Satellite observation on snow

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Why snow?

- Water resources
- Snow disaster
- Climatic change
- Ecological services
- Snow properties for sciences research
SCA-----Snow Cover Area

SD/SWE-----Snow depth/Snow Water Equivalent

SCA and SWE are the most important Snow properties and could be mapped by using satellite data.

\[
[SWE] \div [Density] = \text{Snow Depth}
\]

Snow Water Equivalent (SWE) is a common snowpack measurement. It is the amount of water contained within the snowpack. It can be thought of as the depth of water that would theoretically result if you melted the entire snowpack instantaneously.
Electromagnetic Spectrum
Snow optical properties
(Visible, near infrared, infrared)
0.4-0.7 μm, 0.76-3.0 μm, 0.76-15 μm

- Independent scattering
- Weak polarization
- Small dielectric contrast between ice and water

Snow microwave properties
300 MHz-3000 GHz 1 mm -- 1 m

- Extinction per unit volume
- Strong polarization
- Large dielectric contrast between ice and water

Surface cover objects
Penetrating ground
Topic 1:
Mapping MODIS Snow Cover Products in Qinghai-Tibet Plateau

Topic 2:
Mapping Snow depth and Snow Water Equivalent in Qinghai-Tibet Plateau

moderate-resolution imaging spectroradiometer
Snow is a key component of regional and global climate, and it is vital to have an accurate and long-term database established on snow-extent variability. Change and variability in the Himalayan cryosphere, popularly referred to as ‘the water tower of Asia’, have significant local, downstream and global feedback effects.

Satellite sensors have been employed to map snow cover, and to measure (or estimate) snow depth.
The snow reflection in visible radiation more strongly than it reflects radiation in the middle-infrared part of the spectrum. The core of snow cover retrieval captures the snow optical property in a single quantity—the Normalized Difference Snow Index (NDSI). The NDSI is useful for the identification of snow and ice and for separating snow/ice and most cumulus clouds.

\[
\text{NDSI} = \frac{\text{VIS} - \text{NIR}}{\text{VIS} + \text{NIR}}
\]

VIS is the reflectance of snow in visible band
NIR is the reflectance of snow in near-infrared band

VIS: 0.380~0.780 μm  NIR: 0.78-2.5 μm
MODIS snow products have been available through the National Snow and Ice Data Center (NSIDC) Distributed Active Archive Center (DAAC) since September 13, 2000.

In up to date version (005), snow data products are produced as a series of seven products to a variety of user. A summarized listing of the sequence of products is given in Table.

<table>
<thead>
<tr>
<th>Earth Science Data Type (ESDT)</th>
<th>Product Level</th>
<th>Nominal Data Array Dimensions</th>
<th>Spatial Resolution</th>
<th>Temporal Resolution</th>
<th>Map Projection</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOD10_L2</td>
<td>L2</td>
<td>1354 km by 2000 km</td>
<td>500m</td>
<td>swath (scene)</td>
<td>None. (lat, lon referenced)</td>
</tr>
<tr>
<td>MOD10L2G</td>
<td>L2G</td>
<td>1200km by 1200km</td>
<td>500m</td>
<td>day of multiple coincident swaths</td>
<td>Sinusoidal</td>
</tr>
<tr>
<td>MOD10A1</td>
<td>L3</td>
<td>1200km by 1200km</td>
<td>500m</td>
<td>day</td>
<td>Sinusoidal</td>
</tr>
<tr>
<td>MOD10A2</td>
<td>L3</td>
<td>1200km by 1200km</td>
<td>500m</td>
<td>eight days</td>
<td>Sinusoidal</td>
</tr>
<tr>
<td>MOD10C1</td>
<td>L3</td>
<td>360° by 180° (global)</td>
<td>0.05° by 0.05°</td>
<td>day</td>
<td>Geographic</td>
</tr>
<tr>
<td>MOD10C2</td>
<td>L3</td>
<td>360° by 180° (global)</td>
<td>0.05° by 0.05°</td>
<td>eight days</td>
<td>Geographic</td>
</tr>
<tr>
<td>MOD10CM</td>
<td>L3</td>
<td>360° by 180° (global)</td>
<td>0.05° by 0.05°</td>
<td>month</td>
<td>Geographic</td>
</tr>
</tbody>
</table>

Summary of the MODIS snow data products.
MODIS Snow data products flow chart from NSIDC

MODIS PRODUCT INPUTS

MODIS Surface reflectance data

ANCILLARY INPUTS

Cloud mask data

Land/water mask data

SNOMAP

NDSI ≥ 0.4
B2 > 0.11
B4 > 0.1
Klein MODEL

Daily snow cover product

Compositing

Other snow cover product

MODIS Snow data products flow chart from NSIDC
Three questions in Qinghai-Tibet Plateau for MODIS snow product.

