From hemispheric snow cover products towards an integrated view on the land cryosphere: Remote sensing & snow & carbon cycle


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Outline

• ESA DUE GlobSnow – Hemispheric snow cover products
• Towards an integrated view on the land cryosphere:
  • Remote sensing of snow, freeze-thaw and carbon cycle
ESA DUE GlobSnow-1/-2

• ESA DUE GlobSnow project: Production of novel hemispherical snow extent (SE) and snow water equivalent (SWE) climate data records.

• Generation of long time-series employing FMI supercomputing facilities at Helsinki (daily, weekly and monthly maps of SE and SWE for northern hemisphere) + NRT processing

• Consortium: Finnish Meteorological Institute (FMI) with ENVEO IT GmbH (Austria), GAMMA Remote Sensing (Switzerland), Norwegian Computing Center, Finnish Environment Institute (SYKE), and Environment Canada (EC). + Univ. Bern, MeteoSwiss, ZAMG & Norut

• GlobSnow-1: 11/2008 – 04/2012 (3.5 years)
• GlobSnow-2: 05/2012 – 10/2014 (2.5 years)

• Details and products available at www.globsnow.info
35 year-long CDR time-series on snow conditions of Northern Hemisphere

- First time reliable daily spatial information on SWE (snow cover):
  - Snow Water Equivalent (SWE)
  - Snow Extent and melt (+grain size)
  - 25 km resolution (EASE-grid)
  - Time-series for 1979-2014
- Passive microwave radiometer data combined with ground-based synoptic snow observations
  - Variational data-assimilation
- Available at open data archive (www.globsnow.info)
- Demonstration of NRT processing since October 2010

GlobSnow SWE time series (FCDR)

- Northern Hemisphere
  - 1979 to 1987 (SMMR)
  - 1988 to 2013 (SSM/I, SSMIS)
  - *FPS v1.0 2003 to 2011 (AMSR-E)*

- Daily, weekly, monthly products
- Includes error estimates (statistical std of the SWE estimate in mm)

- Data format HDF4 & NetCDF CF
- EASE-Grid projection (~25km resolution)

- Snow grain data available as well
- Glaciers, mountains & Ice Sheets masked out

- Versions: 1.0; 1.3 and 2.0 (current)
SWE Retrieval ‘Saturation’ (PMW signal)

“what if we would not apply the synop data?”

Chang et al.

EC

GlobSnow
Distributed validation data, e.g. Northern Eurasia & Canada

Snow Survey data (from the former USSR and Russia)

• There are 517 snow path stations with data for (1979 – 2009)
• Manual ground-based measurements on snow depth/SWE
• 1 - 2km snow transects, measurements every 100m - 200m

<table>
<thead>
<tr>
<th>Land Cover</th>
<th>Reference Dataset</th>
<th>Year</th>
<th>n</th>
<th>Mean SWE (mm)</th>
</tr>
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<tbody>
<tr>
<td>Tundra</td>
<td>Intensive Sites; SnowSTAR 2007</td>
<td>2006-2008</td>
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<td>Northern Boreal</td>
<td>EC Snow Surveys</td>
<td>2006-2007</td>
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<td>135</td>
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<td></td>
<td>SWE &lt;150 mm</td>
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<td>2005-2007</td>
<td>41</td>
<td>44</td>
</tr>
</tbody>
</table>
SWE retrieval (data assimilation vs. channel diff.)

- Density scatterplot (assimilated vs. satellite only SWE)
- Russian INTAS SCCONE SWE transect data as reference

![SWE scatterplots](image)
Long term consistency of SWE v2.0 FPS

- RMS error and retrieval bias calculated independently for each year 1980-2009
- Reference data: snow transects from Russia (INTAS-SCCONE)

RMS-Error of SWE retrievals for the evaluated years: 1980 - 2009

Bias of SWE retrievals for the evaluated years: 1980 - 2009

SWE<150 mm; 146,000 samples
CMIP5 vs. GlobSnow SWE (Jan - April)

- **January**
  - Mean January snow mass on January for Northern Hemisphere.
  - Legend includes CMIP5 models trend, ensemble mean +/− SD, etc.

