Snow Algorithms and Products

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Outline

- Techniques
- Algorithms
- Products
- Accuracy

Snow cover: Applications

Information on snow cover is needed for or used in

- Numerical weather prediction
- Hydrology
- Climate studies
- Agriculture, Fire control
- Environmental Applications
- Transportation, Recreation
- Power Generation
- Civil Engineering

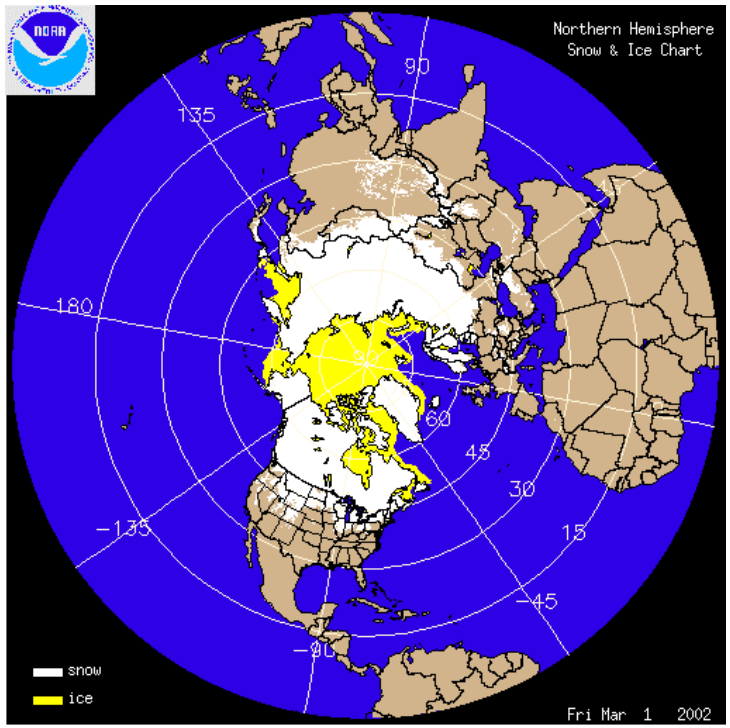
In many cases surface data on snow are unavailable or insufficient, therefore satellite observations should be used

Satellite-based snow mapping techniques

- Interactive
  - *Visible imagery*
    - Snow extent
- Automated
  - Visible/shortwave-(middle-)infrared/infrared
    - Snow extent
    - Snow fraction
  - *Microwave*
    - Snow extent
    - Snow depth, Snow-water equivalent

NOAA Interactive Multisensor Snow and Ice Mapping System (IMS)

35+ years of mapping snow and ice over Northern Hemisphere



- Uses satellite imagery in the visible band
- Imagery examined by human analysts
- "Intelligent guess" is used if cloudy
- Maps are drawn by hand and digitized
- Cover Northern Hemisphere
- Since 1999
  - Daily production
  - 25 km spatial resolution
  - 4 km resolution since 2004

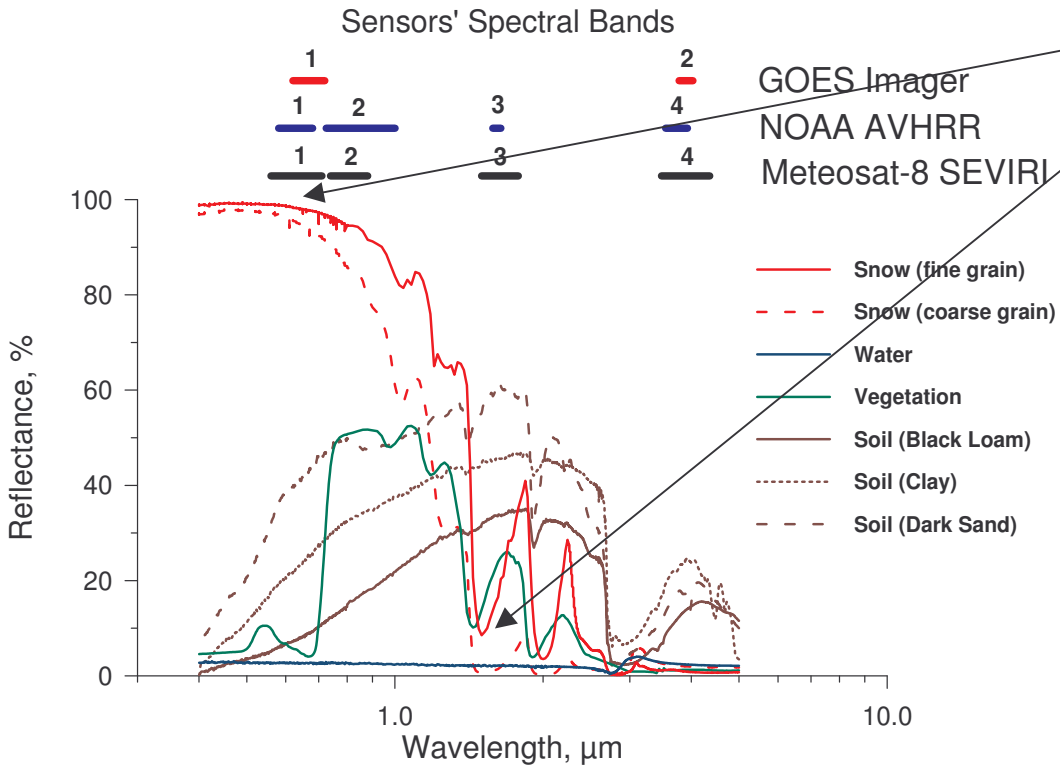
IMS snow maps are incorporated in all NOAA operational NWP models

On the Web: http://www.ssd.noaa.gov/PS/SNOW/index.html

Why automated snow mapping ?

- Objective classification, consistent retrievals
- Reprocessing of historical data
- Full spatial and temporal resolution
- Physical properties of snow cover
- Facilitate interactive analysis

Automated snow detection in VIS/IR: Basics



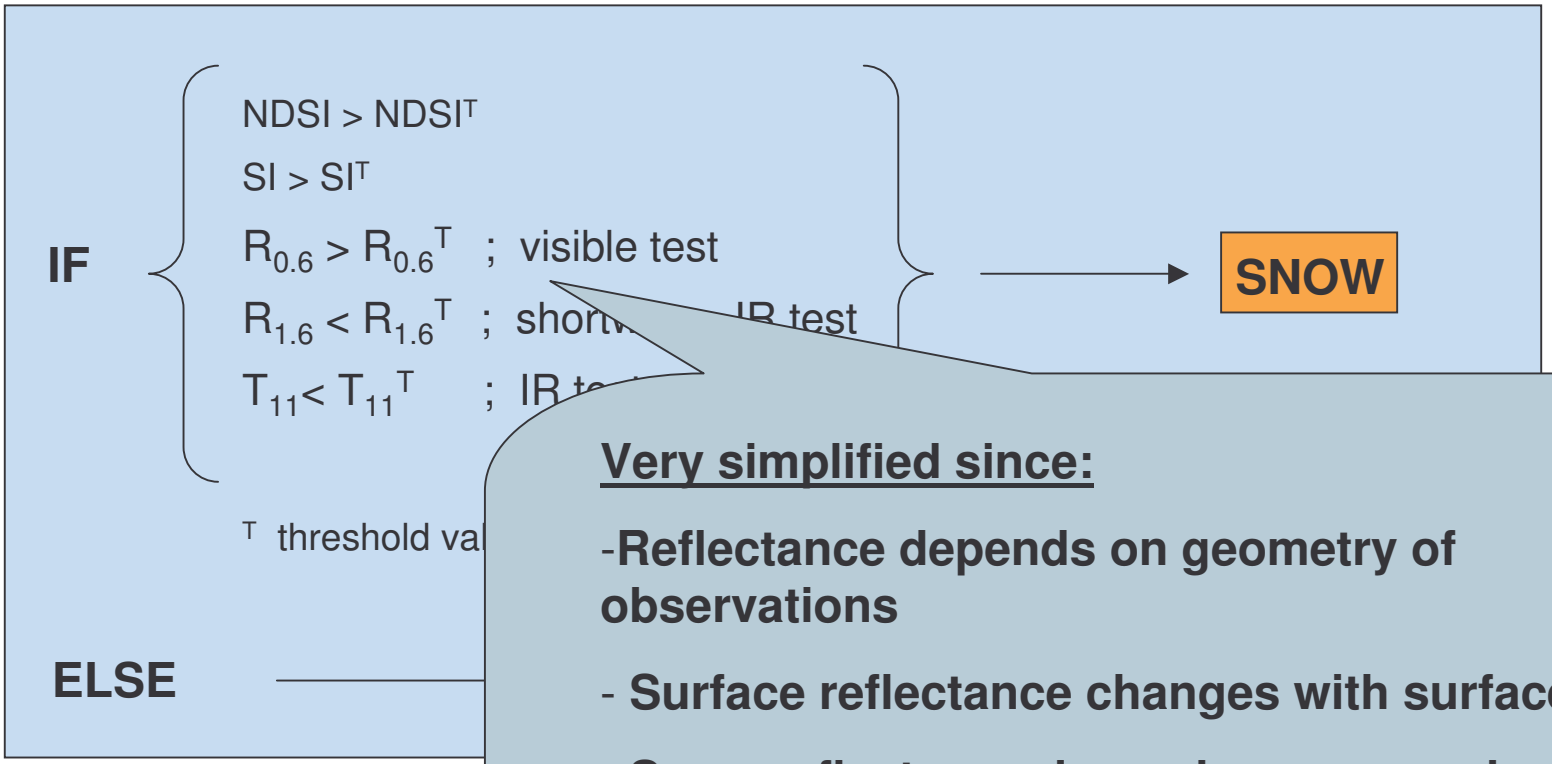
Snow spectral properties in the visible and infrared

