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 km^2
    Southern Hemisphere ~ 1 mln km^2
- 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

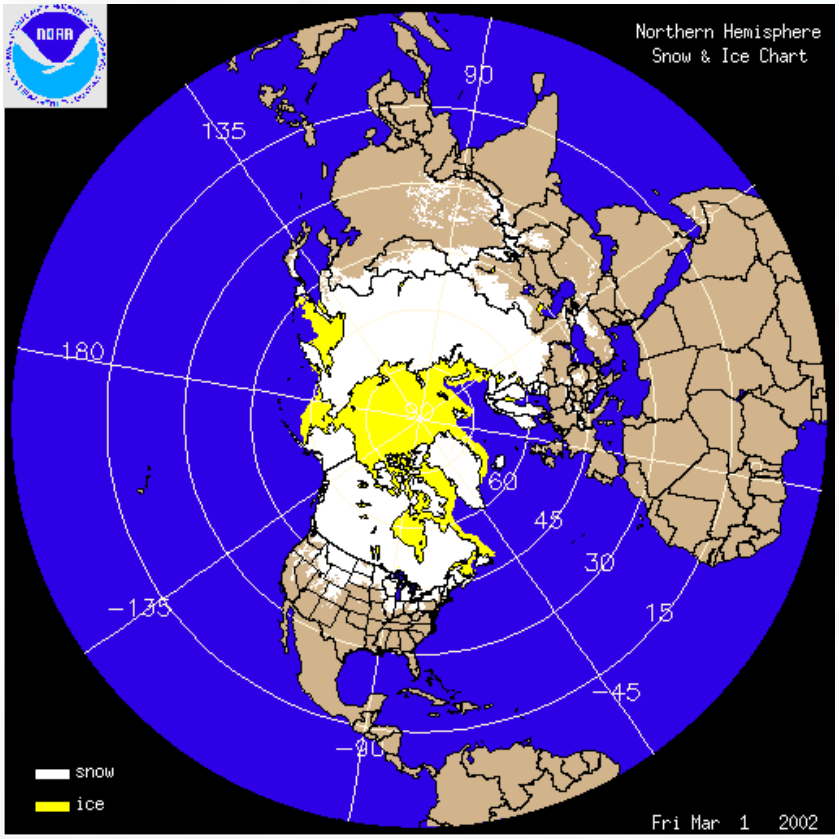
- Interactive
- Automated
  - Visible & infrared
  - Passive microwave
  - Combined visible-infrared-microwave

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

period		*update / resolution*
1972-1997	:	weekly / 180km
1998-2003	:	daily / 24 km
2004-2014	:	daily / 4 km
2015 -	:	twice daily / 1 km

