites for checking satellite and model snow products. In the US, the spatial coverage is different than SNOTEL, but there is overlap at large scales. There appears to be the potential for at least dozens, and perhaps hundreds of new validation sites.

A detailed description of the usefulness of these new validation sites can be obtained from an ongoing comparison among GPS, SNOTEL, and AMSR2/AMSR-E snow observations. Basic findings from this study will be presented.

Examples from comparisons from 84 GPS sites with non-ephemeral snow and 34 GPS sites with ephemeral snow will be presented. These are new snow validation sites in the western part of the US and in Alaska. The GPS sites span more of the Sturm snow categories than do SNOTEL sites, which promises opportunities for more representative/less biased validation against global snow products.

Mon-5.11 Assessing Satellite Snow Products for Assimilation Into the UK Regional Forecasting Model

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At the Met Office the global forecasting model uses a simple assimilation scheme for Northern Hemisphere snow amount, which derives a fractional snow cover from the NOAA Interactive Multisensor Snow and Ice Mapping System snow cover product and uses this to update the model snow amount daily. However, the high resolution UK forecasting model does not currently assimilate snow observations, and efforts are now underway to develop a snow assimilation scheme for the UK Numerical Weather Prediction (NWP) model.

Ground-based synoptic reports represent an important source of snow depth observations and these are widely used in snow assimilation systems at other national meteorological centres. These data, however, have a number of shortcomings. Although the measurement accuracy is generally very high compared with satellite-derived snow products, the coverage is relatively sparse, resulting in representativity issues, especially in regions of complex terrain. In addition, snow depth tends not to be reported in snow-free conditions when, in fact, reports of zero snow depth would be extremely valuable for assimilation purposes, as observations of snow-free area. A summary of the efforts currently underway in the NWP community to address this issue will be presented here.

Additional snow observations from satellite would be valuable for UK assimilation. Most satellite-derived snow products relate to the presence or extent of snow cover and contain no information about depth. These snow extent products vary in their spatial and temporal resolution, depending on whether the data are derived from geostationary or low earth orbit. A major issue is that snow sensing relies primarily on the visible part of the spectrum, which precludes retrieval of surface snow in the presence of cloud. New wet snow mapping products from Synthetic Aperture Radar (SAR) instruments may provide useful complimentary data to optical snow extent products, and could be particularly suitable for the characteristics of snow generally experienced by the UK. Although promising new snow water equivalent datasets are becoming available, such as those from ESA GlobSnow and EUMETSAT H-SAF programmes, it is not clear that they are yet suitable candidates for NWP assimilation.

Available satellite snow data sources for the UK region are currently being assessed for their suitability either for assimilation, along with in situ observations, or as validations data. This presentation will show results of evaluation studies for some of these satellite data as comparisons with ground-based observations and UK NWP model fields, focusing on case studies of recent notable UK snow events.

Mon-5.12 Global SnowPack – A Set of Snow Cover Parameters Made Available on a Global Scale

Andreas Dietz, Claudia Kunzer, Stefan Dech

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With the Global SnowPack the German Remote Sensing Data Center (DFD) of the German Aerospace Center (DLR) provides a new set of medium resolution Snow Cover products generated to fulfill the requirements of both large scale climate studies as well as small scale hydrological analyses. Between 2000 and 2014, Snow Cover Duration (SCD), Early Season SCD (ESS) and Late Season SCD (LSS) are derived from reprocessed operational MODIS daily snow cover products MOD10A1 and MYD10A1 (500m resolution) and AVHRR data (1000m resolution). 139 MODIS tiles are included in the processing workflow to cover the whole cryosphere of the full globe, comprising more than 100.000 scenes per year. For the years before 2000, snow cover is derived from AVHRR LAC and HRPT data relying on a combination of APOLLO (AVHRR Processing Over Land, cLoud and Ocean) and a modified SPARC (Separation of Pixels Using Aggregated Rating over Canada) scheme.

The presentation will give an overview of the status of the processing as well as the used algorithms to interpolate pixels below clouds and during polar darkness: Four successive methods are applied to the input data in order to produce the gap-free time series of daily snow cover data. The accuracy is assessed using cloud-independent station data as well as simulating cloud cover within cloud-free scenes. The reprocessed time series are then used to calculate SCD, ESS, and LSS for each hydrological year. Examples for potential applications of the Global SnowPack are included at the end of the presentation.

