SATELLITE MONITORING OF SNOW COVER AT NOAA

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Outline

• Satellite-based snow cover monitoring at NOAA
  - Sensors, techniques, products
  - Properties, advantages, weaknesses
• Snow depth/SWE (microwave)
• Product evaluation/comparison activities
  - Global Cryosphere Watch, SnowEx

Focus on operational weather satellites and available large-scale snow products
Snow cover: Facts

- About 77% of Earth’s freshwater is frozen
- Seasonal and perennial snow
  - Affects about 30% of land area
  - Found on all continents
    - Northern Hemisphere ~ 40 mln km²
    - Southern Hemisphere ~ 1 mln km²
- Glaciers and Ice Sheets
  - About 10% of land area
- Snow cover controls
  - Albedo, surface temperature
  - Heat fluxes
  - Water balance

Snow melt in Greenland
**Snow cover: Needs and Requirements**

**Applications:**
- NWP, Hydrology, Climate, Remote sensing (Clouds, aerosols etc.)
- Agriculture, Water management, Transportation, Recreation

**Parameters:**
- Snow extent, depth, SWE
- Snow cover fraction, albedo, grain size, physical state

**Requirements:**
- Spatially continuous, large scale coverage, 1 km resolution
- Daily updates, Consistent in time/space
Sources of snow data

- Station data (WMO, Coop, CoCoRAHS, SNOTEL, etc.)
- Models
- Satellites
- NEXRAD (solid precipitation)
- Synergetic
  - Model + Station data (SNODAS, CMC-Canada)
  - Satellite + Station data (IMS3-NOAA, GlobSnow-Finland)

Satellite products:  
- Daily global coverage
- High spatial resolution
- Consistent in time/space (most of the time)
Techniques

Satellite snow mapping/monitoring techniques

- Interactive
- Automated
  - Visible & infrared
  - Passive microwave
  - Combined visible-infrared-microwave

Satellites used

Operational polar-orbiting and geostationary
Interactive snow mapping

NOAA Interactive Multisensor Snow and Ice Mapping System (IMS)

- Visual analysis of satellite imagery
- Snow and ice extent over NH
- Available since early 1970s

<table>
<thead>
<tr>
<th>Period</th>
<th>Update / Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972-1997</td>
<td>weekly / 180km</td>
</tr>
<tr>
<td>1998-2003</td>
<td>daily / 24 km</td>
</tr>
<tr>
<td>2004-2014</td>
<td>daily / 4 km</td>
</tr>
<tr>
<td>2015 -</td>
<td>twice daily / 1 km</td>
</tr>
</tbody>
</table>
Interactive snow/ice mapping: Challenges

- Clouds: analysts make reasonable guess or use in situ data
- Forest areas: snow may not be seen, rely on lake/river ice
- Mountains: elevation-based masking tool often used
  - Results in the loss of southern / northern slope difference
- Snow mapping accuracy is a factor of
  - Analyst skills, abilities, responsibility, image interpretation
  - Time available
  - Degree of change of the NH snow cover since the previous day
Automated techniques

- Potentially better effective spatial resolution
- Potentially better consistency in space/time (no subjectivity)
- Less routine labor
- Other parameters besides snow extent can be inferred

But

- Are affected by physical limitations
- Require substantial efforts to be developed
**Snow from Visible/IR**

- Principal parameter estimated: snow extent, snow cover
- Requires daylight and cloud-clear conditions
- High accuracy, 0.5-4 km resolution, daily updates
- Products routinely available since late 1990s
- Spatial discontinuity hampers model application

Similar products are available from MODIS, VIIRS, SEVIRI, other sensors
Visible/IR: Other snow parameters

**Temperature of snow-covered land**

- Snow melt/freeze identification

**Fractional (sub-pixel) snow cover**

Can be used to characterize
- Land surface albedo
- Forest cover
- Snow depth over non-forested areas
Snow Fraction: VIIRS vs AVHRR

VIIRS, 375m gridded to 1 km
May 12, 2014

AVHRR, 1km gridded to 4 km
May 12, 2014

Gray: clouds
Brown: snow-free land

ABI product spatial resolution: 2 km
Refresh rate: 1 hr

This product will not be operational until 2018
Microwave: The way to look inside the snow pack

Upwelling microwave radiation is emitted by the sub-snow surface and altered by the snow pack.

