SnowPEx

THE SATELLITE SNOW PRODUCTS INTERCOMPARISON AND EVALUATION EXERCISE

A contribution to WMO Global Cryosphere Watch and WCRP CLiC

Thomas Nagler, Gabriele Bippus, Elisabeth Ripper, Chris Derksen, Richard Fernandes, Kari Luojus, Sari Metsämäki, Rune Solberg, Bojan Bojkov, Alessandro Burini
Motivation for SnowPEx

From snow cover from NOAA snow chart CDR derived

Rate of June-SE 1979-2012: -21.5% / decade

Issues Addressed
- Overview on SnowPEx Project
- Approach on intercomparing and validating snow extent products and snow water equivalent products
- Reference data for snow product validation
The primary objectives are

- Intercompare and evaluate global / hemispheric (pre) operational snow products derived from different EO sensors and generated by means of different algorithms, assessing the product.
- Evaluate and intercompare temporal trends of seasonal snow parameters from various EO based products in order to achieve well-founded uncertainty estimates for climate change monitoring.
- Elaborate recommendations and needs for further improvements in monitoring seasonal snow parameters from EO data.

The project will support the setup of a consolidated operational satellite snow observation system for the Global Cryosphere Watch Initiative of the WMO and help to improve the snow cover data base for climate monitoring, as addressed by the WCRP-CliC programme.
Main Tasks within SnowPEx

- Review of Algorithms and products focusing on Snow Extent (SE) and Snow Water Equivalent (SWE)
- Definition of protocols and methods for validation and intercomparison of SE / SWE products
- Definition and compilation of reference data sets for quality assessment of SE and SWE products
- Intercomparison of SE / SWE products from various institutions and the quality assessment against reference data base
- Analysis of Hemispheric/Global SE and Snow Mass Trends and its uncertainty and
- Study the synergy of SE and SWE products
- Conclusion and recommendations for satellite snow monitoring
SnowPEx Project Overview

ISSPI WS-1
July 2014

Compilation of Reference Data Set
Validation and Intercomparison of Products (1st results)

ISSPI WS-2
Q2/Q3 2015

Review of SE / SWE Algorithms and Products

Methods and Protocols for Validation & Intercomparison
Identification of reference data

Trend Analysis of SE / SWE products (1st results)
SE & SWE Synergy (1st results)

Validation and Intercomparison of Products (Final Results)
Trend Analysis (Final)
SE & SWE Synergy Products (Final)