Sharp drop of snow reflectance from visible (VIS) to shortwave infrared (SIR)

Needs observations in
- visible
- shortwave infrared
- infrared

Does not work
- at night
- in cloudy conditions

VIS/IR: General approach to snow detection



Very simplified since:

-Reflectance depends on geometry of observations

- Surface reflectance changes with surface type

- Snow reflectance depends on snow physical properties (e.g. grain size, impurities)

- Vegetation tends to mask snow

- Threshold values are instrument specific

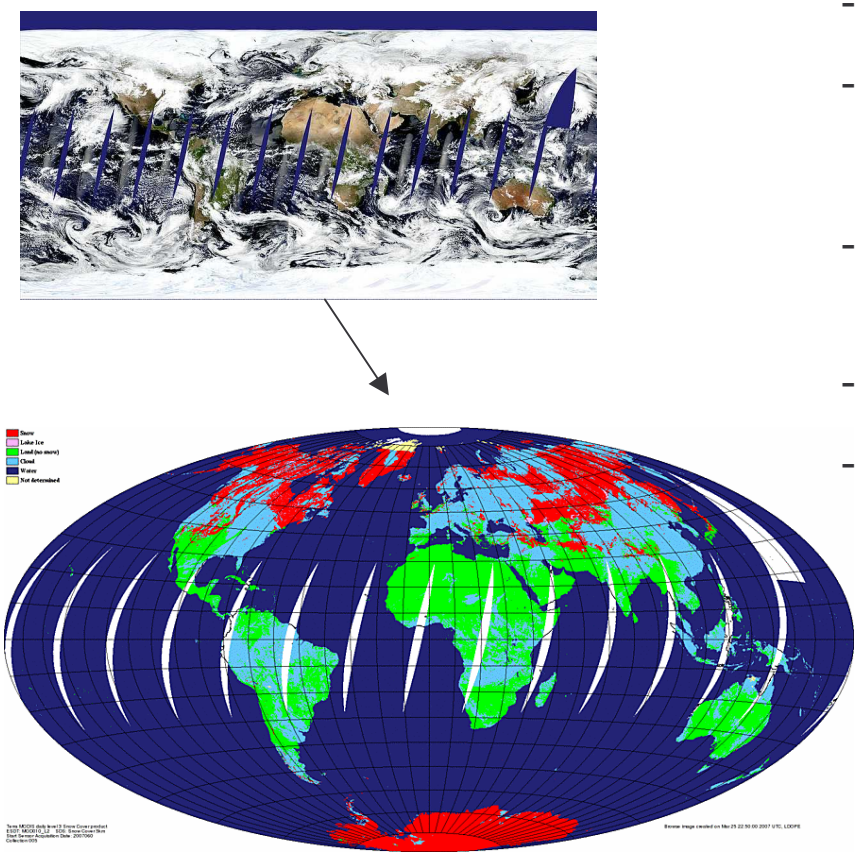
Where

$SI=R_{0.6}/R_{1.6}$ snow index

$NDSI=(R_{0.6}-R_{1.6})/(R_{0.6}+R_{1.6}$

$NDVI=(R_{0.9}-R_{0.6})/(R_{0.9}+R_{0.6})$

MODIS snow map (D. Hall, NASA)



MODIS daily snow map

- Threshold-based decision-tree technique
- Spectral features used:

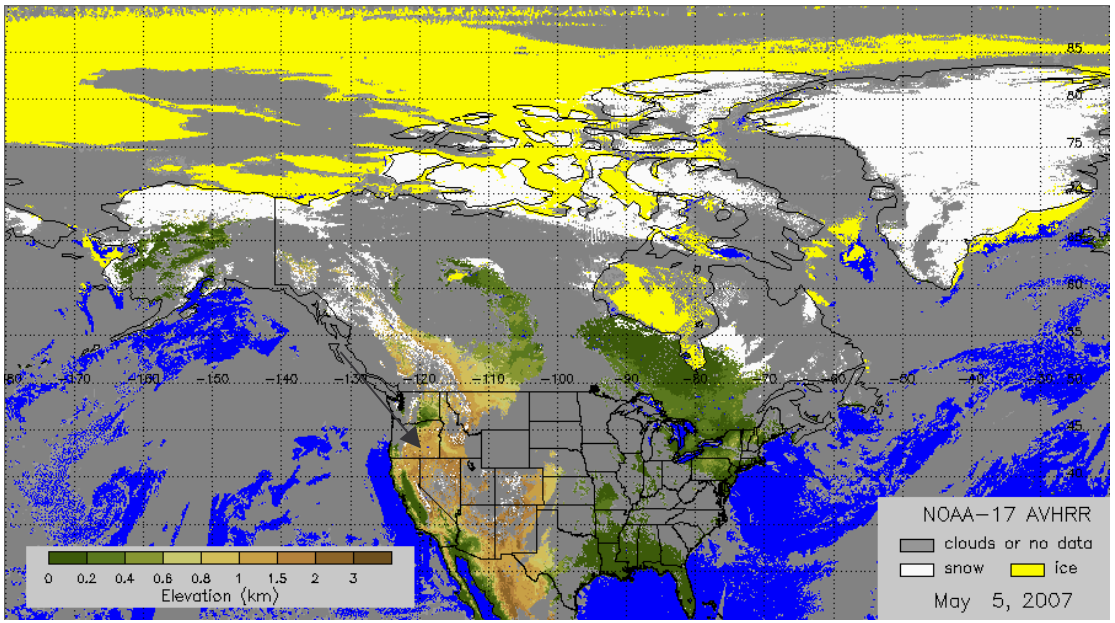
  NDSI, T_{11}, $R_{0.6}$
- NDSI threshold value changes with NDVI to improve snow mapping over forests
- Other threshold values are fixed
- "Never snow" mask is applied

Map features:

- Global, daily
- ~0.5 km max resolution
- Available since 2000
- Terra, Aqua

On the Web: http://modland.nascom.nasa.gov/cgi-bin/browse/browse.cgi

AVHRR/NOAA snow/ice map (NESDIS)



Technique:

- Similar to MODIS
- For NOAA-16 and -18 $R_{3.7}$ is used instead of $R_{1.6}$

<u>Added features:</u>

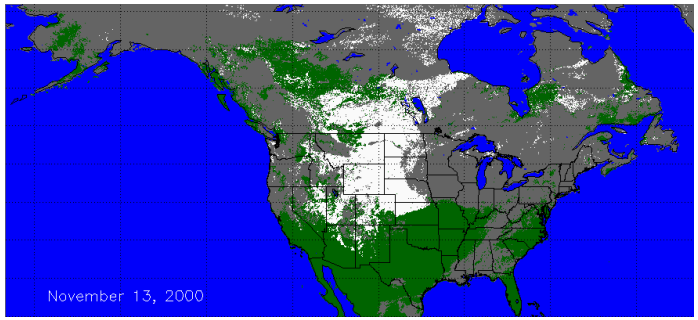
- Land surface temperature climatology to improve cloud detection
- Snow cover climatology to reduce spurious snow
- Cloud texture analysis
- Ice is also mapped

Map features:

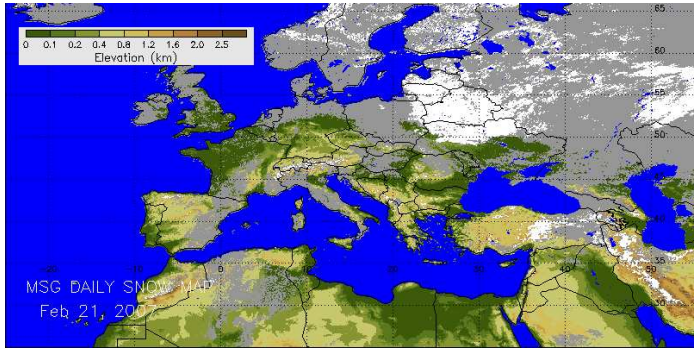
- Daily, global
- 4 km resolution
- Operational since 2005
- NOAA-17, -18

On the Web: http://www.orbit.nesdis.noaa.gov/smcd/emb/snow/HTML/na_avhrr_snow.html

Snow from geostationary satellites



Combined GOES-E and -W snow map
Snow is white, clouds are gray



Snow map from Meteosat-8 SEVIRI

Frequent (30 or 15-min) views:

- Better chance to observe land surface cloud-clear
- Better snow-cloud discrimination

Algorithm includes:

- Cloud-clear image compositing
- Threshold-based classification
- Temporal variability test
- Land surface temperature climatology test
- Snow climatology test

Map features:

- Coverage is limited to 66^0N and S
- Daily maps
-4 km resolution
- Operational since 1999 (GOES)