On the Web: http://www.natice.noaa.gov/ims/

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

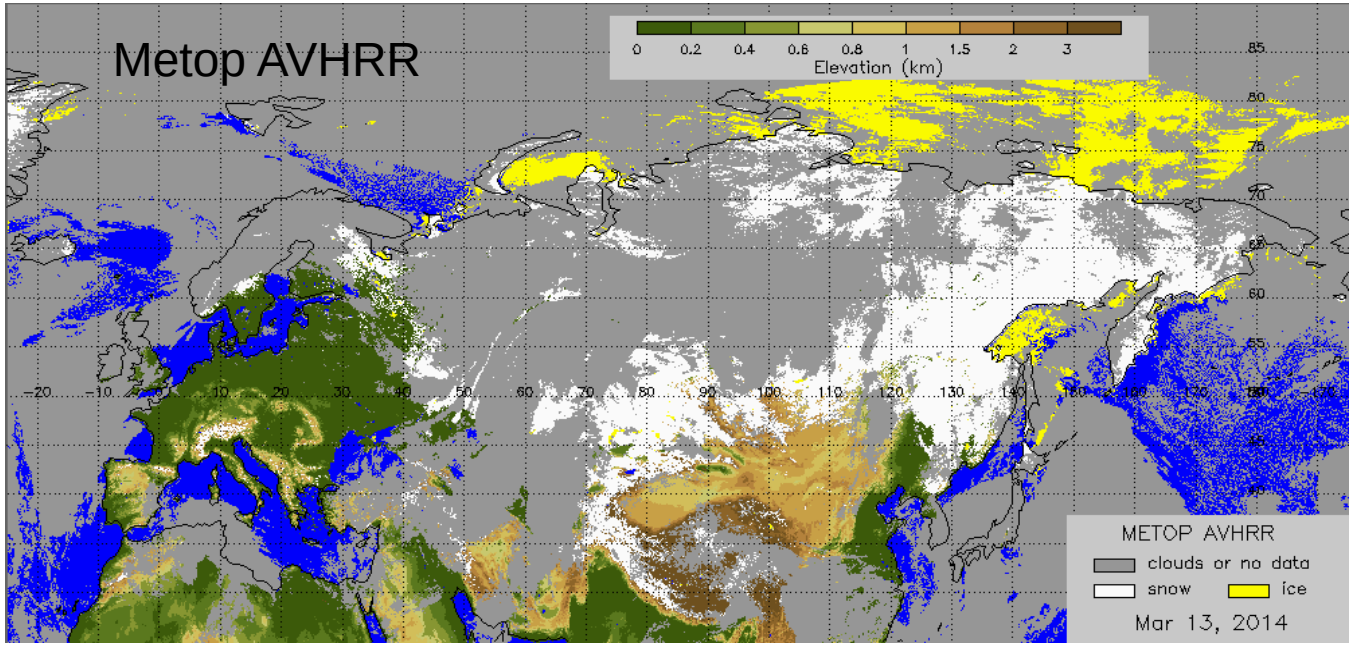
- Potentially better effective spatial resolution
- Potentially better consistency in space/time (no subjectivity)
- Less routine labor
- Other parameters besides snow extent can be inferred

But

- Are affected by physical limitations
- Require substantial efforts to be developed

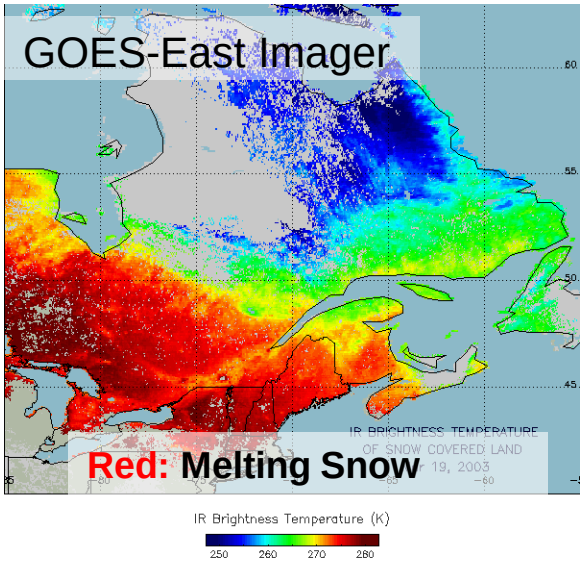
Snow from Visible/IR

- 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



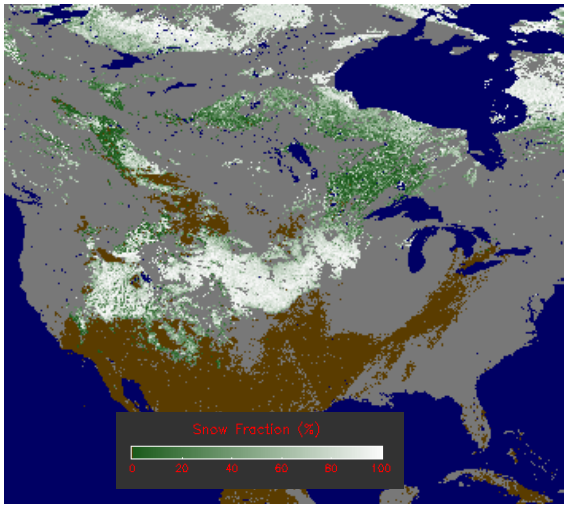
Similar products are available from MODIS, VIIRS, SEVIRI, other sensors