Therefore it carries information on the physical properties of the snow pack.

Spectral range 10-100GHz is most efficient for snow remote sensing

Formation of upwelling radiation in the optical (visible, near infrared), infrared and microwave spectral range
Snow from microwave observations

- Spatial resolution: 10-50 km
- Available since late 1970s
- All weather capability
- Sensitive (theoretically) to the snow depth and snow water equivalent
  - But retrievals are challenging (more on this later)
NOAA AMSR2 Snow Products

Examples of AMSR2 snow products valid on 15 January 2015. AMSR2 snow products are output at 10 km.

These products are now operational (September 2016)
## AMSR2 Validation Results

<table>
<thead>
<tr>
<th>Snow cover</th>
<th>GAASP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall accuracy</td>
<td>81.17 %</td>
</tr>
<tr>
<td>Snow detection rate</td>
<td>78.34 %</td>
</tr>
<tr>
<td>Commission</td>
<td>1.78 %</td>
</tr>
<tr>
<td>Omission</td>
<td>17.05 %</td>
</tr>
<tr>
<td>Number of pixels</td>
<td>1504245</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Snow depth</th>
<th>GAASP</th>
</tr>
</thead>
<tbody>
<tr>
<td>bias</td>
<td>-0.50 cm</td>
</tr>
<tr>
<td>RMSE</td>
<td>18.7 cm</td>
</tr>
<tr>
<td>Number of pixels</td>
<td>2432</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SWE</th>
<th>GAASP</th>
</tr>
</thead>
<tbody>
<tr>
<td>bias</td>
<td>-0.22 mm</td>
</tr>
<tr>
<td>RMSE</td>
<td>31.35 mm</td>
</tr>
<tr>
<td>Number of pixels</td>
<td>26639</td>
</tr>
<tr>
<td>Mean (AMSR2)</td>
<td>62.06 mm</td>
</tr>
</tbody>
</table>

GAASP: GCOM AMSR2 Algorithm Software Package
Microwave snow products: Challenges

- Miss melting, shallow snow, overestimate snow in mountains
- Numerous snow products from different satellites. Which one is better?

NOAA MIRS system
6 satellites
2 daily products from each

NOAA MSPPS system
4 satellites (4 daily products)

Snow maps are different
Larger difference in spring
Combining Vis/IR and Microwave

Start with the a blank daily snow map

Add Vis/IR optical retrievals if clear

Add reliable microwave snow if cloudy

Use the previous day snow map to fill in the remaining gaps in the current day product

This results in a spatially continuous (gap-free) daily snow map
NOAA Global Multisensor Automated Snow and Ice Mapping System (GMASI)

Daily global continuous snow maps at 4 km spatial resolution
Based on combined AVHRR and SSMIS observations
Available since 2006
Most global/hemispherical satellite products agree to surface observations of snow in over 90% of comparisons

- **Vis/IR**: 93-98% agreement (but only for cloud-clear scenes)
- Interactive: 90-95%
- Combined: 90-95%
- Microwave: 80-90%

Agreement rates vary with time of the year and location
Most disagreement is in the snow /no-snow transition zone
Contribution to snow climatology

North America daily snow extent from GMASI

Snow Cover Extent (North America) / Étendue de la couverture de neige (Amérique du Nord) — 2016-2017

- ±1 standard deviation
- ±1 écart type (1990-2011)
- Observations

Last update: Dec 1, 2018
Snow area extent: 13.58 x 10^6 km^2
Snow extent daily anomalies

Snow area extent daily anomalies, AutoSnow and IMS

Autosnow vs IMS daily continental snow extent
- Correlation 0.85-0.89
- RMSD 3-4%
Snow cover duration

Snow Duration 2013-2014, Automated

**Autosnow vs IMS duration, NH**
- Mean bias: -1.1 days
- Mean abs difference: 11.2 days

Largest differences are in the mountains
Snow extent change

Long-term trends estimates are available only from NOAA interactive charts.