Publication of Project Results, Conclusions, Recommendations for satellite snow monitoring
<table>
<thead>
<tr>
<th>SnowPEx (PRODID_VXX)</th>
<th>Product Name</th>
<th>Thematic Parameter</th>
<th>Pixel Sp.</th>
<th>Frequency</th>
<th>Period</th>
<th>Contact Organisation</th>
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<tbody>
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<td>M10C06</td>
<td>MOD10_C6</td>
<td>Fractional Global</td>
<td>0.5 km</td>
<td>daily</td>
<td>2000 (Terra)</td>
<td><a href="mailto:dorothy.k.hall@nasa.gov">dorothy.k.hall@nasa.gov</a> NASA</td>
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<tr>
<td>SCAG</td>
<td>SCAG</td>
<td>Fractional NH</td>
<td>0.5 km</td>
<td>daily</td>
<td>2000 - 2013</td>
<td><a href="mailto:thomas.painter@jpl.nasa.gov">thomas.painter@jpl.nasa.gov</a> JPL NSIDC</td>
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<td>GLSSE</td>
<td>GlobSnow v2.1</td>
<td>Fractional NH</td>
<td>1 km</td>
<td>daily - monthly</td>
<td>1996 - 2012</td>
<td><a href="mailto:sari.metsamaki@ymparisto.fi">sari.metsamaki@ymparisto.fi</a> SYKE</td>
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<tr>
<td>ASNOW</td>
<td>Autosnow</td>
<td>Fractional NH</td>
<td>4 km</td>
<td>daily</td>
<td>2006 - present</td>
<td><a href="mailto:peter.romanov@noaa.gov">peter.romanov@noaa.gov</a> NESDIS</td>
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<tr>
<td>IMS01</td>
<td>IMS</td>
<td>NH</td>
<td>1 km</td>
<td>daily</td>
<td>2014 - &gt;</td>
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<tr>
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<td>NOAA IMS</td>
<td>Binary NH</td>
<td>4 km</td>
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<td>NOAA IMS</td>
<td>Binary NH</td>
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<td>daily</td>
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<tr>
<td>CRCLIM</td>
<td>CryoClim</td>
<td>Binary Global</td>
<td>5 km</td>
<td>daily</td>
<td>1982 - present</td>
<td><a href="mailto:rune.solberg@nr.no">rune.solberg@nr.no</a> NR,METNO</td>
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<td>JXM10</td>
<td>JASMES MDS10C</td>
<td>Binary NH</td>
<td>5 km</td>
<td>Daily weekly half-monthly</td>
<td>2000 – 2013</td>
<td><a href="mailto:hori.masahiro@jaxa.jp">hori.masahiro@jaxa.jp</a> JAXA</td>
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<td>AVHRR Pathfinder</td>
<td>Binary NH</td>
<td>5 km</td>
<td>daily</td>
<td>1985 - 2004</td>
<td>Richard Fernandes CCRS</td>
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<tr>
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<td>MEaSUREs</td>
<td>Binary Global</td>
<td>25 km</td>
<td>daily</td>
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<tr>
<td>CRYOL</td>
<td>CryoLand</td>
<td>Fractional (PanEur)</td>
<td>0.5 km</td>
<td>daily</td>
<td>2000 - present</td>
<td><a href="mailto:thomas.nagler@enveo.at">thomas.nagler@enveo.at</a> ENVEO</td>
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<tr>
<td>HSAF10</td>
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<td>Binary (PanEur)</td>
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<td>daily</td>
<td>2009-present</td>
<td><a href="mailto:Mathias.Takala@fmi.fi">Mathias.Takala@fmi.fi</a> FMI</td>
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<td>EURACSnow</td>
<td>Binary (Alps)</td>
<td>0.25 km</td>
<td>daily</td>
<td>2002 - present</td>
<td><a href="mailto:claudia.notarnicola@eurac.edu">claudia.notarnicola@eurac.edu</a> EURAC</td>
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</tbody>
</table>
GlobSnow, 1 km, Fractional SE
1-14. March 2012 – MAX SE
Intercomparison and Validation approach for SE Products

**Product Intercomparison**
- Data stack of SE products
- Transformation to common projection – (EASE-2) and pixel size
- Apply common mask of non-valid areas (e.g. sea)
- Intercomparison of SE products (surfaces classes)
  - Pixel by Pixel (multi-looking)
  - Statistical approach (by R.F.)
  - Spatial difference maps

**Product Validation**
- High Resolution Optical Data
- Binary or FSC Snow Map and uncertainty (applying different algorithms)
- Fractional Snow Map
  - Exclude areas with: no-data, clouds, open water
  - Separate FSC for forest/non-forest/plain areas/mountains
- Aggregate SE to FSC at original resolution of SE product

**Conversion to Snow Extent**
- In-Situ snow measurements

**Pixel by Pixel Intercomparison**
- Spatial Difference Map
  - Number of snow pixels
  - RMSD, MAbsDif, Bias
  - Correlation Coefficient
  - Thiel-Sen Slope, Offset
  - Fraction of total SE
  - Scatterplot
  - Timeseries of parameters
Maximum Snow Extent for Period 1-7 Mar 2010

MOD10

GlobSnow

IMS

Legend:
- Water
- Clouds
- 0%
- 10%
- 20%
- 30%
- 40%
- 50%
- 60%
- 70%
- 80%
- 90%
- 100%
- No data
Mean Absolute FSC Difference
MOD10 versus GlobSnow - 1.3.-31.5.2010

\[
\frac{\sum |FSC_{\text{MOD10}} - FSC_{\text{GlobSnow}}|}{N}
\]

forest

number of pixels (N)
Intercomparison of GlobSnow-2 SE v2.1 vs. MOD10.C5
More than 400 Landsat Scenes
Generation of Reference SE Data Set for Validation of Global Snow Products