Visible/IR: Other snow parameters



Temperature of snow-covered land

- Snow melt/freeze identification

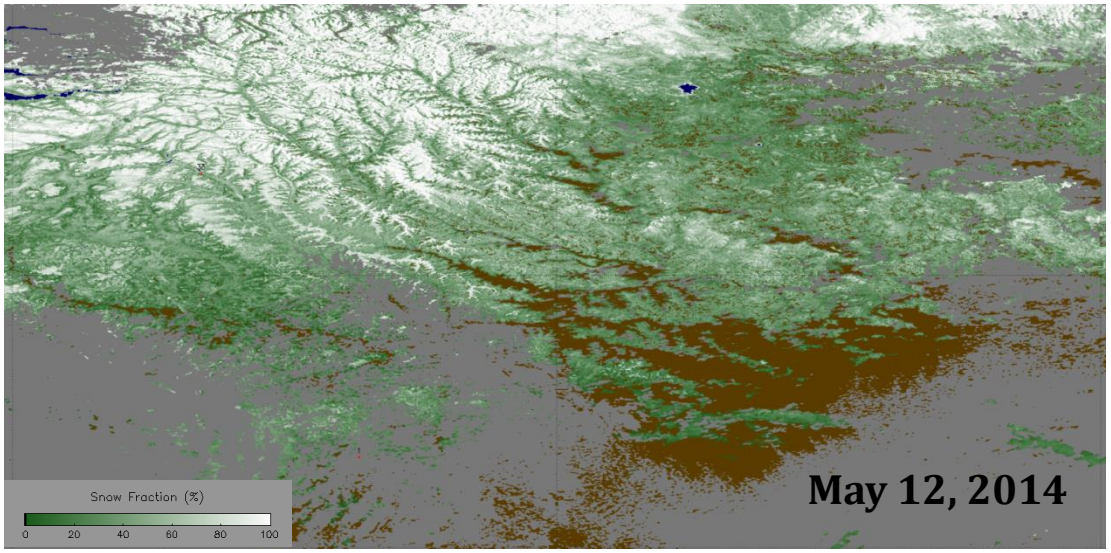


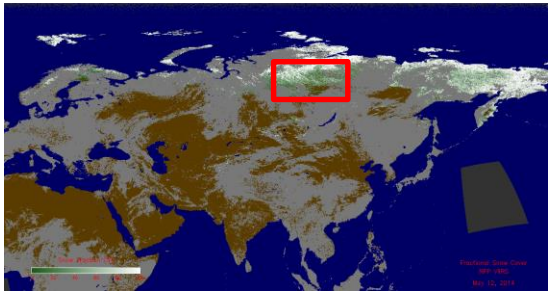
Fractional (sub-pixel) snow cover

Can be used to characterize
- Land surface albedo
- Forest cover
- Snow depth over non-forested areas