TUE-1 TUESDAY, 22 JULY 2014 – SNOW WATER EQUIVALENT

Tue-1.1 The GlobSnow Snow Water Equivalent Product

Kari Luojus, Jouni Pulliainen, Matias Takala, Juha Lemmetyinen, Tuomo Smolander, Chris Derksen

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The European Space Agency (ESA) data user element (DUE) funded GlobSnow project has produced a daily hemisphere-scale satellite-based snow water equivalent (SWE) data record spanning more than 30-years. The GlobSnow SWE record, based on methodology by Pulliainen (J. Pulliainen, 2006) utilizes a data-assimilation based approach for the estimation of SWE which was shown to be superior to the approaches depending solely on satellite-based data (Takala et al. 2011).

The GlobSnow SWE data record is based on the time-series of measurements by two different space-borne passive radiometers (SMMR and SSM/I) combined with ground-based weather station observations. The time series spans from 1980 to present day at a spatial resolution of approximately 25 km. A notable feature of the SWE product, when compared with the previously available datasets, is the inclusion of a statistically derived accuracy estimate accompanying each SWE estimate (on a pixel level). The current GlobSnow SWE data record has been released and is available through the GlobSnow web-pages (www.globsnow.info).

The GlobSnow SWE dataset is intended to be intercompared with the other existing hemispherical SWE datasets within the ESA SnowPEx initiative.

References:

Pulliainen, J. Mapping of snow water equivalent and snow depth in boreal and sub-arctic zones by assimilating space-borne microwave radiometer data and ground-based observations. Remote Sensing of Environment. 101: 257-269. DOI: 10.1016/j.rse.2006.01.002.

Takala, M., Luojus, K., Pulliainen, J., Derksen, C., Lemmetyinen, J., Kärnä, J.-P, Koskinen, J., Bojkov, B., “Estimating northern hemisphere snow water equivalent for climate research through assimilation of space-borne radiometer data and ground-based measurements”, Remote Sensing of Environment, Vol. 115, Issue 12, 15 December 2011, Pages 3517-3529, ISSN 0034-4257, DOI: 10.1016/j.rse.2011.08.014.

Tue-1.2 NASA Operational Approaches and Exploratory Activities for Improving SWE Estimates And Snowmelt Detection From Passive Microwave Observations

Marco Tedesco

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Microwave instruments have been measuring the natural upwelling microwave radiation from the Earth for more than 30 years, allowing estimates of snow parameters at large spatial scales and high temporal resolution over the entire Earth, especially over those areas or regions where ground observations are sparse or lacking. Despite many efforts and progress, there is still a large potential for improving algorithms and provide improved estimates of snow parameters such as snow depth, snow water equivalent (SWE) and freeze/thaw cycles. Over the past decades, indeed, operational and research algorithms have been using solely remote sensing observations, with little or no usage of ancillary information. However, the use of such ancillary data can provide tremendous benefit and considerably reduce uncertainty. Moreover, the spatial resolution at which microwave-based snow products are currently generated has been largely driven by the resolution at which passive microwave data is currently distributed (25 km). Nevertheless, recent efforts have made available the so-called 'enhanced spatial resolution' products, creating the opportunity to test snow retrievals at spatial resolutions of the order of down to 7.5 km.

In the first part of the talk I will present activities carried out by the NASA AMSR-E/2 US Science Team focusing on the implementation of an operational retrieval scheme for improved retrieval of snow parameters at global scale making use of a combination of numerical techniques (e.g., artificial neural networks), electromagnetic model and ingestion of ancillary climatology data for the estimation of snow depth. In the scheme, differently from previous ones, density (which is used to obtain SWE by multiplying density by snow depth) is not static in space or time, but it is obtained for every day and pixel in a dynamic fashion. In the case of the wet/dry snow state discrimination, the algorithm employs recently developed approaches based on the difference between night- and day-time acquisitions.