On the Web: http://www.orbit.nesdis.noaa.gov/smcd/emb/snow/HTML/snow.html

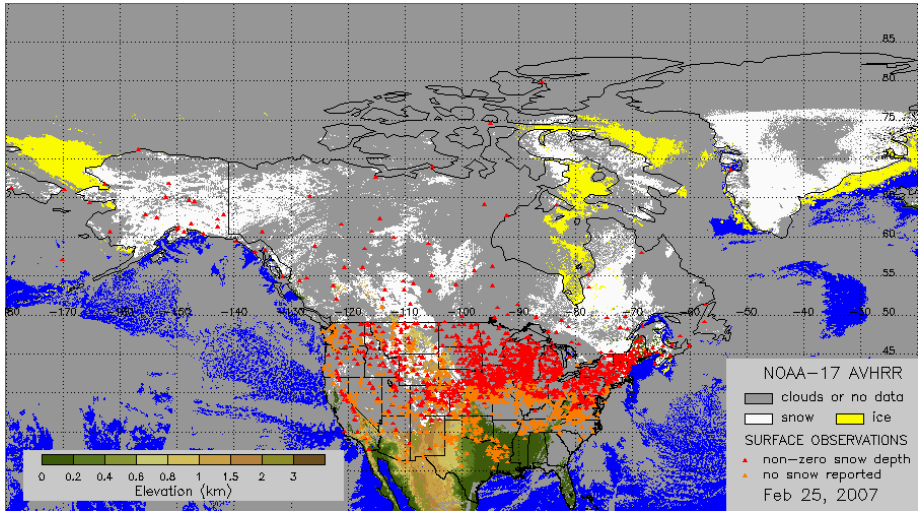
Accuracy of VIS/IR snow maps

vs surface observations

- up to about 2,000 daily station reports over the globe to compare with
- 92%-97% overall agreement

vs NOAA interactive snow charts

- compared over Northern Hemisphere
- 96%-98% overall agreement



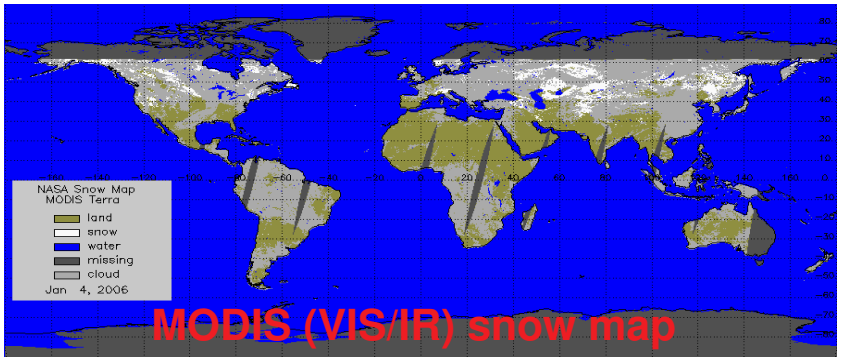
NOAA/AVHRR snow map with surface observations overlaid

Comparison is performed only over areas identified in now maps as cloud-clear

VIS/IR principal problem: cloud cover

- In instantaneous images clouds cover ~60% of land area
- More clouds over snow boundary area
- Clouds hamper/prevent from
  - Continuous snow monitoring
  - Estimating total snow extent on daily basis

- Repeated observations bring only slight improvement
  - Terra+Aqua reduce cloud contamination by 8%
  - Geo satellites reduce cloud-obscured area by ~20%

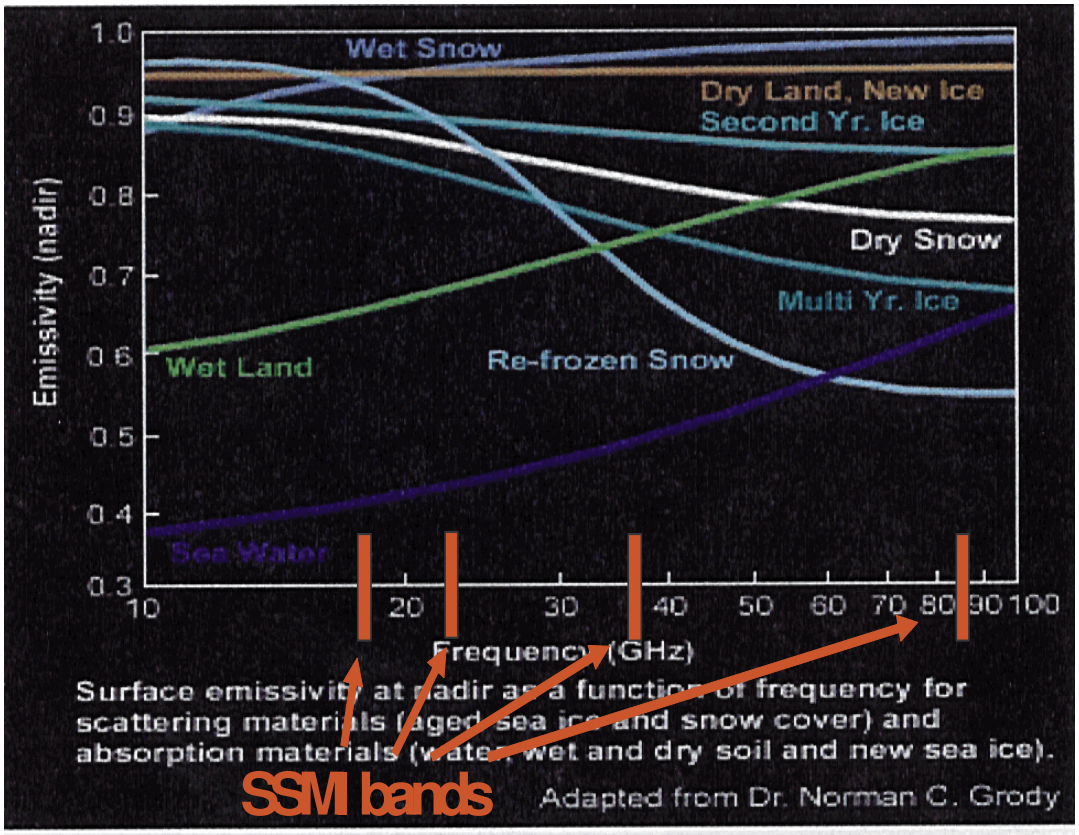


MODIS (VIS/IR) snow map

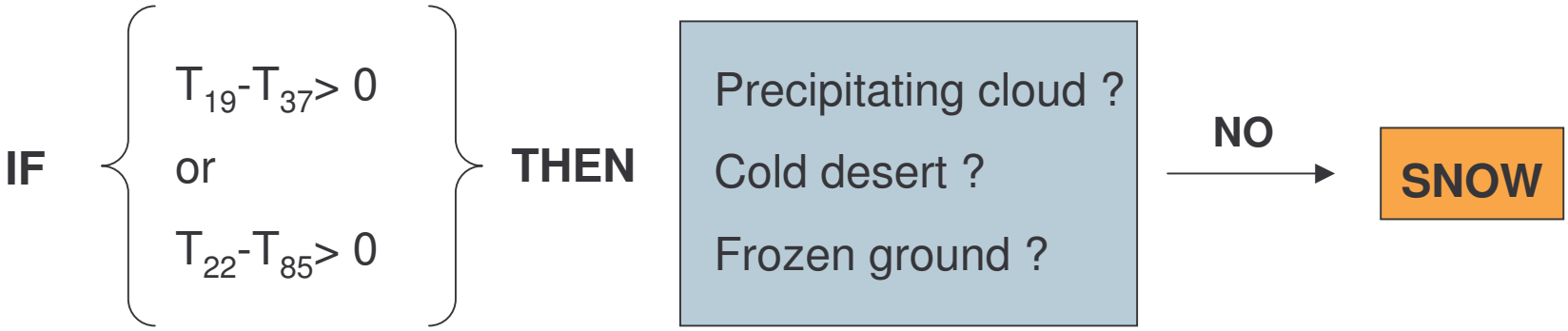
Automated snow detection in the microwave: Basics

Spectral range from 10GHz to 100GHz (~3 cm to ~0.3 cm)

- Dry snow grains scatter upwelling radiation
- Scatter increases with increasing frequency
- Scatter increases with the depth of snow pack
- Increasing scatter reduces emissivity and brightness temperature of snow pack



General approach to snow detection in MW



T_{19}, T_{22}, T_{37}, T_{85} : Brightness temperature at 19, 22, 37, 85 GHz

In some algorithms slightly positive or negative threshold values are used

Snow depth/SWE algorithms

$SD=a(T_{19}-T_{37})+b$ (Chang, 1987 algorithm)

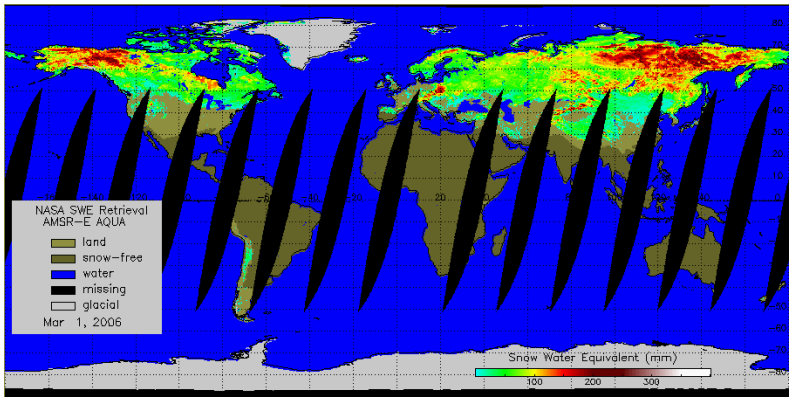
$SD=a(T_{19}-T_{37})/(1-c*ff)$ (Kelly, 2003),