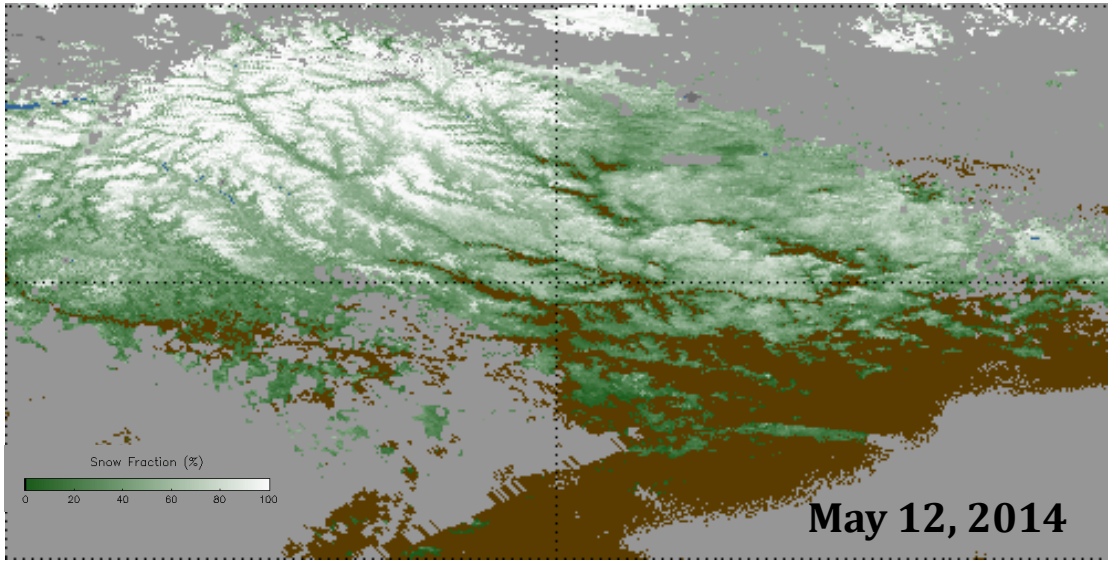
SNPP VIIRS

Snow Fraction: VIIRS vs AVHRR





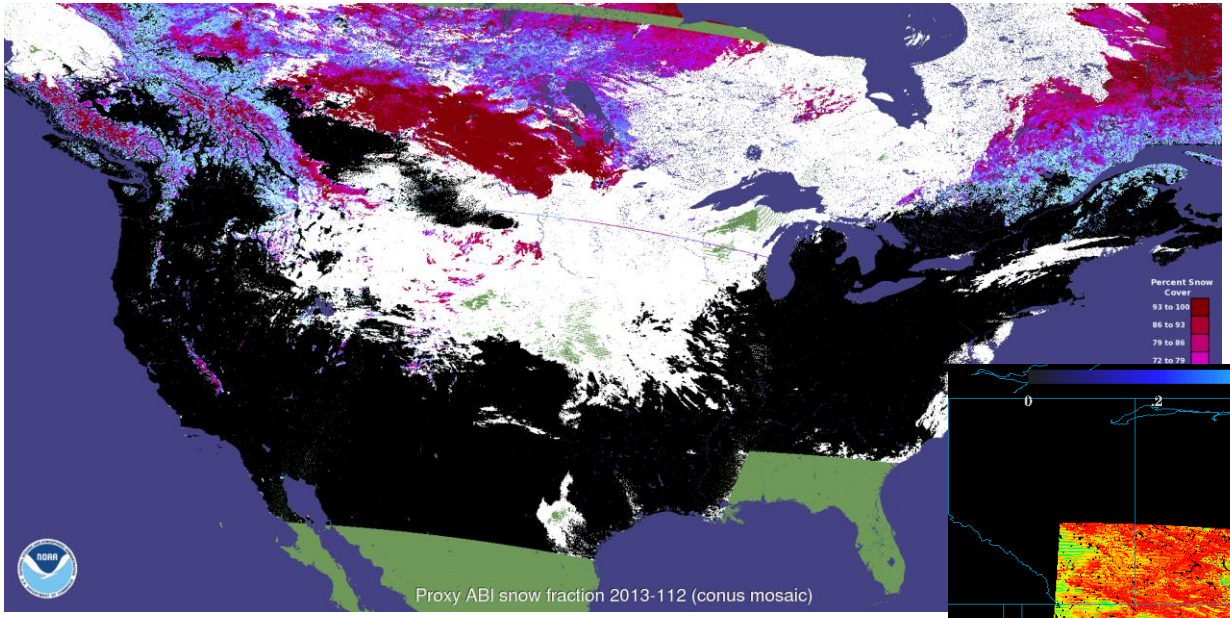
VIIRS , 375m gridded to 1 km



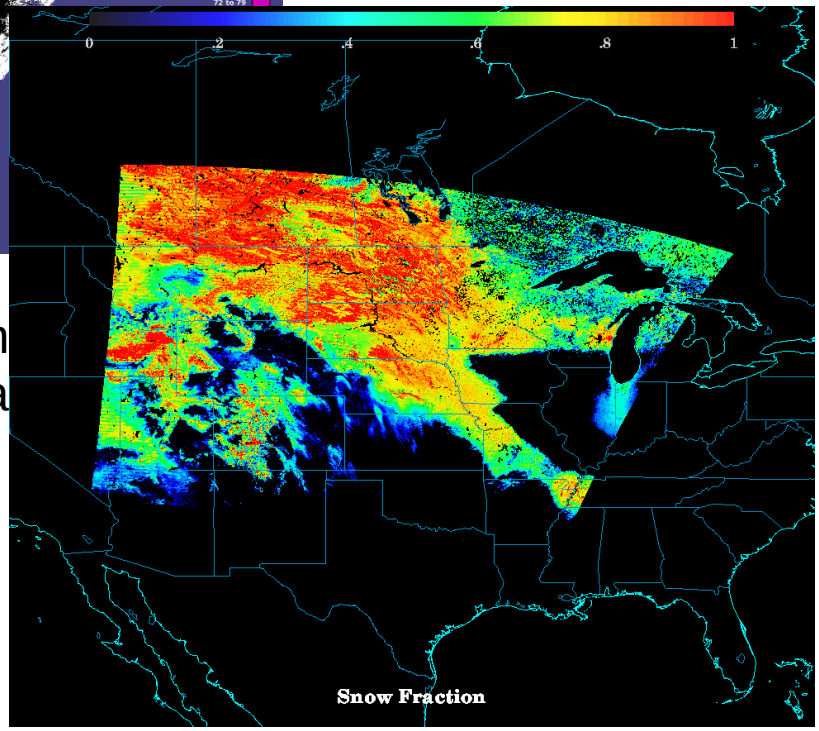
AVHRR , 1km gridded to 4 km

Gray: clouds
Brown: snow-free land