In the second part I will focus on the results obtained from the analysis of brightness temperature maps with 'enhanced spatial resolution' (7.5 km). This is the first time, to the best of my knowledge, that such dataset is applied to the retrieval of snow parameters. I will provide results focusing on the sensitivity of brightness temperature products to snow on ground in the case of the coarse and 'enhanced' products, focusing on mountain areas, where a finer spatial resolution might provide greater benefits. If successful, such approach will be integrated in future operational tools.

Tue-1.3 Snow Water Equivalent Estimation From GCOM-W1 AMSR2 Observations

Richard Kelly, Nastaran Saberi, Qinghuan Li

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Estimates of snow depth and snow water equivalent 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 snow depth product for AMSR2 has been updated through the use of an implementation of the Dense Media Radiative Transfer (DMRT) model originally developed by Tsang et al. (2000) and more recently implemented by Picard et al. (2011). 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 which drives an empirical grain growth model, and snow density is estimated from the Sturm et al. (2010) scheme.

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 REFERENCE DATA - 1

Tue-2.1 On the importance of accessible reference datasets for the evaluation of satellite snow products

Bojan Bojkov

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The evaluation of satellite-derived snow properties can be broken down into two distinct processes to meet product and service needs: 1) Monitoring of the measurement; and 2) Validation of derived geophysical parameters. Reference datasets, both in-situ data and high-resolution images, play an essential role in the evaluation and validation of satellite snow products and is used to quantify the snow data quality throughout the lifetime of the missions.

Space agencies depend on reference snow datasets collected through the WMO/GTS, the NSIDC, from networks such as the Canadian or Finnish Snow Observation stations, and as well as on data from individual scientific efforts. Many of the infrastructures underpinning the global monitoring of various snow parameters rely heavily on individual efforts, have uncertain long-term funding, and require coordination across many national and international organisations.

Today much of the satellite snow observations are research products, but this will significantly change as the operational demands from new missions, such as the JPSS-series or the European Sentinels, and snow services increase. The evaluation of these future fleets of different sensors requires not only a significant amount of in-situ data and hi-resolution reference images to evaluate the snow product performances in time, under different weather conditions and for varying geophysical areas, but also in an easy, sustainable and timely accessible way. It is crucial that access to the required reference datasets is guaranteed.

Tue-2.2 *In situ Snow and Vegetation Properties Along a Latitudinal Transect in North-Eastern Canada: A Reference Data Set to Assess Satellite SWE Products*

L. Brucker 1, 2, A. Langlois 3, A. Royer 3, L. Arnaud 4, P. Cliche 3, K. Goïta 3, G. Picard 4, A. Roy 3, C. Derksen 5

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Retrieving accurate snow water equivalent (SWE) is important for improving water planning (domestic, agricultural, and energetic) and for flood forecasting. To assess the accuracy of existing satellite SWE algorithms and products, and eventually to enhance regional and hemispheric SWE retrievals from space, we present in situ snow and vegetation measurements collected in northern Québec, Canada, during the ten-day International Polar Year experiment in February 2008.

The latitudinal variation of snow and vegetation properties were characterized over a transect of ~8º of latitude (~2000 km) in northern Québec. The transect started in dense boreal forest (at 50°N) and finished in open tundra (58°N). Sampling occurred approximately every 40 km along the transect. In addition, detailed in-situ and airborne measurements were collected along the transect over four high resolution nodes, with different ecological environments (dense boreal forest, forested taïga, open taiga, and tundra). On these high resolution nodes, located at Sept-Îles, Schefferville, Kuujjuaq and Puvernituq, sampling was conducted at 1-km intervals over an 8 km × 16 km grid, close to the microwave radiometer spatial resolution typically used for monitoring SWE. The region surveyed is interesting due to the latitudinal gradient in SWE and vegetation. Moreover, the availability of high resolution nodes offers a refined set to test and validate the SWE algorithms.

Our database includes measurements of SWE, snow depth, snow density and temperature (both at 3 cm vertical resolution). Near infrared photographs are also available at nodes, which provide information on the stratigraphy of the cover and grain size/type. In addition, the database includes vegetation measurements such as tree height, tree diameter at breast height, density, dominant species, and an estimate of the cover fraction.