Estimated yearly mean snow extent decrease rate in NH is ~2% per decade since 1970
Scaling issue

- Algorithms and analysts typically map pixel with any marginal amount of snow as “snow covered”

- As a result, older coarser spatial resolution products may be partially biased towards larger snow extent.

- This effect is most pronounced over mountains
Decrease in the snow occurrence in mountainous areas is mostly spurious.

It is due to the improvement of the spatial resolution of base snow maps over time from 180 km to 4 km.

Snow occurrence on week 33 (Aug 13-19) estimated from NOAA Interactive snow maps.
# Summary of NOAA’s snow datasets (from satellites)

<table>
<thead>
<tr>
<th>Product</th>
<th>Spatial Resolution</th>
<th>Coverage</th>
<th>Frequency</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIIRS snow cover and snow fraction</td>
<td>375 m</td>
<td>Global</td>
<td>Every orbit</td>
<td></td>
</tr>
<tr>
<td>AMSR2 snow cover, snow depth, SWE</td>
<td>10 km</td>
<td>Global</td>
<td>Every orbit</td>
<td>All-sky</td>
</tr>
<tr>
<td>GOES-R ABI snow fraction</td>
<td>2 km</td>
<td>Western Hemisphere</td>
<td>Hourly</td>
<td>Not yet available</td>
</tr>
<tr>
<td>GMASI</td>
<td>4 km</td>
<td>Global</td>
<td>Daily</td>
<td>Multisensor, all-sky</td>
</tr>
<tr>
<td>IMS</td>
<td>1-180 km</td>
<td>NH</td>
<td>Twice daily to weekly</td>
<td>Interactive, multisensor</td>
</tr>
<tr>
<td>MIRS</td>
<td>50 km</td>
<td>Global</td>
<td>Daily</td>
<td>All-sky</td>
</tr>
</tbody>
</table>
The WMO Global Cryosphere Watch (GCW) Snow Watch Team is assessing the maturity and accuracy of snow products through the ESA intercomparison project “SnowPEx”. An initial inventory of snow products is available online under three categories:

- Satellite-derived snow products
- Analyses, reanalyses and reanalysis-driven snow products and datasets
- In situ snow products and datasets