- **February**
  - Mean February snow mass on February for Northern Hemisphere.
  - Legend includes CMIP5 models trend, ensemble mean +/− SD, etc.

- **March**
  - Mean March snow mass on March for Northern Hemisphere.
  - Legend includes CMIP5 models trend, ensemble mean +/− SD, etc.

- **April**
  - Mean April snow mass on April for Northern Hemisphere.
  - Legend includes CMIP5 models trend, ensemble mean +/− SD, etc.
GlobSnow v2.0 SWE vs. Ensemble historical & RCP8.5 "forecast"

March, Preliminary: 16 models

Mean terrestrial snow mass on March for Northern Hemisphere
GlobSnow v2.0 SWE vs. Ensemble historical & RCP8.5 "forecast"
April, Preliminary: 16 models

Mean terrestrial snow mass on April for Northern Hemisphere

- **Mean April Snow mass from studied CMIP5-models**
- **Ensemble mean +/- SD**
- **GlobSnow, satellite-based, snow mass for April**
GlobSnow vs. alternative SWE datasets

Temporal extent

- Alternative long term datasets on Global scale: Monthly from 1978, daily from 2002
- **GlobSnow: Daily 35 years** (… begins from autumn 1979)

Thematic accuracy

- Current alternative algorithms
  - Global scale 40mm – 200mm
  - Regional scale 20mm – 50mm (methods often regionally adjusted)
- **GlobSnow algorithm:**
  - RMSE of 43.4 mm for Eurasia (diagnostic dataset; > 161 000 samples)
  - RMSE of 32.1 mm for Eurasia (for SWE < 150mm; >144 000 samples)

Error estimates (error bars)

- Alternative methods do not provide information on estimation error
- **GlobSnow SWE algorithm:** Error estimates for each SWE estimate
  Additionally, GlobSnow provides an ensemble of 3 different products: v1.0; v1.3; v2.0
GlobSnow Snow Extent (SE) dataset

- 17 years SE data record has been produced using optical imagery from ESA ATSR-2 (1995-) and AATSR (2002-) on a hemispherical scale. NPP VIIRS from 2012-
- SYKE’s SCAmod method for fractional snow cover mapping implemented for Northern hemisphere
- Cloud detection algorithm developed by SYKE (+ contributed by ENVEO, FMI & NR)

- Methodology developed especially for forested regions – basically a tough challenge for optical SE retrieval
- Uncertainty estimate provided for each grid cell, data available as NetCDF CF
- Operational data production at the Finnish Meteorological Institute (FMI)

Daily, weekly and monthly products
Optical data ~ 1km spatial resolution

3 March 2010
1 March 2010
March 2010
SCAmod retrieval algorithm

- Based on reflectance model where forest canopy effect into the observed reflectance is compensated through pre-determined canopy transmissivity
- Designed to provide FSC in forested areas, and overall well applicable globally over any terrain
- A single band approach - Applicable to optical wavelengths and to a variety of sensors

\[
\rho_{\lambda,\text{obs}}(FSC) = (1 - t_\lambda^2) \cdot \rho_{\lambda,\text{forest}} + \frac{t_\lambda^2}{2} \left[ FSC \cdot \rho_{\lambda,\text{snow}} + (1 - FSC) \cdot \rho_{\lambda,\text{ground}} \right]
\]

\[
FSC = \frac{1}{t_\lambda} \left( \frac{1}{2} \cdot \rho_{\lambda,\text{obs}}(FSC) + (1 - \frac{1}{2}) \cdot \rho_{\lambda,\text{forest}} - \rho_{\lambda,\text{ground}} \right) \frac{\rho_{\lambda,\text{snow}} - \rho_{\lambda,\text{ground}}}{\rho_{\lambda,\text{snow}} - \rho_{\lambda,\text{ground}}}
\]

