Remote Sensing of Snow and Ice

Lecture 21
Nov. 9, 2005
Topics

• Remote sensing snow depth: passive microwave (covered in Lecture 14)

• Remote sensing sea ice and ice sheet elevation change: Lidar - ICESat (covered in Lecture 15)

• Remote sensing snow cover based on MODIS (covered in this lecture)
MODIS data-product sequence

Input MODIS Level 1B bands 1, 2, 4, 6 (MOD02_HKM), 31 & 32 (MOD02_1km)

Input MODIS 1-km resolution geolocation, cloud mask MOD35 and land/water mask MOD03

Calculate NDSI, NDVI, grouped-criteria tests, vegetation polygon

Apply surface temperature screen (≥ 283K)

Swath snow 500-m product MOD10_L2 (includes FSC)

Daily snow tile product 500-m resolution MOD10A1 (includes daily snow albedo)

Daily snow CMG 0.05° resolution MOD10C1

Monthly snow CMG 0.05° resolution MOD10CM

Algorithm Heritage:
Kyle et al., 1978
Bunting and d'Entremont, 1982
Crane and Anderson, 1984
Tucker et al., 1985
Dozier, 1989
Romanov et al., 2000

Source: Hall, 2004
MOD10_L2: Level 2, 500-m swath product of California and the western U.S., October 31, 2004

MODIS true-color image (left - bands 1, 4, 3) and snow map (right)

Source: Hall, 2004
MOD10A1: Daily Tile Snow Map

Snow in northern Italy - March 29, 2002

MOD09 bands 1,4,3 (Surface Reflectance Product) MOD10A1 (Snow Daily Tile Product)

Source: Hall, 2004
Daily snow albedo product (MOD10A1) 500-m resolution

Snow albedo swaths – North America

Source: Hall, 2004
MOD10A2: 8-day Composite Tile Snow Map

Western North America - April 23, 2002

MOD09 bands 1,4,3 (Surface Reflectance Product)
MOD10A2 (Snow 8-Day Tile Product)

Source: Hall, 2004
MOD10A1 snow product represents an improvement over the NOHRSC operational snow product in many areas

Table IV. Summary of image comparisons with observations. Numbers in italics indicate that the differences between MODIS and NOHRSC are statistically significant at a 95% confidence level based on a paired t-test.

<table>
<thead>
<tr>
<th></th>
<th>Fraction of pixels classified as snow or no-snow&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Fraction of pixels classified as cloud&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Fraction of misclassified snow and no-snow pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MODIS</td>
<td>NOHRSC</td>
<td>MODIS</td>
</tr>
<tr>
<td>All days</td>
<td>0.59</td>
<td>0.56</td>
<td>0.41</td>
</tr>
<tr>
<td>Cloudiest days</td>
<td>0.47</td>
<td>0.44</td>
<td>0.53</td>
</tr>
<tr>
<td>Clearest days</td>
<td>0.70</td>
<td>0.67</td>
<td>0.30</td>
</tr>
<tr>
<td>Forested pixels</td>
<td>0.63</td>
<td>0.48</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td><strong>Missouri River basin</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All days</td>
<td>0.51</td>
<td>0.36</td>
<td>0.49</td>
</tr>
<tr>
<td>Cloudiest days</td>
<td>0.34</td>
<td>0.20</td>
<td>0.66</td>
</tr>
<tr>
<td>Clearest days</td>
<td>0.68</td>
<td>0.52</td>
<td>0.32</td>
</tr>
<tr>
<td>Forested pixels</td>
<td>0.52</td>
<td>0.35</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td><strong>Columbia River basin</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> These values consider pixels containing ground observations reporting snow or no-snow only.

From Maurer et al. (2003)

Source: Hall, 2004
Agreement between the MODIS and NOHRSC snow maps was 86% for the 2000 to 2001 snow season.
MOD10C1: Daily CMG snow map
(0.05° resolution)

April 25, 2004

Source: Hall, 2004
MOD10C2: 8-Day Composite CMG snow map
fractional snow cover from 1 - 100% not shown

The 8-day composite CMG maps maximize snow cover and minimize cloud cover for the compositing period

Source: Hall, 2004
MOD10CM: 0.05° Monthly Climate-Modeling Grid (CMG) Snow Maps

February 2004

Source: Hall, 2004
Applications of MODIS snow data in Afghanistan for the Famine Early Warning System (FEWS)

The map on the top illustrates the current year snow conditions while the map on the bottom shows the snow extent for the same 8-day MODIS period from last year.


Courtesy: Michael Budde/USGS
**Merged MODIS Snow Cover Extent and AFWA Snow Depth**

Daily snow depth values from the Air Force Weather Agency (AFWA) and NOAA are used to create a maximum 8-day snow depth corresponding to the MODIS composite period. These two data sources are then merged to produce a product that identifies snow depth (AFWA) in terms of the snow extent identified using MODIS. The merged product maintains the spatial resolution of MODIS and provides snow depth measurements.