These measurements reveal a strong and rapid decrease in vegetation volume. It is associated with a decrease in SWE. The presence of lake in this region makes it also possible to test the different algorithms where a fraction of lake is present in the field of view. Thus, such a database could be used to assess the SWE algorithm and to characterize their sources of uncertainty. Of note, coincident airborne passive microwave brightness temperatures were measured by Environment Canada at 19 and 37 GHz in both vertical and horizontal polarizations along the transect and over the four nodes.

Tue-2.3 Snow Course Observations in the Mountainous Regions of the North Pacific Rim

Konosuke Sugiura [1], Tetsuo Ohata [1], Gombo Davaa [2], Larry Hinzman [4], Vladimir Makarov [4],Trofim Maximov [5], Masahiro Hori [6]

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Melnikov Permafrost Institute, Russia [4] ; Institute for Biological Problems of Cryolithozone, Russia [5]; JAXA, JP [6]
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The North Pacific Rim is underlain by continuous and discontinuous permafrost. Snowpack conditions in this region are sensitive to a change in a climate. For clarifying the differences of snowpack characteristics in this region and for reducing the uncertainty of reliably estimating the amount of snow in the cryosphere, the snow surveys in the mountainous regions of the North Pacific Rim have been carried out selectively. The snow depth, snow water equivalent, snow hardness, snow temperature, snow type and size were measured using a snow stick, a cylindrical snow sampler with a cross-sectional area of 0.005-m2, a weight scale, a push gauge, a thermometer and a snow grain size gauge. In addition, the air temperature, altitude, latitude and longitude were measured using a thermometer and a handy-type GPS. The traverse lines were set to the Brooks Range, Alaska Range, Verkhoyansk Range, Stanovoy Range, Hentei Range and Altai Range, and were characterized by a tundra, taiga and steppe. It was found that the bottom of the snowpack in the mountainous regions is composed of the typical depth hoar layer, the total snow water equivalent in the coastal area increases with an increase in altitude, and the altitude dependence on snow water equivalent in the internal area becomes weak. This presentation will also describe the progress and present preliminary results of snow surveys including last winter. These snow survey data will enable us to carry out further analysis and development of validation datasets.

TUE-3 REFERENCE DATA 2

Tue-3.1 Reference Data for Assessing Satellite Snow Products in Europe and Canada

Gabriele Bippus[1], Thomas Nagler[1], Sari Metsämäki[2], Chris Derksen[3], Richard Fernandes[4], Kari Luojus[5], Rune Solberg[6]

ENVEO IT GmbH, AT [1]; Finnish Environment Institute, FI[2]; Environment Canada, CA [3];
Canada Centre for Remote Sensing, Government of Canada, CA[4]; Finnish Meteorological Institute, FI [5];
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Reference data, such as very high resolution satellite data or in-situ measurements, approximating the "ground truth", are crucial for assessing the quality of global or hemispheric snow products from satellite data. A unique data set of high resolution optical satellite images is available from the Landsat satellites, which are not only available free of charge, but also for a period of more than 30 years, and provide global coverage with 30 m pixel size. Satellite images with pixel sizes <=10 m, as acquired e.g. by SPOT-5 or Quickbird, closely represent the "ground truth", but are only available at a high cost. With an increase in the spatial resolution, the spatial coverage of a scene decreases, and the revisit time increases. Additionally, for all optical satellite data cloud cover can significantly limit the number of scenes usable as reference data.

In-situ snow measurements reporting the ground-truth at single points are available from most countries with a seasonal snow cover. To be suitable for spatial intercomparison with global or hemispheric snow products the spatial validity of in-situ measurements must be considered, which is especially challenging when point measurements are compared with 1 km x 1 km snow extent or 25 x 25 km snow water equivalent products. Short transect measurements (snow courses) better represent the local variability in snow distribution, but are available only for a few regions worldwide (e.g. Finland) and are sampled only intermittently through time (e.g. monthly). Temporally continuous and spatially intensive sub-grid measurements of snow cover (which are ideal for product evaluation) are very rare, but represent important reference locations for detailed assessment.

In this presentation we give an overview of the reference data currently available at the SnowPEx partners in Europe and Canada, including very high and high resolution optical satellite data as well as in-situ snow measurements covering multiple years and different snow-climate zones for intercomparison with global and hemispheric snow products.