"ff" is forest fraction

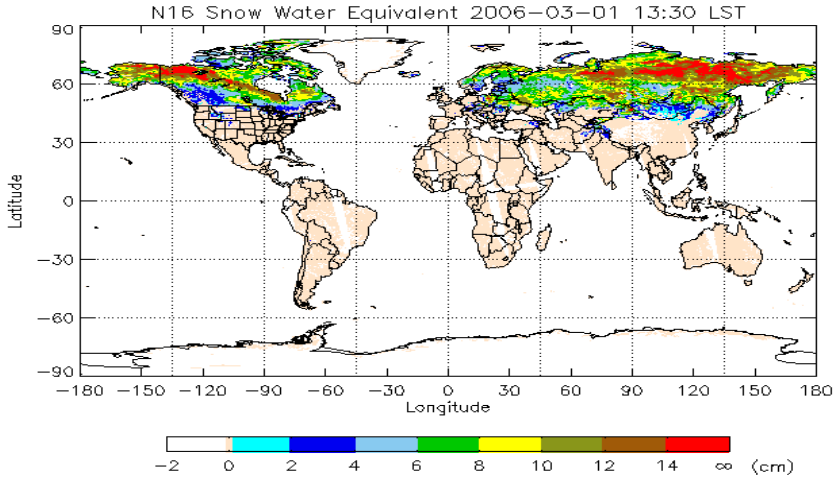
Coefficients (a, b, c) relating microwave brightness temperature gradient and snow depth (SD) are derived empirically

Other linear and non-linear algorithms have also been proposed

Microwave daily snow products



AMSR-E Aqua
Snow water equivalent
R. Kelly, J. Foster, NASA
25 km resolution



AMSU NOAA
Snow water equivalent
R. Ferraro, C. Kongoli, NOAA
50 km resolution

- No estimates over Tibet

- All weather capability (most clouds are transparent)
- Misses of shallow and melting snow
- Cold rocks confused with snow

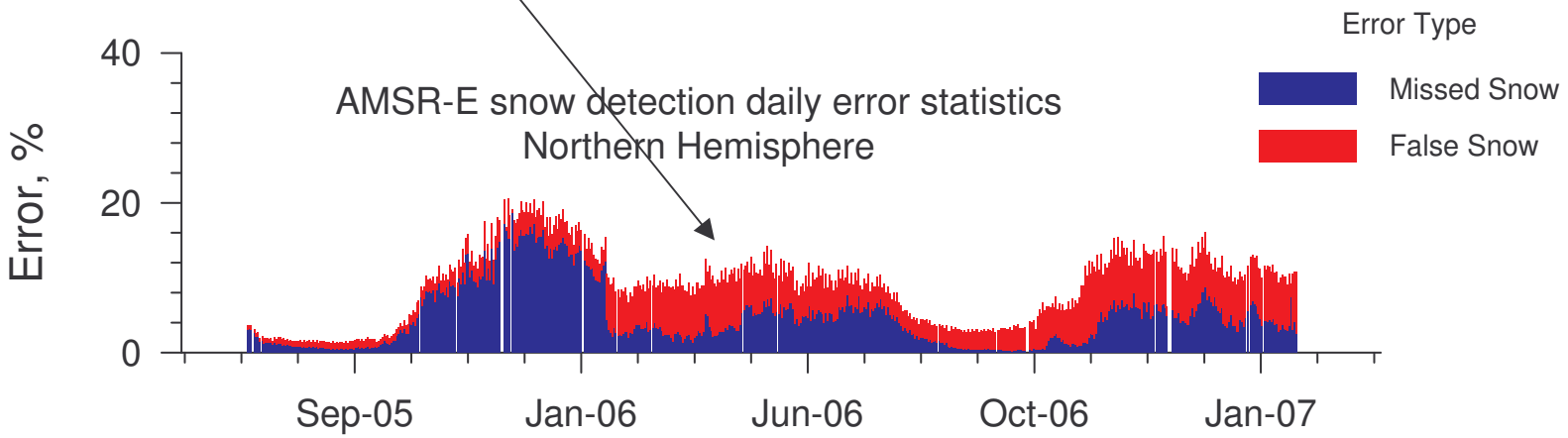
Accuracy of microwave snow products

vs surface observations

- Snow cover: 87% (SSM/I)
- Snow depth error estimate: very optimistic: 10%-20% (Canada, prairies)
  more realistic: 30%-100% (other studies)

vs NOAA interactive snow charts

- ~ 90% overall agreement (AMSR-E)
- i.e. snow mapping errors are 2-3 times larger than for VIS/IR



Microwave: principal problems

- Coarse spatial resolution of sensors
- Underestimates of snow extent in autumn and in spring
- Overestimates of snow cover in the mountains
- Accuracy of snow depth retrievals is poor, estimates are unavailable when needed most (snow melt)

Combining snow retrievals in VIS/IR and microwave

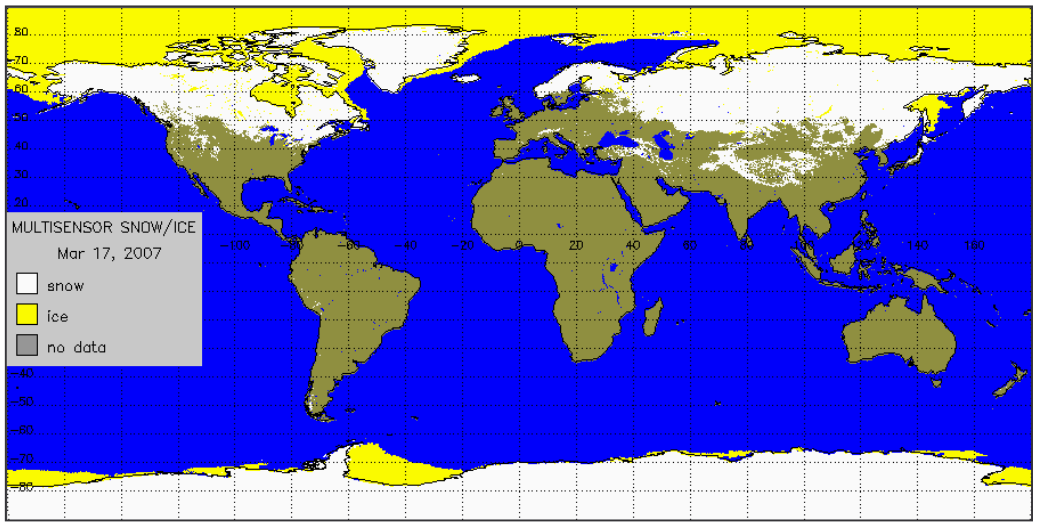
Motivation:

Generate continuous (with no gaps) snow map on a daily basis at highest possible spatial resolution and accuracy

Basic idea:

Make maximum use of advantages of both techniques and compensate for their limitations

NOAA Multisensor Automated Snow and Ice Mapping System



Algorithm:

- Combine cloud-clear retrievals from all VIS/IR sensors
- Retain only reliable microwave retrievals
- Fill in cloudy pixels in VIS/IR map with microwave data
- Use the previous day map to fill in remaining undetermined pixels.

Satellite data used:

Imager/GOES-10 and -12
SEVIRI/MSG
AVHRR/NOAA-17, 18
SSMI/DMSP-13,14,15

Map features:

- Daily, global
- 4 km resolution
- Continuous coverage
- Operational since 2005

On the Web: http://www.orbit.nesdis.noaa.gov/smcd/emb/snow/HTML/multisensor_global_snow_ice.html

Multisensor snow map: accuracy

- Cloud clear estimates: same accuracy as VIS/IR

- Cloudy conditions: better than in microwave products

- 3% daily average and 1% yearly average difference with IMS in the estimate of continental snow extent (north America and Eurasia)

Summary

- A substantial number of snow products is available
- No technique/product is perfect
- Interactive: reliable, subjective. Impossible to reprocess the data
- VIS/IR: high spatial resolution but cloud gaps, hence lack of temporal continuity. Errors are about 5% when cloud-clear.
- Microwave: All weather but low spatial resolution and frequently fails. Precautions needed when using the data. Errors are over 10%
- Combined: Improves snow mapping (spatial resolution, temporal continuity), but more difficult to implement.

Implementation in direct readout environment

No problems are anticipated in implementing the algorithms

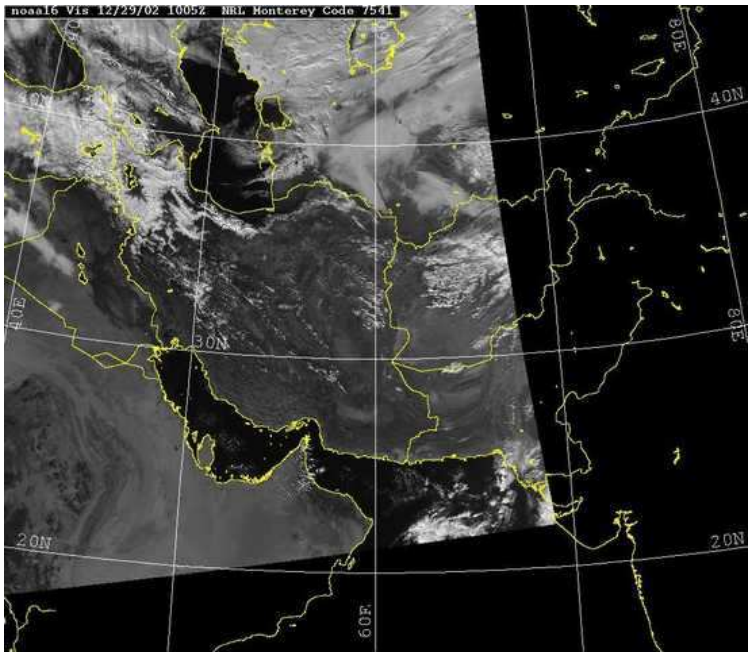
Multisensor techniques are harder to implement