GOES-R ABI Snow Fraction



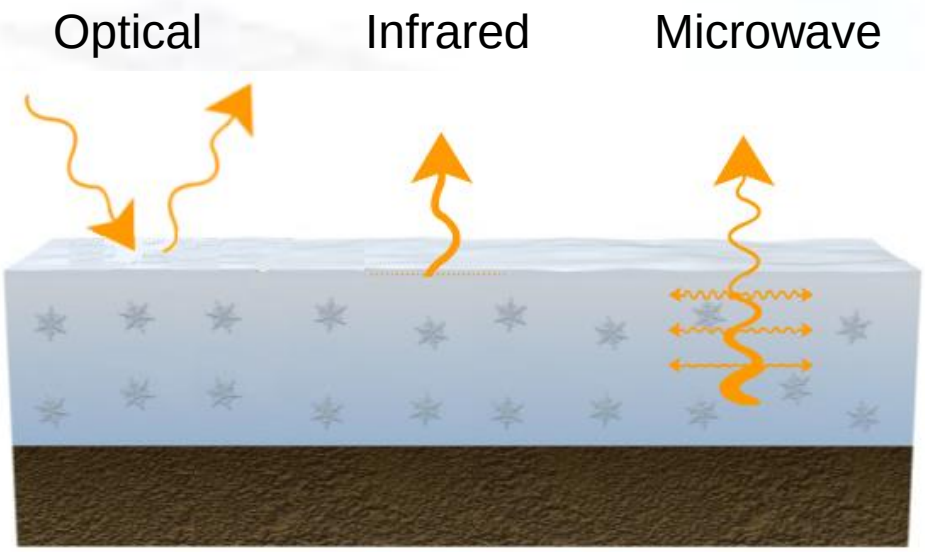
This product will not be operational until 2018



Simulated GOES-R ABI Snow Fraction from GOESRSCAG processing of proxy ABI data from MODIS. Left: March 1, 2009. Above: Multi-orbit mosaic for April 22, 2013.