Tue-3.2 Accuracy Standards for Partially Cloudy Landsat Visible/Infrared Snow Maps

Christopher Crawford, Dorothy K. Hall

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Accuracy standards are proposed to guide snow cover climate data record (CDR) development from Landsat TM, ETM+, and OLI/TIRS visible/infrared snow-covered area (SCA) retrievals. Because Landsat's observational timescale now exceeds four decades, and interests in long-term seasonal snow cover monitoring are increasing, efforts to design high quality Landsat snow cover CDR products are timely. While Landsat's acquisition frequency is constrained to every 16 days, concurrent acquisitions by TM and ETM+ during 2000-2011, and now ETM+ and OLI/TIRS from 2013 onwards, guarantees the potential for 8-day SCA retrievals. Based on a case study in western Wyoming, USA, minimum accuracy standards are developed for each image pre-processing algorithm prior to 30-meter SCA retrieval. Using a 365-image sample from TM, ETM+, and OLI/TIRS during discrete peak accumulation and melt intervals from 2000-2014, time domain error metrics are derived for cloud saturation, cloud/shadow masking, local solar illumination normalization, snow underneath dense forests, and SCA uncertainty around the snow/snow-free transition zone. Our results suggest that SCA map accuracy is strongly tied to the ability to minimize cloud/shadow omission errors in particular. If the heritage automated cloud cover assessment (ACCA) algorithm is combined with solar geometry cloud shadow projections, average map accuracy in the time domain is 95% with a standard deviation of 4% for partially cloudy images. Local solar illumination is highly variable in time and across space with near- and shortwave-infrared wavelengths showing the greatest sensitivity over snow-covered topography. The snow-dense forest interaction is seasonally dependent but stable in time, and the normalized difference snow index (NDSI)-normalized difference vegetation index (NDVI) criteria are most appropriate when derived on an image basis. SCA uncertainty within the snow/snow-free transition zone is well constrained, and is useful for generating SCA confidence intervals. To reduce observational differences across the Landsat mission, one must establish the accuracy of Landsat SCA mapping for each sensor, increase cloud/shadow-masking confidence, and establish that Landsat CDRs are free from non-climatic biases.

Tue-3.3 SNODAS Assimilation from 2003-2014: Qualifications as a Reference Analysis

Greg Fall, Carrie Olheiser, Logan Karsten, Andy Rost

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NOAA's operational Snow Data Assimilation System (SNODAS), operated and maintained at the National Hydrologic Remote Sensing Center (NOHRSC), is a source of daily quantitative snow analysis information for the Coterminous United States and southern Canada. SNODAS consists of a near-real-time gridded model analysis, short-term (currently 72 hours once per day) model forecasts, and regular assimilation of data from three primary sources: observed snow depth and snow water equivalent from surface stations and surveys, snow water equivalent measured by airborne gamma detection systems, and binary snow cover from satellite sensors.

SNODAS is often cited as a reference source for snow information, and this is its purpose. However, the assimilation process, which brings SNODAS model states into line with observations, is irregular. It does not occur on a fixed schedule, and it is typically performed only on a relevant subset of the modelling domain when adequate data are available and when measured errors in the modelled snowpack are sufficiently correlated spatially. Consequently, there can be significant gaps in space and time between recently-assimilated areas, where model states can be assumed to have low uncertainty, and areas which have been treated less recently and where error growth has therefore not been eliminated.

This presentation will provide, for the first time, a comprehensive description of the aspects of SNODAS assimilation described above. We will demonstrate the benefits of frequent assimilation and discuss the reasons for, and consequences of, infrequent assimilation. The need to improve forcing data and model physics in data-poor areas will be addressed, as will possible improvements in the frequency and accuracy of snow data assimilation. The primary objective of this report will be to discuss the nature of SNODAS as a reference data product, in order to inform potential users of its benefits and drawbacks as such. However, the expectation that operational satellite snow products will contribute to operational snow analyses in the future is implied throughout the discussion.