All algorithms are global or continental developed for year-round application

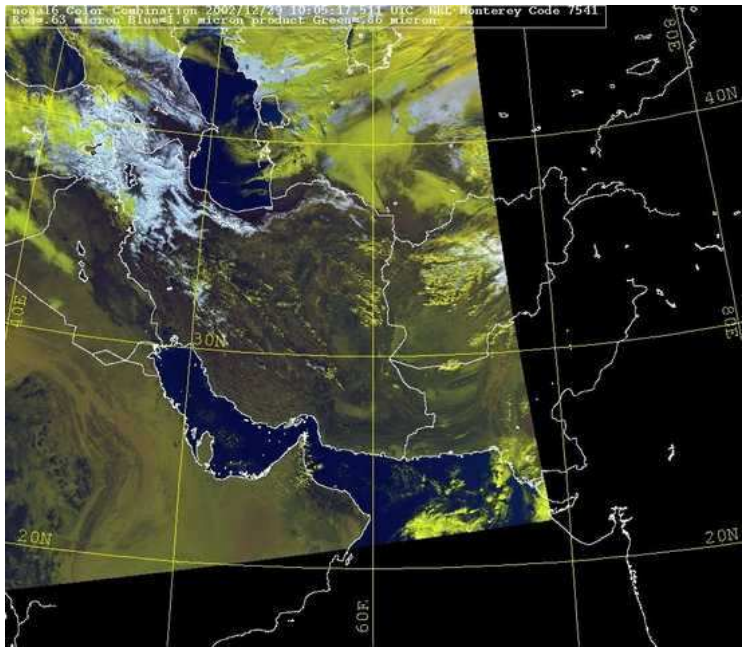
Fine-tuning may help to improve algorithm performance over smaller areas

Questions

NOAA AVHRR: visible vs color composite



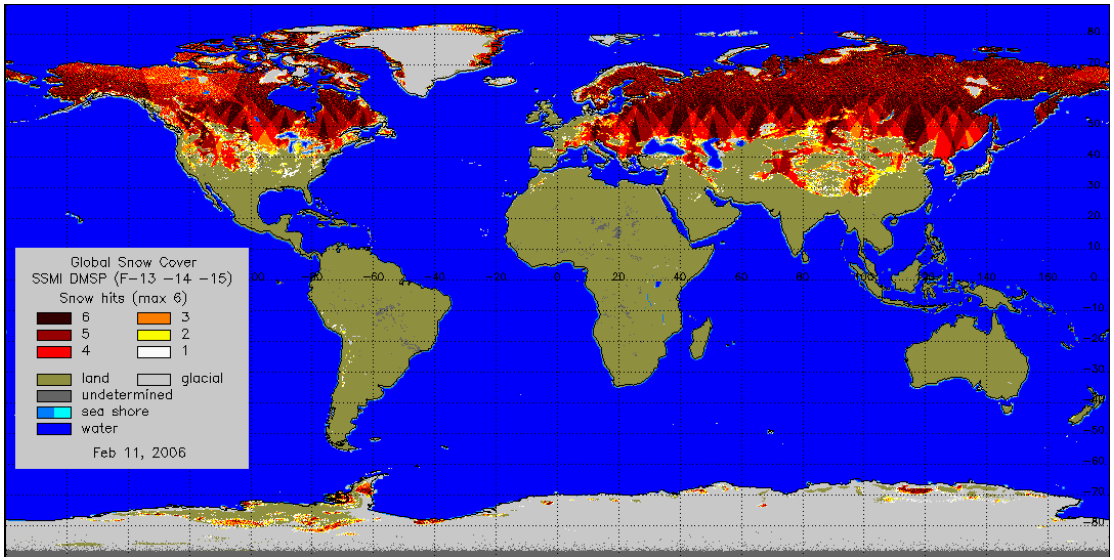
NOAA visible channel



NOAA color composite

Visible/near-infrared/shortwave-infrared

Multiple observations make snow map more reliable



SSMI-based daily map showing the total number of snow identifications made with three DMSP satellites during one day

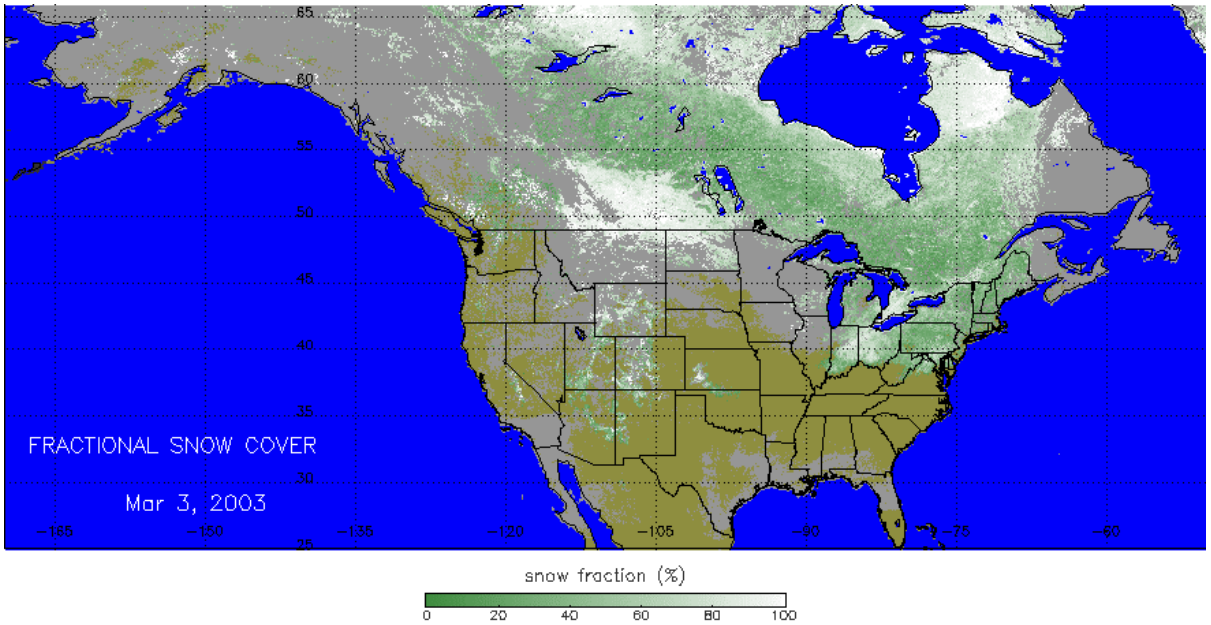
- Up to 6 daily SSM/I views are available from three DSMP satellites

Repeated “snow hit” is indicative of snow cover

One “hit” may indicate misclassified precipitating cloud

On the Web: http://www.orbit.nesdis.noaa.gov/smcd/emb/snow/HTML/ssmi_global_snow_ice.html

Snow fraction



Daily snow fraction map

Fraction of snow within a pixel as seen by satellite instrument

Needed in NWP models to calculate albedo

- **Derived from visible reflectance ($R_{0.6}$)**
- **Linear mixture approach used:**

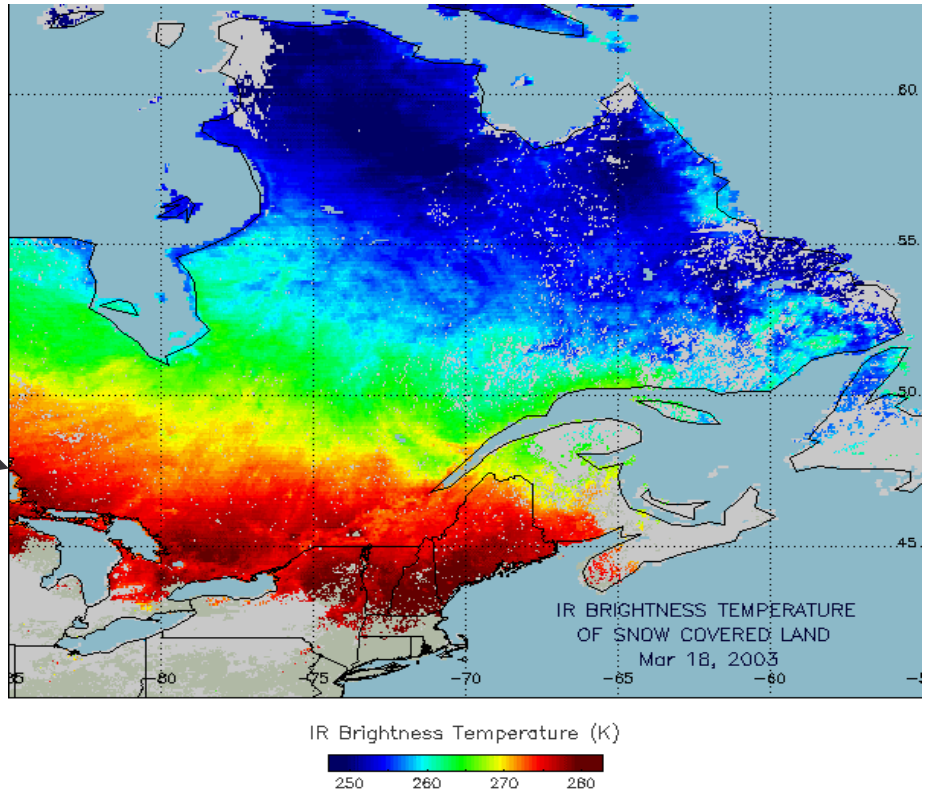
$$F = (R_{obs} - R_{land}) / (R_{snow} - R_{land})$$