Surface Classification Map -> Landsat L1T
- Radiometric Calibration, Conversion to TOAR
- Topographic Correction
- Cloud Screening
  - Cloud Mask

Snow Detection
- Klein et al. (1998) BINARY
  - NDSI, NDVI, NIR & Green band thresholds
- Dozier & Marks (1987) BINARY
  - NDSI & NIR threshold
- Salomonson & Appel (2006) FRACTIONAL
  - NDSI based, linear model
- Painter et al. TMSCAG FRACTIONAL
  - MS unmixing

Aggregation to Pixel Spacing of Medium resolution SE product
- Klein et al. (1998) Fractional
- Dozier & Marks (1987) Fractional
- Painter et al. Fractional
Reference Dataset for the Alps from Landsat DataAlps

Dozier 1 km
Klein 1 km
Salomonson 1 km

Dozier 1 km
Klein 1 km
Salomonson 1 km
Uncertainty of Snow Reference Data from High Resolution Optical images

Landsat 7 ETM+ (202/33), Spain, 10 Jan 2003

<table>
<thead>
<tr>
<th>Alg.</th>
<th>Corr. Coef.</th>
<th>BIAS</th>
<th>RMSE</th>
<th>Unbiased RMSE</th>
<th>Class</th>
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<td>0.85</td>
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<td>SALOMONSON</td>
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<td>SALOMONSON</td>
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<td>Non-forest</td>
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<td>KLEIN</td>
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<td>0.78</td>
<td>7.53</td>
<td>7.49</td>
<td>Non-forest</td>
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<td>DOZIER</td>
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<td>3.61</td>
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<td>ENVEO</td>
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<td>2.54</td>
<td>8.81</td>
<td>8.43</td>
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<tr>
<td>SALOMONSON</td>
<td>0.83</td>
<td>6.03</td>
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<td>KLEIN</td>
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<td>DOZIER</td>
<td>0.83</td>
<td>5.93</td>
<td>19.13</td>
<td>18.18</td>
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</table>

Landsat-SE Versus GlobSnow

MS ENVEO

SALOMONSON

KLEIN

DOZIER
### Validation using In-situ data

<table>
<thead>
<tr>
<th>SNOWPEX Regions</th>
<th>Environment</th>
</tr>
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<tbody>
<tr>
<td>Quebec / Northern US</td>
<td>Agricultural, forest</td>
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<tr>
<td>Finland</td>
<td>Boreal</td>
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<tr>
<td>Alps</td>
<td>Mountains</td>
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<tr>
<td>Alaska</td>
<td>Tundra</td>
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<tr>
<td>Sierra Nevada</td>
<td>Mountains</td>
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<tr>
<td>Russia test Site</td>
<td>Boreal</td>
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<tr>
<td>Chinese Test site</td>
<td>/ TBD</td>
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<tr>
<td>Montana</td>
<td>Mountains, Prairie</td>
</tr>
</tbody>
</table>

#### Relate depth to snow cover

- **MODIS SCAMOD** — versus Snow Transect Measurements, Finland

#### Scale of measurement

\[
\text{scale of measurement} \ll \text{scale of product}
\]
Mass of Seasonal Snow from different products

Observation of SWE by means of Passive MW, partly using in-situ data, and snow pack models.
## Participating SnowPEx SWE Datasets