- The NDSI threshold from NSIDC is 0.4. However, the NDSI threshold value is uncertainty in different regions.
- The daily snow cover is partly missing by data gap.
- The daily snow cover products covered by the extent of cloud pixels.
Landsat-ETM+ "true" snow cover

Method: SNOMAP

Hall (1995)

Reflectance

NDSI = \frac{(TM2 - TM5)}{(TM2 + TM5)}

NDSI ≥ 0.4
TM4 > 0.11

Landsat ETM+5, 4, 2

ETM+ true snow cover
Select two alpine snow regions from Qinghai-Tibet, China. Name as A,B.

In these regions, the accuracy of NSIDC snow cover products were validated by Landsat-ETM+ “true” snow cover.

Adjust the NDSI threshold value.
The comparison between true snow and MOD10A1

<table>
<thead>
<tr>
<th>NDSI</th>
<th>“A” subregion overall accuracy, Kappa coefficient, proportion of snow cover</th>
<th>“B” subregion overall accuracy, Kappa coefficient, proportion of snow cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.39</td>
<td>86.82%、0.676、27.73%</td>
<td>94.73%、0.708、10.17%</td>
</tr>
<tr>
<td>0.38</td>
<td>86.81%、0.678、28.36%</td>
<td>94.74%、0.711、10.48%</td>
</tr>
<tr>
<td>0.37</td>
<td>86.76%、0.679、29.02%</td>
<td>94.62%、0.709、10.79%</td>
</tr>
<tr>
<td>0.36</td>
<td><strong>86.73%、0.680、29.63%</strong></td>
<td>94.51%、0.707、11.08%</td>
</tr>
<tr>
<td>0.35</td>
<td>86.63%、0.679、30.25%</td>
<td>94.39%、0.706、11.48%</td>
</tr>
<tr>
<td>0.34</td>
<td>86.54%、0.679、30.87%</td>
<td>94.26%、0.703、11.82%</td>
</tr>
<tr>
<td>0.33</td>
<td>86.45%、0.679、31.51%</td>
<td>94.16%、0.702、12.16%</td>
</tr>
<tr>
<td>0.32</td>
<td>86.28%、0.677、32.13%</td>
<td>94.04%、0.700、12.53%</td>
</tr>
<tr>
<td>0.31</td>
<td>86.13%、0.676、32.66%</td>
<td>93.88%、0.697、12.89%</td>
</tr>
<tr>
<td>0.30</td>
<td>86.05%、0.676、33.23%</td>
<td>93.69%、0.692、13.28%</td>
</tr>
</tbody>
</table>

The rational threshold value in QTP: $\frac{(0.36+0.38)}{2}=0.37$
The main limitation for the direct usage of MODIS snow cover data in environmental studies is the extent of cloud-covered pixels. In the study, there are three steps, based on a combination of different spatial and temporal information, to reduce cloud obscuration. The output from each step was the input for the next step.

1. The composition of MODIS Terra and Aqua snow cover
2. Adjacent temporal interpolation
3. Blending MODIS snow cover and improved AMSR-E Snow water equivalent data
The satellites pass over the equator in the morning (Terra at 10:30 a.m.) and afternoon (Aqua at 1:30 p.m.), provide two snow cover images for the same location per day.

This step combines improved snow cover (from Terra and Aqua) on the same day with about three hours time difference. The compositing rules are based on the following prioritization scheme: snow – no snow – cloud. If snow cover was found in any satellite image pairs, the pixel was assigned as snow. If the pixel was observed as ‘no snow’ by one satellite and cloud by another, the cell is assigned as ‘no snow’ as true pixel cover (Eq. 1).

\[ S_{(x,y)} = \max(S^T_{(x,y)}, S^A_{(x,y)}) \]
The data gap of daily snow product

The composition snow cover of Terra and Aqua not only eliminate the data gap, but also reduce the cloud pixels.
Second Step: Adjacent temporal interpolation

This step deduces the cloud-covered pixel based on the one day forward and one day backward information of same pixel. It is based on the assumption that if both the previous and the next day of the cloud pixel have the same surface condition (either snow or no snow. Hence, if the corresponding pixel of both the previous and the next day of observed day are snow, the cloud cover pixel is set as snow (Eq. 2). Similarly, a cloud pixel is deduced as no snow if the corresponding pixel of both the previous and the next day has ‘no snow’ cover (Eq. 3).

\[
\text{if } (S_{(x,y,t-1)} = \text{snow } \text{and } S_{(x,y,t+1)} = \text{snow}) \text{ then } S^c_{(x,y,t)} = \text{snow,} \quad 2
\]

\[
\text{if } (S_{(x,y,t-1)} = \text{no snow } \text{and } S_{(x,y,t+1)} = \text{no snow}) \text{ then } S^c_{(x,y,t)} = \text{no snow,} \quad 3
\]
The comparison of first step and second step