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

Microwave: The way to look inside the snow pack



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

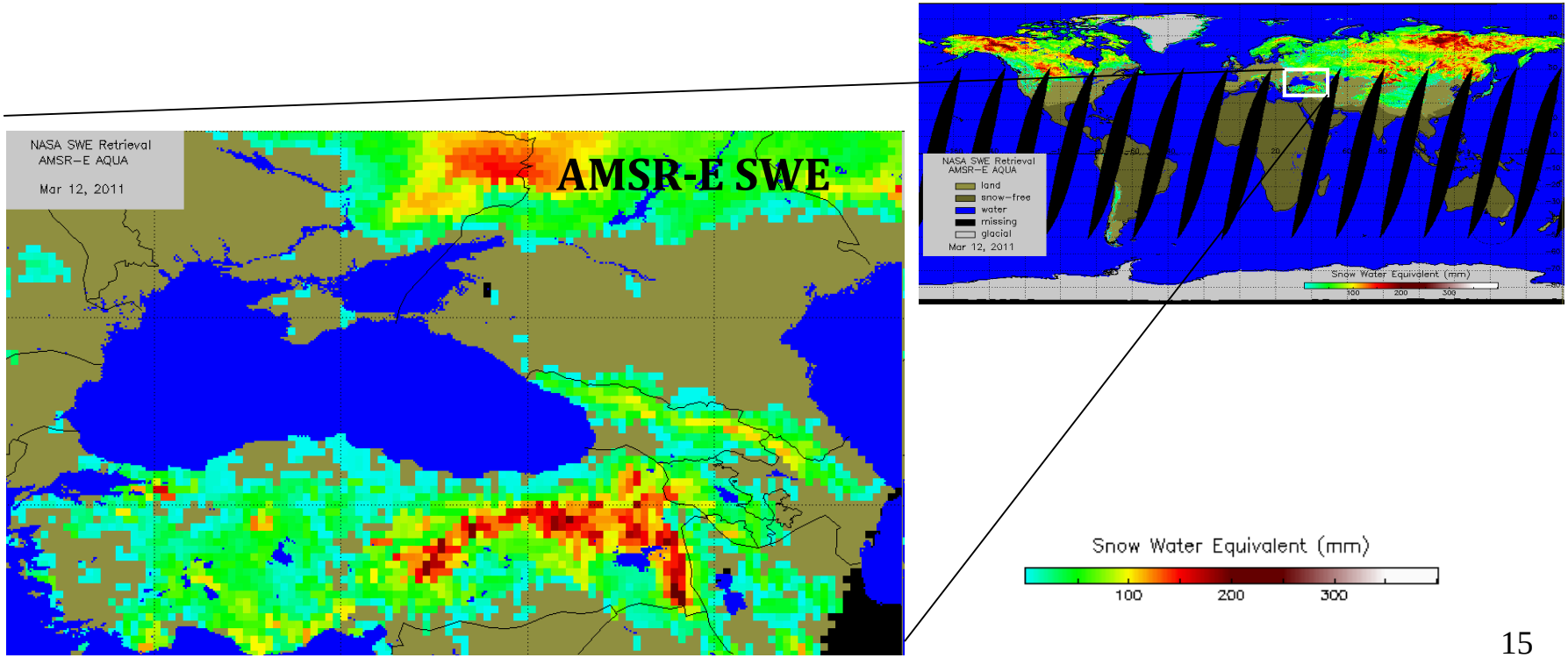
Upwelling microwave radiation is emitted by the sub-snow surface and altered by the snow pack.