Tue-3.4 Evaluation of Satellite-based Snow Data For Estimating SWE and SCA for Water Resource Applications

Carrie M. Vuyovich[1], Jennifer M. Jacobs[2], Steven F. Daly[1], Elias J. Deeb[1], Steven F. Newman[1], Blaine F. Morriss[1], Elke Ochs[1]

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In the United States, a dedicated system of snow measurement stations and snowpack modelling products are available to estimate the snow covered area (SCA) and snow water equivalent (SWE) throughout the winter season. In other regions of the world that depend on snowmelt for water resources, snow data can be scarce, and these regions are vulnerable to drought or flood conditions. Even in the U.S., water resource management is hampered by limited snow data in certain regions, as evident by the 2011 Missouri Basin flooding due in large part to the significant Plains snowpack. This study evaluates the use of satellite data to provide important snow information in water resource applications. Passive microwave data have shown some skill in estimating SWE in several regions of the United States, as compared with the SNODAS spatially distributed estimates. However, the SNODAS product contains greater uncertainty in regions with limited observations or that experience wind redistribution of snow. Here we present an evaluation of SWE estimates from AMSR-E and SSM/I satellites compared to the SNODAS product, by HUC8 watersheds throughout the United States. To understand differences in the SWE estimates in the Great Plains region, we then selected several watersheds to evaluate through a water budget analysis. Watersheds large enough to be appropriate for passive microwave resolution were selected from the Hydro-Climatic Data Network (HCDN), which identifies basins with minimal human impacts to stream flow. We 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 addition, we evaluated a new algorithm to produce accurate representations of SCA that are not impacted by misclassified cloud pixels. Single-day snow covered area (SCA) products are often inadequate representations of ground conditions due to short term variations in cloud cover, snow cover, and sensor geometry. To mitigate these effects, we developed a by-pixel filtering algorithm to produce relatively cloud-free SCA products based on 16 days of MODIS imagery. The generated products are less temporally variable than their respective single day inputs and are essentially cloud-free, making them more reliable indicators of ground conditions on any given day. Combined, these products can provide reliable snow data in under-sampled regions for use in water resource applications.

WED-1 WEDNESDAY, 23 JULY 2014

Wed-1.1 Global Cryosphere Watch and SnowPEx

Barry Goodison[1] and Jeff Key[2]

[1]Vice-Chair, GCW Steering Group, Canada
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on behalf of GCW Steering Group, World Meteorological Organization

There is now an unprecedented demand for authoritative information on the past, present and future state of the world's snow and ice resources. The cryosphere is one of the most useful indicators of climate change, yet is one of the most under-sampled domains in the climate system. The World Meteorological Organization (WMO) recognized that there was an urgent need for a sustained, robust, end-to-end cryosphere observing and monitoring system, not only for polar and alpine regions, but globally, and with its partners is now developing and implementing a Global Cryosphere Watch (GCW). Improved cryospheric monitoring, integration of information across cryospheric domains and the provision of data and service-oriented information, are essential for use in real time, for risk management and to fully assess, predict, and adapt to the variability and change which we now witness in weather, climate, water and other environmental sectors. GCW's Snow Watch activity and ESA's SnowPEx initiative are critical in developing the snow monitoring component of this system. Such a system must be a combination of ground-based measurements, satellite remote sensing, aircraft measurements, modelling, and data management.

GCW Snow Watch has identified critical issues affecting the ability to provide authoritative information on the current state of snow cover, and has initiated projects to address priority areas. These include improving the real time flow and access to in-situ snow measurements; initiating a satellite snow products evaluation and intercomparison activity; developing hemispheric "snow anomaly trackers" for snow extent and snow water equivalent; and, developing an inventory of existing snow datasets. The Snow Watch efforts to improve the real-time flow and access to in-situ measurements are critical to continuing development of regional and global satellite snow products. SnowPEx will provide the snow intercomparison activity for GCW.

Also of importance for current and future snow monitoring is the initiation of a surface-based cryosphere observing network called "CryoNet" which will build on existing efforts and provide sustained surface observations based on best practices and guidelines for cryospheric measurement for compatible observations from all GCW constituent observing and monitoring systems. Some CryoNet sites, termed "Integrated sites", will provide long-term data for calibration and validation of satellite products and for verification of cryospheric processes in weather, climate and hydrological models.