18 satellite-derived, 22 in situ, and 20 analysis/reanalysis datasets

globalcryospherewatch.org
## SnowPEx – Snow Extent Products

<table>
<thead>
<tr>
<th>SnowPEx PROD. ID</th>
<th>Product Name</th>
<th>Thematic Parameter</th>
<th>Frequency</th>
<th>Period</th>
<th>Pixel Sp.</th>
<th>Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASNOW</td>
<td>Autosnow</td>
<td>Binary, Global</td>
<td>daily</td>
<td>2006 – present</td>
<td>4 km</td>
<td>P. Romanov / NESDIS</td>
</tr>
<tr>
<td>CRCLIM</td>
<td>CryoClim</td>
<td>Binary, Global</td>
<td>daily</td>
<td>1982 – present</td>
<td>5 km</td>
<td>R. Solberg / NR</td>
</tr>
<tr>
<td>CRYOL</td>
<td>CryoLand</td>
<td>Fractional, PanEU</td>
<td>daily</td>
<td>2000 – present</td>
<td>0.5 km</td>
<td>T. Nagler / ENVEO</td>
</tr>
<tr>
<td>EURAC</td>
<td>EURACSnow</td>
<td>Binary, Alps</td>
<td>daily</td>
<td>2002 – present</td>
<td>0.25 km</td>
<td>C. Notarnicola / EURAC</td>
</tr>
<tr>
<td>GLSSE</td>
<td>GlobSnow v2.1</td>
<td>Fractional, NH</td>
<td>daily - monthly</td>
<td>1996 – 2012</td>
<td>1 km</td>
<td>S. Metsämäki / SYKE</td>
</tr>
<tr>
<td>HSAF10</td>
<td>HSAF H10</td>
<td>Binary, PanEU</td>
<td>daily</td>
<td>2009 – present</td>
<td>5 km</td>
<td>M. Takala / FMI</td>
</tr>
<tr>
<td>IMS01</td>
<td>IMS</td>
<td>Binary, NH</td>
<td>daily</td>
<td>2014 – present</td>
<td>1 km</td>
<td>S. Helfrich / NOAA</td>
</tr>
<tr>
<td>IMS04</td>
<td>NOAA IMS</td>
<td>Binary, NH</td>
<td>daily</td>
<td>2004 – present</td>
<td>4 km</td>
<td>S. Helfrich / NOAA</td>
</tr>
<tr>
<td>IMS24</td>
<td>NOAA IMS</td>
<td>Binary, NH</td>
<td>daily</td>
<td>1997 – 2004</td>
<td>24 km</td>
<td>S. Helfrich / NOAA</td>
</tr>
<tr>
<td>JXAM5</td>
<td>JASMES GHRM5C</td>
<td>Binary, Global</td>
<td>daily, weekly half-monthly</td>
<td>1979 – 2013</td>
<td>5 km</td>
<td>M. Hori / JAXA</td>
</tr>
<tr>
<td>JXM10</td>
<td>JASMES MDS10C</td>
<td>Binary, Global</td>
<td>daily, weekly half-monthly</td>
<td>2000 – 2013</td>
<td>5 km</td>
<td>M. Hori / JAXA</td>
</tr>
<tr>
<td>M10C05</td>
<td>MOD10_C5</td>
<td>Fractional, Global</td>
<td>daily</td>
<td>2000 – present</td>
<td>0.5 km</td>
<td>D. Hall, G. Riggs / NASA</td>
</tr>
<tr>
<td>MEASU</td>
<td>MEaSUREs</td>
<td>Binary, Global</td>
<td>daily</td>
<td>1999 – 2012</td>
<td>25 km</td>
<td>D. Hall / NASA</td>
</tr>
<tr>
<td>PATHF</td>
<td>AVHRR Pathfinder</td>
<td>Fractional, NH</td>
<td>daily</td>
<td>1985 – 2004</td>
<td>5 km</td>
<td>R. Fernandes / NRCAN</td>
</tr>
<tr>
<td>SCAG</td>
<td>SCAG</td>
<td>Fractional, NH</td>
<td>daily</td>
<td>2000 - 2013</td>
<td>0.5 km</td>
<td>T. Painter / NASA</td>
</tr>
</tbody>
</table>
SnowPEx – Snow Extent Products

Snow Extent Products in EASE-GRID 2.0

- MEaSUREs
- JASMES MDS10C
- JASMES GHRM5C
- AVHRR Pathfinder
- CryoClim
- NOAA IMS
- AutoSnow
- GlobSnow
- MOD10_C5
- SCAG
Uncertainty in NH Seasonal Snow Mass

Spread in NH snow mass between **model-based** and **Satellite-based** estimates!

“Satellite-based” GlobSnow SWE estimate
Multiple products, need to be aware of strength/weaknesses

Products are daily and global. Algorithms tuned for specific regions may be more accurate.

Products may differ. Differences are due to different techniques, data sources, time of observation.

Snow extent: Below several km resolution, over 90% accuracy. Resolution of 1 km and below can only be achieved in clear sky.

Snow depth/SWE: Resolution 10 - 50 km. Errors above 15 cm.

Synergy of Vis/IR and microwave can bring automated algorithms and product very close to interactive in performance/accuracy