On the Web: http://www.orbit.nesdis.noaa.gov/smcd/emb/snow/HTML/fraction.htm

Temperature of snow-covered land surface

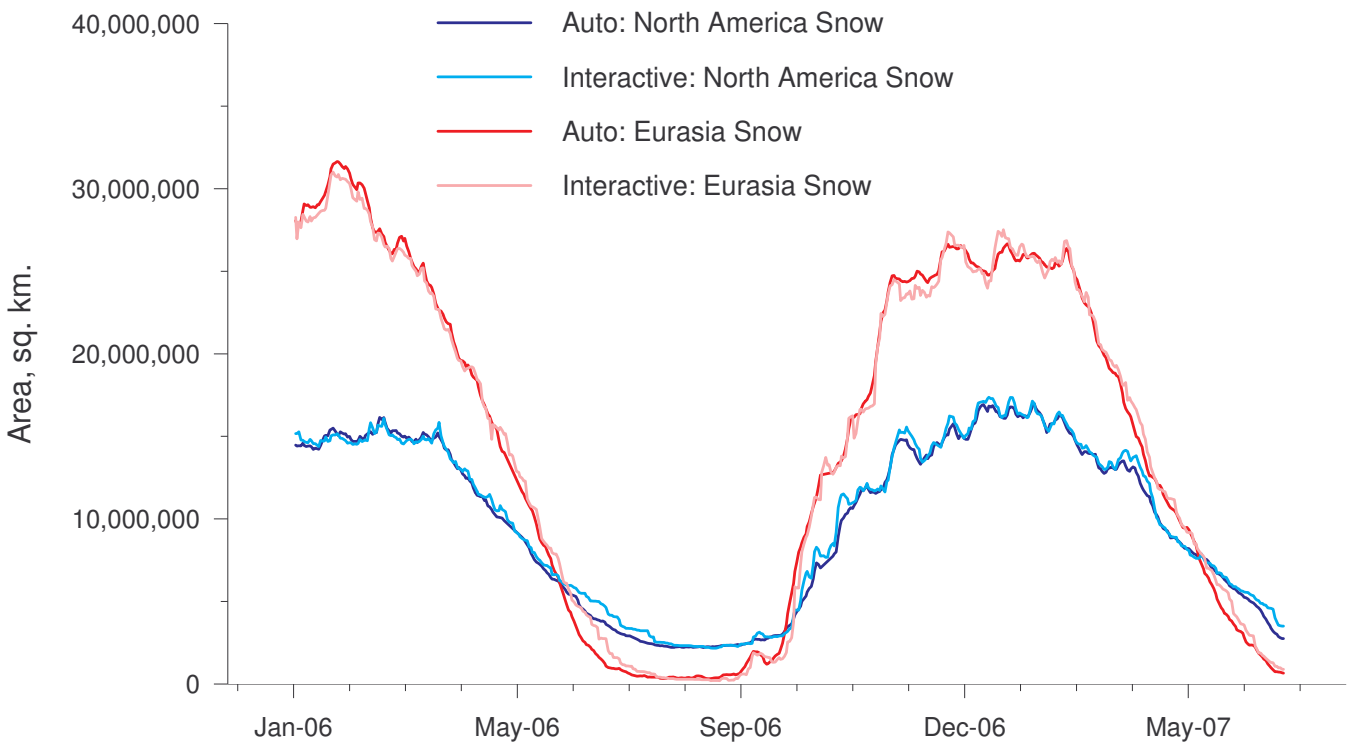
GOES-Imager data

Helps to identify areas of active snow melt



New England and Quebec

Total snow extent from multisensor auto and interactive product

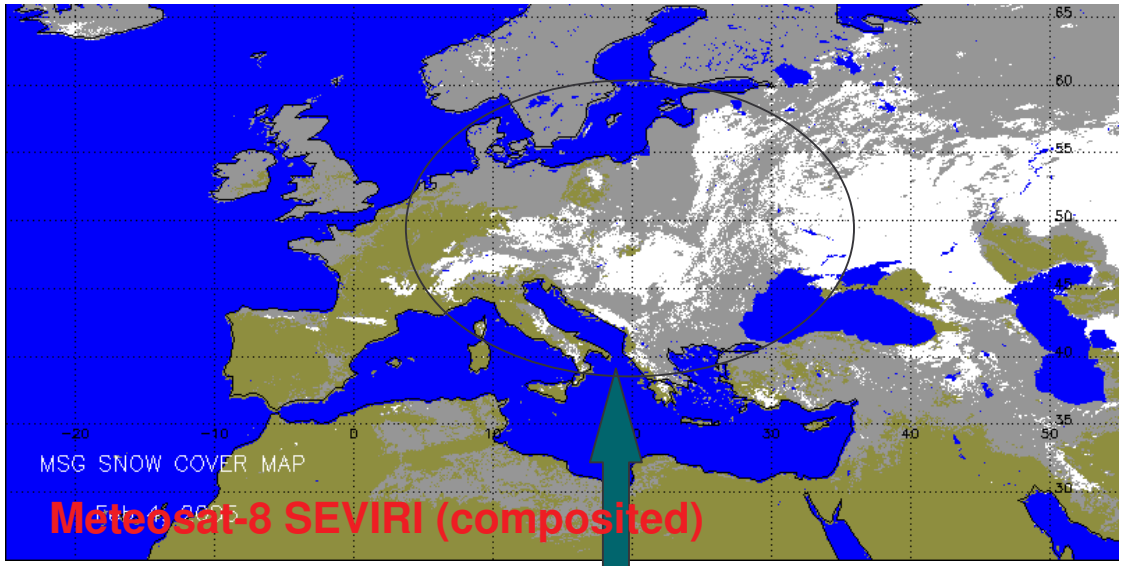


Difference in snow extent estimate

Daily average : about 3%

Yearly average: about 1%

Max temperature image compositing



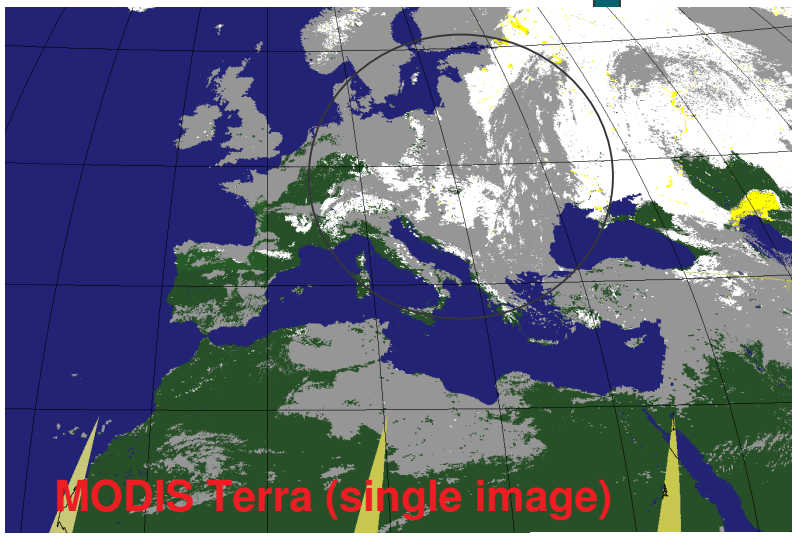
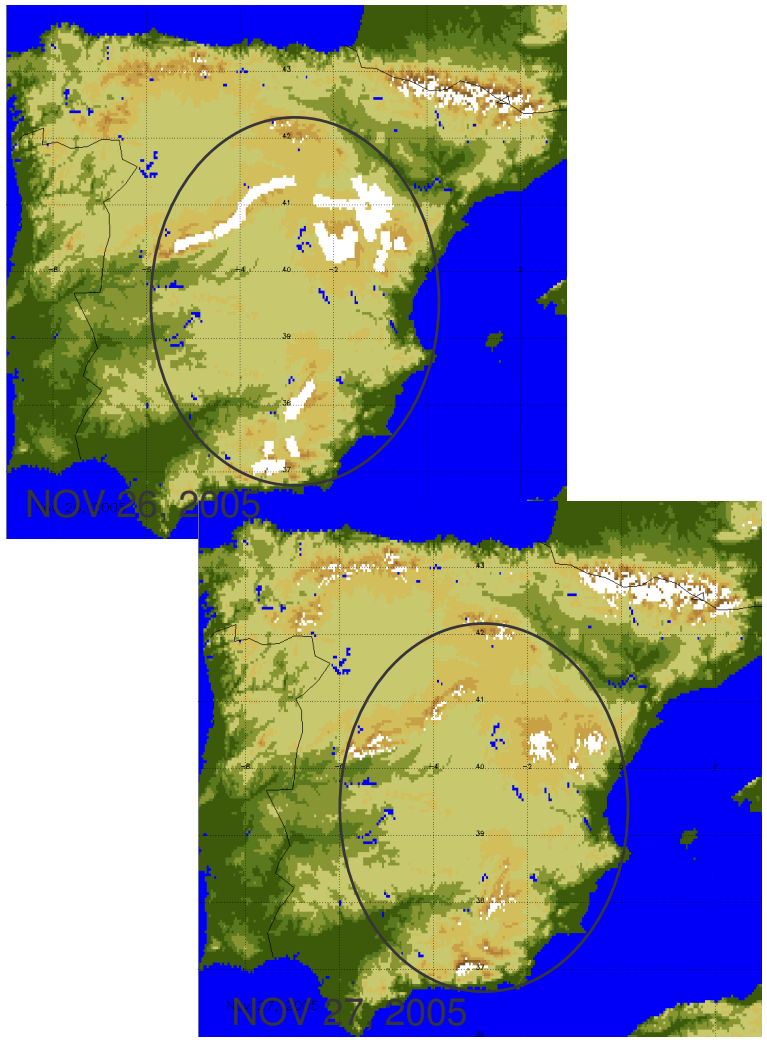