Courtesy Michael Budde/USGS
Greenland

Enhanced algorithm will separate land, bare ice and snow-covered ice in the daily product, MOD10A1

Source: Hall, 2004
Greenland
July 7, 2002

True color composite (1,4,3)

Supervised classification

Source: Hall, 2004
A Case Study in New Mexico

Evapotranspiration
Precipitation

73,000 (97.3%)
75,000

Elephant Butt Reservoir

Zhu, Xie, and Hendrickx, 2005
Reduced Water in Reservoir over Time

Images taken from the USGS Global Visualization Viewer
MODIS 8-day Snow Cover over Time

20% of decrease
Time series of the 8-day MODIS snow cover of Upper Rio Grande river basin and the corresponding 8-day mean streamflow at Otowi gauge station.
Outliers due to the rain storm. If removed, \( r = -0.615 \)

- \( y = -2.8783 \ln(x) + 48.939 \)
- \( R^2 = 0.163 \)
- \( r = -0.403 \)
- \( n = 195 \)
- \( p < 0.001 \)
No outlier in 2002, better correlation achieved

For year 2002

\[
y = -2.9654 \ln(x) + 43.811
\]

- \( R^2 = 0.6061 \)
- \( r = -0.779 \)
- \( n = 46 \)
- \( p < 0.001 \)

\( y \), streamflow (\( \text{m}^3/\text{s} \))

\( x \), snow extent from 8-day MODIS product (\( \text{km}^2 \))
MODIS snow map on March 22, 2002

Rio Grande

Land or vegetation
Inland water
Cloud
Snow

Otowi Streamflow Station

Kilometers
<table>
<thead>
<tr>
<th>Station</th>
<th>Land type (data sets) identified by SNOTEL</th>
<th>MODIS 8-day (MOD10A2)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bateman/NM (91.8%)</td>
<td>Snow (98)</td>
<td>84</td>
<td>11</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(85.7%)</td>
<td>(11.2%)</td>
<td>(3.1%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Land (97)</td>
<td>2</td>
<td>95</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.1%)</td>
<td>(97.9%)</td>
<td>(0.0%)</td>
<td></td>
</tr>
<tr>
<td>Beartown/CO (89.7%)</td>
<td>Snow (122)</td>
<td>117</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(95.9%)</td>
<td>(1.6%)</td>
<td>(2.5%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Land (73)</td>
<td>11</td>
<td>58</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(15.1%)</td>
<td>(79.5%)</td>
<td>(5.4%)</td>
<td></td>
</tr>
<tr>
<td>Middle Creek/CO (87.2%)</td>
<td>Snow (120)</td>
<td>104</td>
<td>14</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(86.7%)</td>
<td>(11.7%)</td>
<td>(1.6%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Land (75)</td>
<td>5</td>
<td>66</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(6.7%)</td>
<td>(88.0%)</td>
<td>(5.3%)</td>
<td></td>
</tr>
<tr>
<td>North Costilla/NM (87.2%)</td>
<td>Snow (97)</td>
<td>82</td>
<td>11</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(84.5%)</td>
<td>(11.3%)</td>
<td>(4.2%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Land (98)</td>
<td>9</td>
<td>88</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(9.2%)</td>
<td>(89.8%)</td>
<td>(1.0%)</td>
<td></td>
</tr>
</tbody>
</table>

Land surface types as identified by the SNOTEL stations are assumed to be the truth.
Overall accuracy:
- 50.3% to 56.8%, MODIS daily product
- 83.6% to 92.3%, MODIS 8-day product

<table>
<thead>
<tr>
<th></th>
<th>S→S</th>
<th>S→L</th>
<th>S→C</th>
<th>L→S</th>
<th>L→L</th>
<th>L→C</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODIS daily</td>
<td>45.0–51.7%</td>
<td>1.7–9.5%</td>
<td>45.2–46.6%</td>
<td>0.0–4.1%</td>
<td>50.2–64.9%</td>
<td>35.0–45.7%</td>
</tr>
<tr>
<td>MODIS 8-day</td>
<td>84.5–95.9%</td>
<td>1.6–11.7%</td>
<td>1.6–4.2%</td>
<td>2.1–15.1%</td>
<td>79.5–97.9%</td>
<td>0.0–5.4%</td>
</tr>
</tbody>
</table>

S=snow, L=land, C=cloud. “S→L” means snow observed by SNOTEL is classified as land by the MODIS daily or 8-day algorithms. Accuracy or error ranges are derived from the selected four SNOTEL stations.
Conclusions

• (1) the MODIS 8-day product has higher classification accuracy for both snow and land;
• (2) the omission error of misclassifying snow as land is similar for both products, both are low;
• (3) the MODIS 8-day product has a slightly higher commission error of misclassifying land as snow than the MODIS daily product; and
• (4) the MODIS daily product has higher omission errors of misclassifying both snow and land as clouds.
• (5) Clouds are the major cause for reduction of the overall accuracy of the MODIS daily product. Improvement in suppressing clouds in the 8-day product is obvious from this comparison study. The sacrifice is the temporal resolution that is reduced from 1 to 8 days.
• (6) For clear sky days, the MODIS daily algorithm works quite well or even better than the MODIS 8-day algorithm.