- \( \rho_{\lambda,\text{obs}}(FSC) \): observed reflectance from unit area
- \( \rho_{\lambda,\text{snow}} \): wet snow reflectance
- \( \rho_{\lambda,\text{ground}} \): snow-free ground reflectance
- \( \rho_{\lambda,\text{forest}} \): forest canopy reflectance
- \( \hat{t}_\lambda \): forest canopy transmissivity for unit area
- \( FSC \): fraction of snow covered area
Mean Absolute FSC Difference
MOD10 versus GlobSnow - 1.3.-31.5.2010

\[
\left( \sum |FSC_{MOD10} - FSC_{GlobSnow}| \right) / N
\]

forest

number of pixels (N)

Thomas Nagler / ENVEO
GlobSnow-2, Suomi NPP VIIRS SE product

~1km spatial resolution, full daily hemispherical coverage

Near Real Time production since early 2013
Summary of GlobSnow

Production of novel global snow extent (SE) and snow water equivalent (SWE) climate data records (17 and 35 years of snow cover information)
- Version 2.0 for SWE and SE are available

SWE: the first reliable long term satellite based record on SWE
SE: a new FSC retrieval methodology for northern hemisphere (esp. forests)

The near-real-time GlobSnow processing system online at least for 2014-2015

Products “permanently” available via www.globsnow.info
Towards an integrated view on the land cryosphere

- Carbon cycle – snow cover – soil freeze & thaw
  - Combination of SWE and SE time-series (Snow ECV/CDR)
  - Soil Freeze and Thaw
Current topics in the remote sensing of cryosphere

• Evolution of the seasonal snow cover
  - ECV time-series for climate research including the validation and parametrization of General Circultion Models/Earth System Models
    - Snow mass evolution (SWE): until recently reliable global information has not exist
    - Need of combined products describing all characteristics of snow cover (SWE, Snow Extent (SE), Fractional Snow Cover (FSC))

• Effect to carbon cycling and radiation balance
  - CO2 and CH4 cycling
    - For example, methane emissions on wetlands during winter are affected by the snow cover; changes in permafrost regions active layer characteristics related to changes in snow cover

• Hydrological and meteorological forecasting
  - Consideration of snow cover and lake ice
  - Data assimilation
Integrated view on the land cryosphere: snow and soil processes (Carbon cycle)

- Soil and vegetation processes in addition to snow cover
- Frost maps for Northern Hemisphere
- Based on SMOS data applying the frost detection algorithm developed with the aid of Elbara-II L-band observations at the Sodankylä site
Frost maps for Northern Hemisphere

20-Oct-2010
Snow accumulation and dry snow cover from GlobSnow SWE

A detailed description of maximum snow cover for the winter of 1989
Direct use of satellite products as proxy indicators

- Example: Detection of Start of the Growing Season from space-borne data derived snow melt (GlobSnow product)
Measured snow depth and soil frost depth

ELBARA-II brightness temperature

CH4 flux

CO2 flux

Since 2013, ELBARA-II installed at wetland (peatbog) site
Way forward: Combined products to monitor the seasonal cycle of carbon exchange related phenomena

- Relevant microwave and optical satellite instruments/missions
  - SSMI/I, AMSR-E (2), SMOS, Envisat ASAR, TerraSAR-X, MODIS, AATSR, MERIS, Sentinel 1, Radarsat-1/2, Chinese FY-series …
  - Future missions: Sentinels 2 and 3, NASA SMAP

- Combination of snow, soil and vegetation products
  - Monitoring of all C-relevant processes of the land cryosphere

- Combined use with *in situ* data and assimilation with models
  - Proxy indicators (developed with *in situ* data)
  - Use with LSM