Image compositing reduces cloud contamination and thus improves area coverage

Advantages and limitations of interactive technique



- Simple logic, easy to implement
- No serious errors in mapping snow

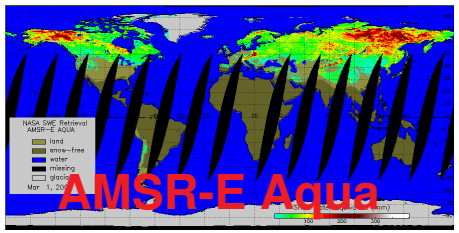
But

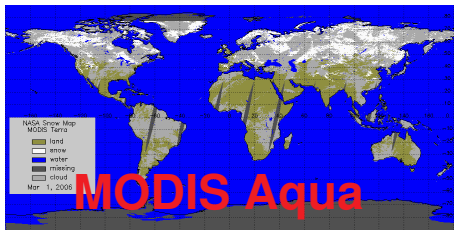
- Subjective
- Can not utilize full potential of data
  - Max spatial resolution
  - Multispectral measurements
- Hard to reprocess data

Snow extent over Spain for two consecutive days. Maps were generated by different analysts.

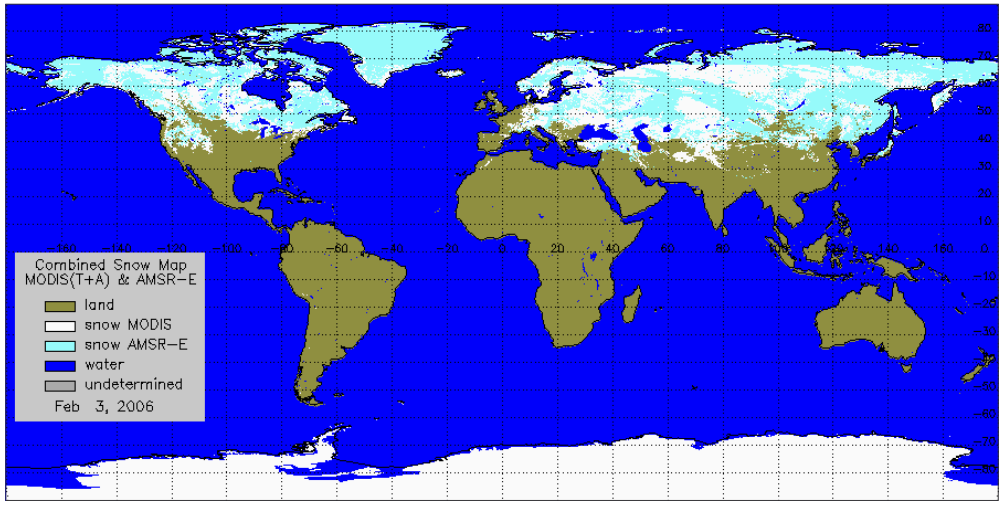
Combining MODIS and AMSR-E snow

Microwave

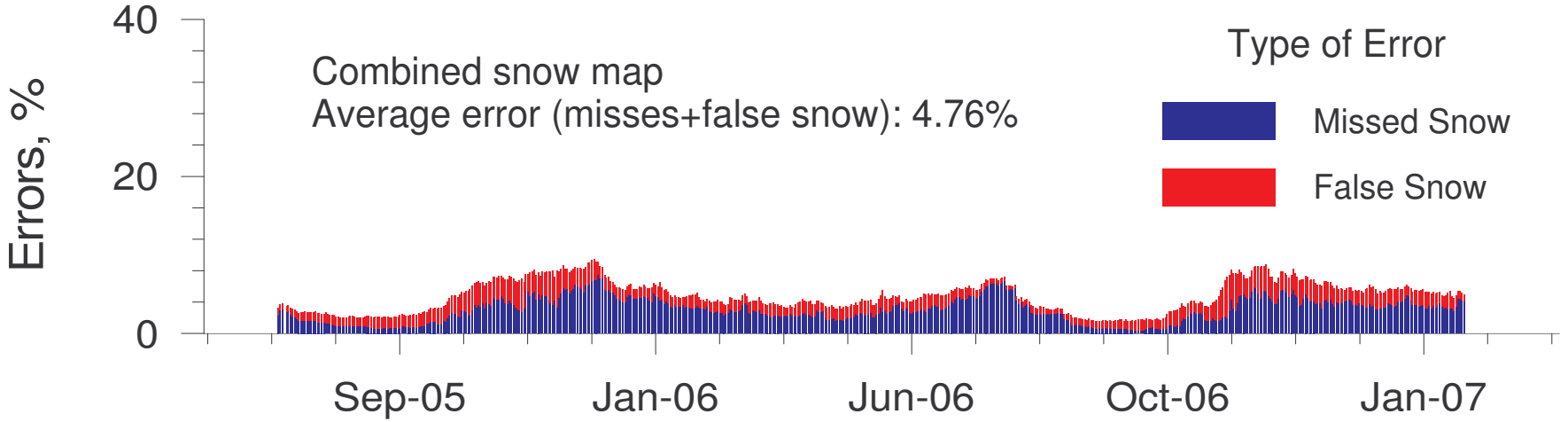




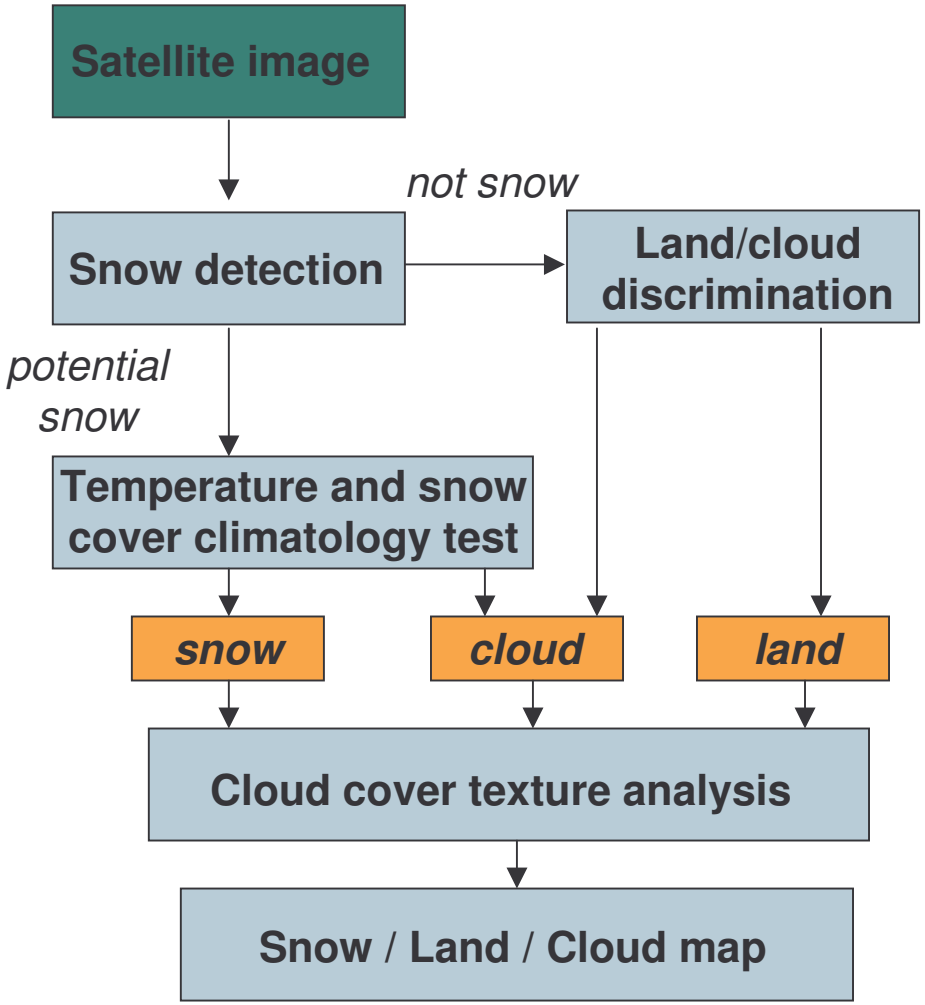
Vis/IR



Combined snow map

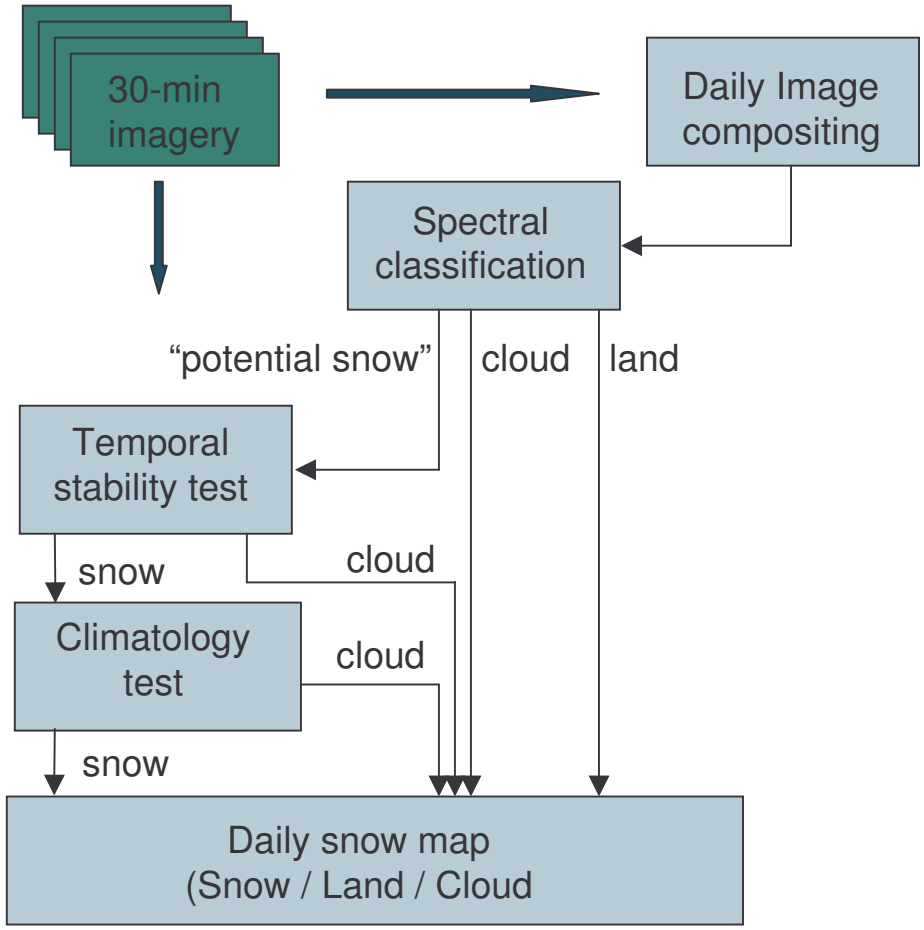


Snow mapping with NOAA/AVHRR

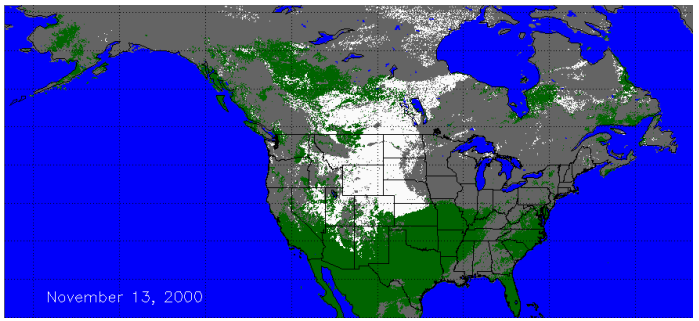


- Threshold-based classification
- Uses $R_{0.6}$, $R_{1.6}$, T_{11}, NDSI, SI, NDVI
- For NOAA-16 and -18 $R_{3.7}$ is used instead of $R_{1.6}$
- Land surface temperature and snow cover climatology tests are added
- Ice is also mapped