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Method</th>
<th>Time Period</th>
<th>Res.</th>
<th>Comments</th>
<th>Reference</th>
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<tbody>
<tr>
<td>ESA GlobSnow</td>
<td>Microwave + ground stations</td>
<td>1979-present</td>
<td>25 km</td>
<td></td>
<td>M. Takala, 2011</td>
</tr>
<tr>
<td>NASA AMSR-E (prototype)</td>
<td>Microwave + ground station climatology</td>
<td>2002-2011</td>
<td>25 km</td>
<td>Prototype algorithm</td>
<td>R. Kelly / M. Tedesco</td>
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<td>JAXA AMSR-E2</td>
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<td>2012-present</td>
<td>25 km</td>
<td>Northern Hemisphere</td>
<td>R. Kelly</td>
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<td>HSAF - FMI</td>
<td>Microwave + ground stations</td>
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<td>25 km</td>
<td>Europe</td>
<td>M. Takala / FMI</td>
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<td>MERRA-Standard</td>
<td>Catchment LSM driven by MERRA 3DVAR assimilation</td>
<td>1979-2013</td>
<td>0.5° x 0.67°</td>
<td>Precipitation inconsistencies in MERRA-Land</td>
<td>Rienecker et al., 2011</td>
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<td>GLDAS-Noah</td>
<td>Noah LSM driven by GLDAS2.0</td>
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<td>Rodell et al., 2004</td>
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<td>ERA-interim-HERESSEL</td>
<td>HRESSEL LSM driven by ERA-Interim + GPCP v2.1</td>
<td>1979-2010</td>
<td>80 km</td>
<td></td>
<td>Balsamo et al., 2013</td>
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<td>ERA-interim-CROCUS/ISBA</td>
<td>CROCUS snow model in ISBA LSM forced by ERA-interim</td>
<td>1979-2013</td>
<td>1° x 1°</td>
<td>Recently applied to NH</td>
<td>Brun et al., 2013</td>
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</table>

**Earth Observation Land Surface Model**

**EASE Grid 2 Northern Regridded to 1°**
SWE Validation and Inter-Comparison Approach

- BERMS
- Sodankyla
- Bratt's
- Trail Valley
- Imnavait
- RusHydroMet
- SYKE

- Hydro-Quebec
- CLPX
- ASO

- MERRA
- GLDAS
- ERA-int-land
- ERA+Crocus

- Land cover
- Lake fraction
- NDVI
- DEM
- Perm. snow+ice

- Dense Network Measurements
- Regional Gridded in situ Measurements
- Static Ancillary Data

- Ensure common grid and temporal resolution

- Gridded product versus landscape average (RMSE; bias; correlation CV)

- Spatial inter-comparison of SnowPEX products (RMSE; bias; correlation)

- SWEmax versus streamflow comparison

- Static Ancillary Data

- Ensure common grid and temporal resolution

- SnowPEX EO Datasets

- Basin-scale streamflow Nash-Sutcliffe
Protocols for intercomparing and validating snow extent and snow water equivalent products have been defined, and are available at the project website http://calvalportal.ceos.org/projects/snowpex. The methods are implemented and are currently tested using various data sets.

Participating products are converted to SnowPEx format. Overall 2 (+3) years of daily snow maps from 15 products.

Snow reference data set, including in-situ data and information from high resolution sensors, need to be handled carefully when they are intercompared with medium resolution products because of scale issues and their own uncertainty. The generation of the data set is ongoing.

First intercomparison and validation results and trend analysis of snow products planned for March 2015.

2nd International Satellite Snow Product Intercomparison (ISSPI) WS is planned for Q2/Q3 2015, will be announced in February 2015.
<table>
<thead>
<tr>
<th>Product Providers</th>
<th>Kari Luojus, Mathias Takala</th>
</tr>
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<tbody>
<tr>
<td>Dorothy Hall, George Riggs, Chris Crawford, Igor Appel</td>
<td>FMI</td>
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<tr>
<td>Dave Robinson</td>
<td>Marco Tedesco</td>
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<tr>
<td>Thomas Painter, Karl Rittger</td>
<td>The City College of New York</td>
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<tr>
<td>Sean Helfrich</td>
<td>Chris Derksen</td>
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<tr>
<td>Rune Solberg</td>
<td>UNIVERSITY OF WATERLOO</td>
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<tr>
<td>Hori Masahiro</td>
<td>Richard Kelly</td>
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<td>Hongxu Zhao, Richard Ferndandes</td>
<td>EURAC research</td>
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<tr>
<td>Thomas Nagler, Gabrielle Bippus Elisabeth Ripper</td>
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<td>NOAA CREST</td>
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<td>Peter Romanov</td>
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