Improved data exchange and provision of authoritative products and information are critical to the success of GCW. The GCW Data Portal (gcw.met.no) will provide the ability to exchange data and information among a distributed network of providers. The "Watch" is provided through the GCW website (globalcryospherewatch.org) and will provide authoritative, clear, and useable data, information, and analyses on the past, current and future state of the cryosphere to meet the needs of WMO Members and partners. SnowPEx is an essential contribution to meeting GCW goals. The presentation will further define the linkages between GCW and its activities and SnowPEx.

NCWCP Conference Center Logistics

<u>FACILITY</u>

NOAA Center for Weather and Climate Prediction
5830 University Research Court
College Park, MD 20740

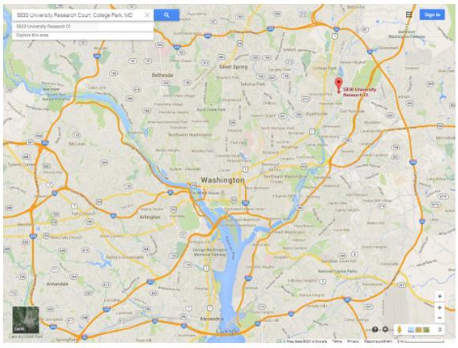
<u>ARRIVING AT NCWP</u>

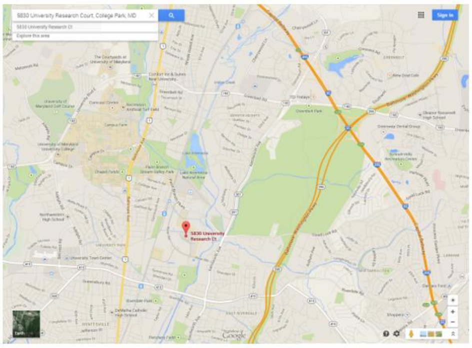
DIRECTIONS

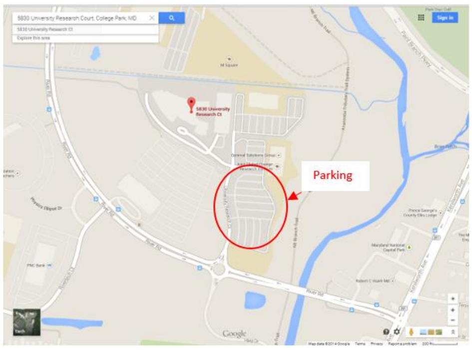
From Maryland: Take I-495 East to exit 23A (Kenilworth Ave/MD-201 S). Stay on 201 S and make a right onto River Rd. Take the 1st right onto University Research Court. The NCWCP building is at the end of the cul-de-sac on the left-hand side.

From Virginia Merge onto I-495 OUTERLOOP/Capital Beltway/ toward Alexandria. Take the I-295 N/National Harbor exit, EXIT 2A-B, toward Washington. Keep right to take DC-295 N toward US-50 E (crossing into Maryland stay in Middle lane) to 201 North Kenilworth Ave). Turn left onto River Rd. Take the 1st right onto University Research Court. The NCWCP building is at the end of the cul-de-sac on the left-hand side.

From Washington DC: Take I-295 North (Middle lane) to 201 North Kenilworth Ave. (Cross East-West Hwy/MD-410) left onto River Rd. Take the 1st right onto University Research Court. The NCWCP building is at the end of the cul-de-sac on the left-hand side.







Via METRO: The NCWCP is accessible via the Green or Yellow Line to the College Park/University of Maryland station. It is a 15-20 minute walk (to the east down River Road) from the station to the NCWCP. A shuttle is also available during peak commute periods. You may view a detailed shuttle schedule here. UM Shuttle (109 River Road) will drop passengers off at end of cul-de-sac. NCWCP building is the large glass building to the left. Most local hotels offer shutter service to and from the Metro stops. Please check with your hotel regarding arrangements.

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Room numbers for the ISSPI Meeting are 1602, 1604, and 1606.

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You are not permitted to enter the secure areas unless you are a NOAA employee or you have a NOAA host and have gone through appropriate paperwork for a visit. The ISSPI Workshop did not arrange such visits. Please arrange your visit accordingly, if needed.