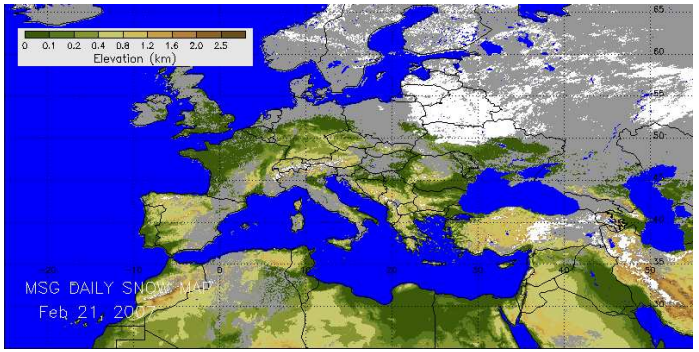
Snow from GOES and Meteosat



Snow mapping flow chart



Combined GOES-E and -W snow map
Snow is white, clouds are gray

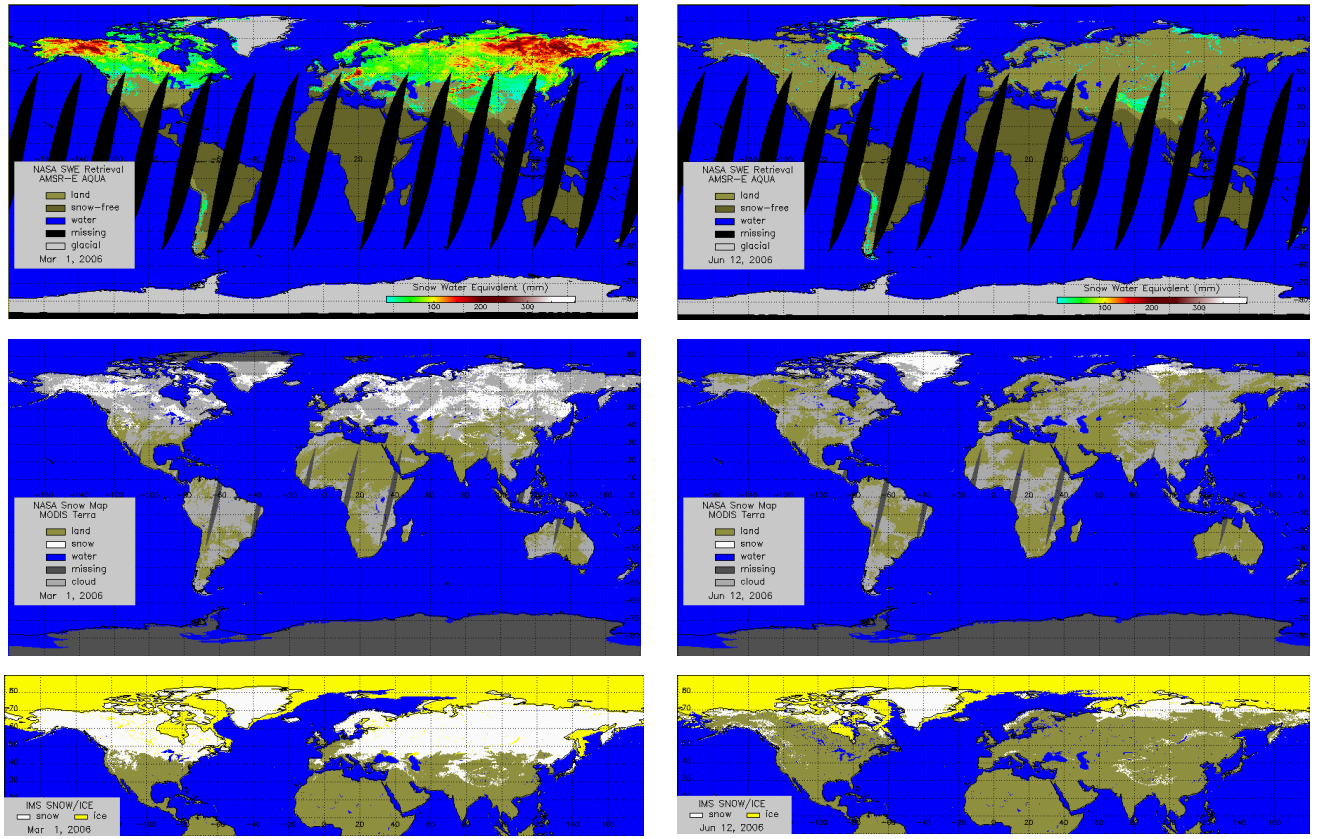


Snow map from Meteosat-8 SEVIRI

On the Web: http://www.orbit.nesdis.noaa.gov/smcd/emb/snow/HTML/snow.html

How do satellite snow maps compare ?

AMSR-E Aqua, MODIS-Terra vs NOAA Interactive snow charts



AMSR-E SWE

MODIS-Terra snow map

NOAA snow chart

March 1, 2006

June 12, 2006

Accuracy of EOS snow products

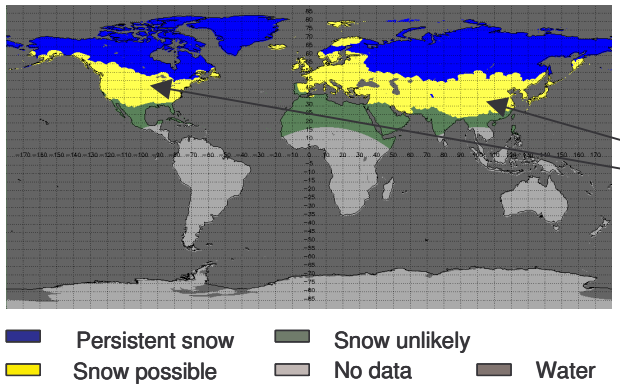
Daily average area fraction of errors

AMSR-E Aqua, MODIS-Terra, Aqua vs NOAA Interactive snow charts

	All cases			*"Snow Possible"*		
	Missed Snow	False Snow	**Total error**	Missed Snow	False Snow	**Total Error**
MODIS Terra	1.85	0.76	**2.61**	5.19	2.14	**7.33**
MODIS Aqua	2.09	0.45	**2.54**	5.90	1.34	**7.24**
MSR-E Aqua	3.67	5.30	**8.97**	7.66	12.06	**19.72**

Cloud-clear scenes only

Northern Hemisphere, daily data, July 2005-February 2007



"Snow Possible" area for week 9 (Feb 26-Mar 4)