Composition of Terra and Aqua

- No snow: 14.5%
- Cloud: 70.1%
- Snow: 15.4%

Adjacent temporal interpolation

- No snow: 26.8%
- Cloud: 57.0%
- Snow: 16.2%
Third Step: Blending MODIS snow cover and improved AMSR-E Snow water equivalent data

Multi-sensor combination uses AMSR-E to map those areas where MODIS cannot map because of clouds. It takes advantage of high spatial resolution and high accuracy in clear-sky condition of MODIS images and the cloud transparency ability of improved AMSR-E snow water equivalent products. Since there are AMSR-E image gaps and the locations of these gaps change daily, the pixel values within the image gaps are replaced by the previous day's AMSR-E image (Eq. 4).

\[
\text{if } (S_{(x,y)} = \text{cloud} \text{ and } A_{SWE(x,y)} > 0) \text{ then } S_{(x,y)}^c = \text{snow},
\]

\[
\text{if } (S_{(x,y)} = \text{cloud} \text{ and } A_{SWE(x,y)} = 0) \text{ then } S_{(x,y)}^c = \text{no snow},
\]
Remote sensing of snow water equivalent

- Based on passive microwave remote sensing data (such as SMMR, SSM/I and AMSR-E), retrieval of snow depth and snow water equivalent has been widely studied, and global snow products have been obtained in the past several decades.
  - Chang algorithm: \( a^*(T_{h,19} - T_{h,37}) \)
  - Foster algorithm: \( a^*(T_{h,19} - T_{h,37}) / f \)
  - Kelly algorithm: \( b^*(T_{h,19} - T_{h,37})^2 + c^*(T_{h,19} - T_{h,37}) \)
  - Grody decision classification tree method:

- NSIDC global SWE products:
  - Combination of the Foster algorithm and Kelly algorithm

- CAREERI China SWE products:
  - **Che algorithm**: Combination of the modified Foster algorithm and Grody’s method
So far, AMSR-E is the latest passive microwave sensor, it plays an important role at research on cryosphere.

According to che(2008), Snow depth is derived based on algorithm:

\[
    sd = \frac{0.78[T_B(18H) - T_B(37H)]}{1 - f}
\]

Where, \( sd \) is snow depth in cm, \( T_B(18H) \) and \( T_B(37H) \) are brightness temperature at 18 and 37 GHz in horizontal polarization, respectively, \( f \) is the forest area fraction.
Improved snow depth data from AMSR-E in Qinghai-Tibet plateau
The general view of the improved algorithm at January 25, 2008.
The improved blending snow products in Qinghai-Tibet plateau
A flow chart of blending daily snow cover products

- Terra MODIS Surface reflectance data (MOD09)
- Aqua MODIS Surface reflectance data (MYD09)
- Cloud mask data
- Land/water mask data
- Terra MODIS daily snow product (MODS)
- Aqua MODIS daily snow product (MYDS)
- Terra&Aqua daily combination (MOYDS)
- Adjacent Temporal Interpolation (MOYDTS)
- Blending daily snow cover (MOYDTAS)

SNOMAP

NDSI≥ 0.37
B2>0.11
B4>0.1

Aqua AMSR-E improved SWE
Resample
500m resolution SWE
In the study, using in situ observation data at 48 climatic stations from January 1, 2003 to August 31, 2007 in northern Xinjiang area, China, the accuracy of blending snow cover products were validated.
The study shows the overall accuracy of blending snow cover products is 93.08%. The commission snow pixels is lower. However, the omission error is 16.52%. It is likely that blending snow cover products detects less snow cover.
The primary objective of this study is to reduce cloud obscuration and to generate accuracy daily snow cover products. Various methods including daily combination, adjacent interpolation and multi-sensor blending are examined in Qinghai-Tibet Plateau, China. The improved snow products will satisfy the requirements for different applications.
Mapping Snow depth and Snow Water Equivalent in Qinghai-Tibet Plateau

\[ SWE = \rho_s \ d \quad (mass/area) \]

\[ SWE = \frac{\rho_s}{\rho_w} \ d \quad (depth) \]

\[ \rho_s, \rho_w = \text{density of snow, water} \]

\[ d = \text{snow depth} \]
Why passive microwave?