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

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

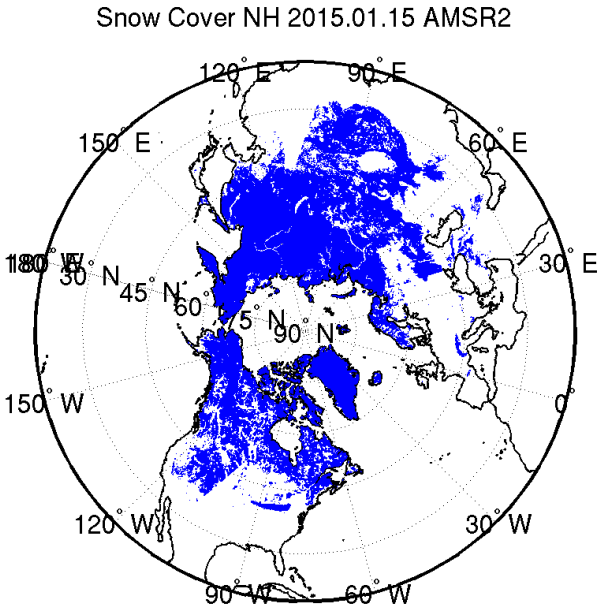
Snow from microwave observations

- 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)



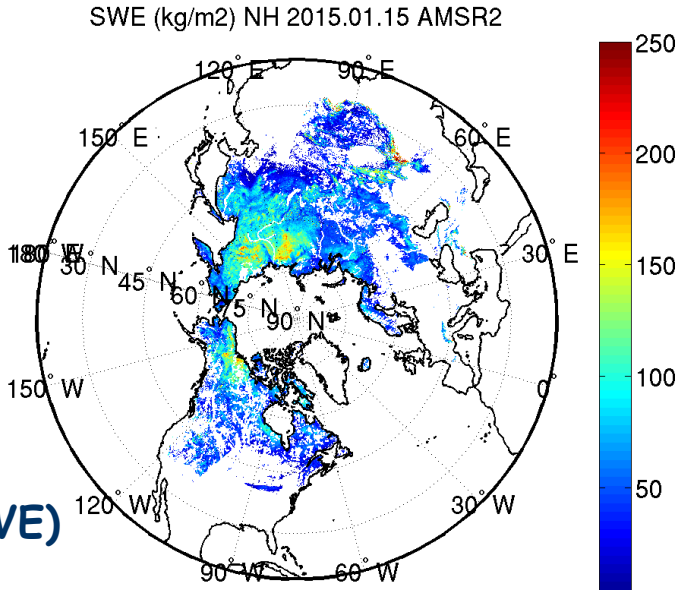
NOAA AMSR2 Snow Products

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

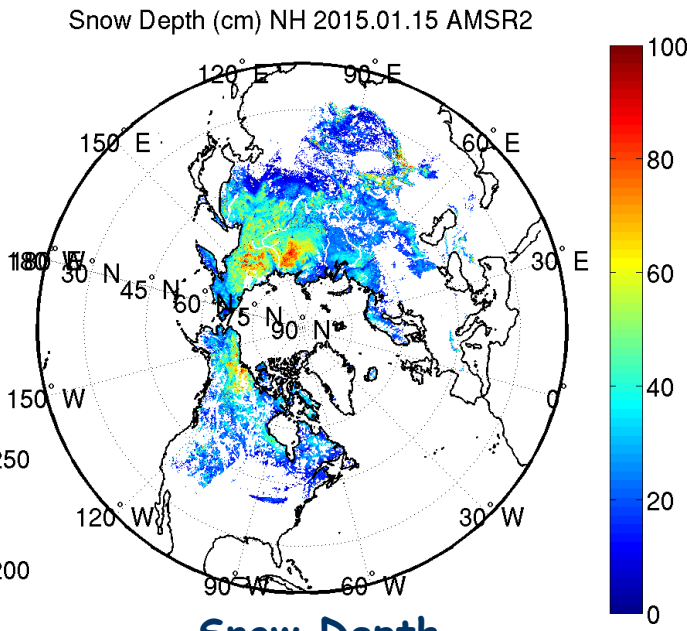


Snow Cover

These products are now operational (September 2016)