- Snow depth and snow water equivalent
- Independent of sun
- Penetration of cloud
- High temporal resolution
- Larger coverage

1~1 000mm
Microwave radiative transfer model of snow

• Physical model
  – IEM Model for Backscattering From Rough Surfaces (IEM, AIEM)
  – Dense media radiative transfer theory (DMRT)
  – Vector radiative transfer model (VRT, DVRT)

• Physical + empirical model
  – Microwave Emission Model of Layered Snowpacks (MEMLS)
  – Helsinki University of Technology (HUT) snow microwave emission model
The difference of brightness temperature at 19 and 37 GHz can be used to retrieve the snow depth. The difference will reach its maximum (be saturated) when snow depth is larger than 50 cm.
Retrieval of snow depth

• Prototype algorithm (Chang, 1987)

\[ SD = a(T_{b,18} - T_{b,37}) \]

For North America: \( a = 1.59 \)
For Europe and Asia: \( a = 0.78 \)

• Considering the forest influence (Foster, 1997)

\[ SD = \frac{a(T_{b,18} - T_{b,37})}{1.00 - f} \]

\( f \) is the fraction of forest cover
Snow depth retrieval in China

- Data and methodology
- Modification of prototype
- Classification tree of snow cover
- Correction of snow grain size and snow density
- Preliminary results
Special Sensor Microwave Imager

**Scanning Multi-channel Microwave Radiometer**

The Advanced Microwave Scanning Radiometer

### Passive microwave remote sensing data

<table>
<thead>
<tr>
<th></th>
<th>SMMR</th>
<th>SSM/I(F08)</th>
<th>AMSR-E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platform</td>
<td>NIMBUS-7</td>
<td>DMSP-F08-17</td>
<td>EOS-Aqua</td>
</tr>
<tr>
<td>Channels(GHz) &amp; Footprint(km)</td>
<td>18.7:55×41</td>
<td>19.35: 69×43</td>
<td>18.7: 27×16</td>
</tr>
<tr>
<td></td>
<td>37:27×18</td>
<td>37: 37×28</td>
<td>36.5: 14×8</td>
</tr>
<tr>
<td>Polarization</td>
<td>V &amp; H</td>
<td>V &amp; H</td>
<td>V &amp; H</td>
</tr>
<tr>
<td>Viewing Angle(°)</td>
<td>50.2</td>
<td>53.1</td>
<td>55</td>
</tr>
<tr>
<td>Swath width(km)</td>
<td>780</td>
<td>1400</td>
<td>1445</td>
</tr>
</tbody>
</table>

Snow depth observation stations

Other data:
Lake distribution map
Vegetation distribution map
Methodology

Passive microwave brightness temperature data

Dry snow?
- YES
  - Water body?
    - NO
      - Modified algorithm considered vegetation
    - YES
      - Modified algorithm

Scattering signature?
- YES
  - Precipitation?
    - NO
      - Cold desert?
        - NO
          - Frozen ground?
            - NO
              - Snow cover
            - YES
              - Snow depth
    - YES
      - Snow depth data in stations

Snow depth data in stations

Final algorithm considered seasonal snow grain size and density variations

Vegetation maps

Modified algorithm considered vegetation
Modification of prototype

For SMMR:

\[ SD = 0.78(T_{b,18} - T_{b,37}) \]

For SMM/I:

\[ SD = 0.66(T_{b,19} - T_{b,37}) \]
- Scattering signature
  - $T_B(19V) - T_B(37V) > 0$

- Precipitation
  - $T_B(22V) > 258$ or $258 \leq T_B(22V) \leq 254$ and $T_B(19V) - T_B(37V) \leq 2$

- Cold desert
  - $T_B(19V) - T_B(19H) \geq 18$ and $T_B(19V) - T_B(37V) \leq 10$

- Frozen ground
  - $T_B(19V) - T_B(19H) \geq 8K$ and $T_B(19V) - T_B(37V) \leq 2K$ and $T_B(37V) - T_B(85V) \leq 6K$

- Snow cover
  - Other else
Correction of snow grain size and snow density

<table>
<thead>
<tr>
<th>Month</th>
<th>Average offset (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SMMR</td>
</tr>
<tr>
<td>Oct</td>
<td>-3.64</td>
</tr>
<tr>
<td>Nov</td>
<td>-3.08</td>
</tr>
<tr>
<td>Dec</td>
<td>-1.91</td>
</tr>
<tr>
<td>Jan</td>
<td>-0.19</td>
</tr>
<tr>
<td>Feb</td>
<td>1.51</td>
</tr>
<tr>
<td>Mar</td>
<td>2.65</td>
</tr>
<tr>
<td>Apr</td>
<td>3.32</td>
</tr>
</tbody>
</table>
Preliminary results

Snow depth and snow cover duration distribution in China
Seasonal and inter-annual variations of snow mass in China from 1978 to 2010 based on the SMMR, SSM/I and AMSR-E data
Thanks

Please send email to me for your Question?

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