Snow water equivalent (SWE)



Snow Depth

AMSR2 Validation Results

Snow cover	GAASP
Overall accuracy	81.17 %
Snow detection rate	78.34 %
Commission	1.78 %
Omission	17.05 %
Number of pixels	1504245

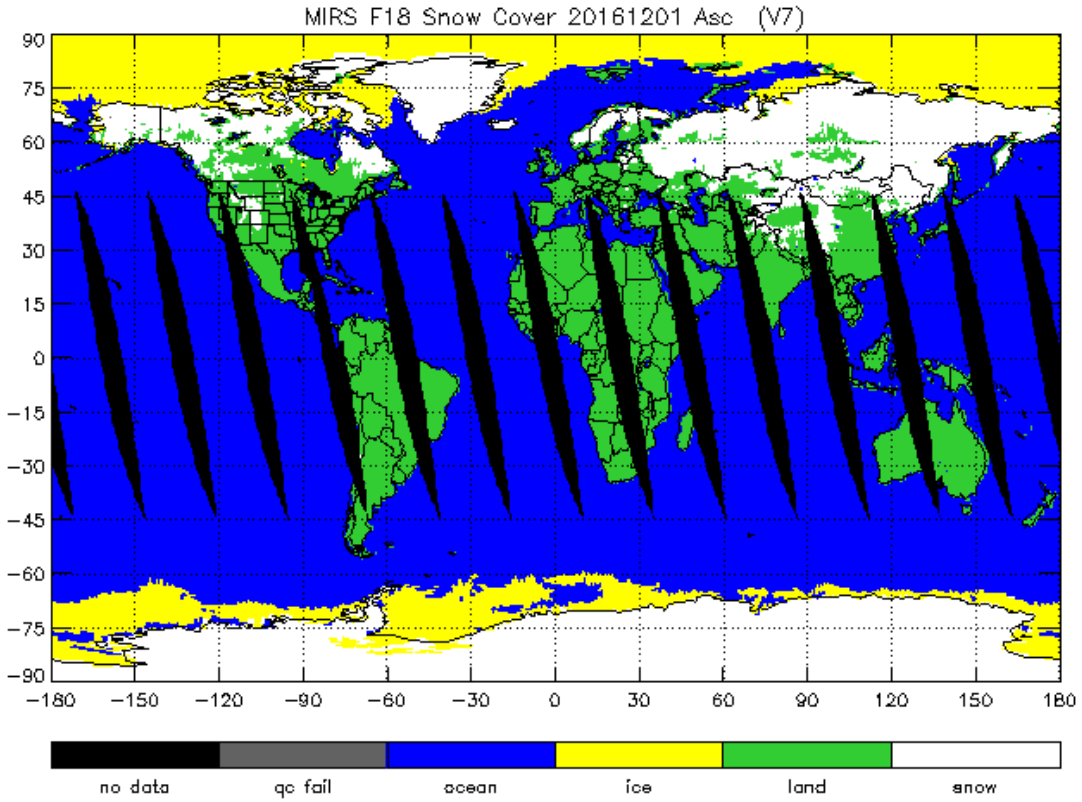
Snow depth	GAASP
bias	-0.50 cm
RMSE	18.7 cm
Number of pixels	2432

SWE	GAASP
bias	-0.22 mm
RMSE	31.35 mm
Number of pixels	26639
Mean (AMSR2)	62.06 mm

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

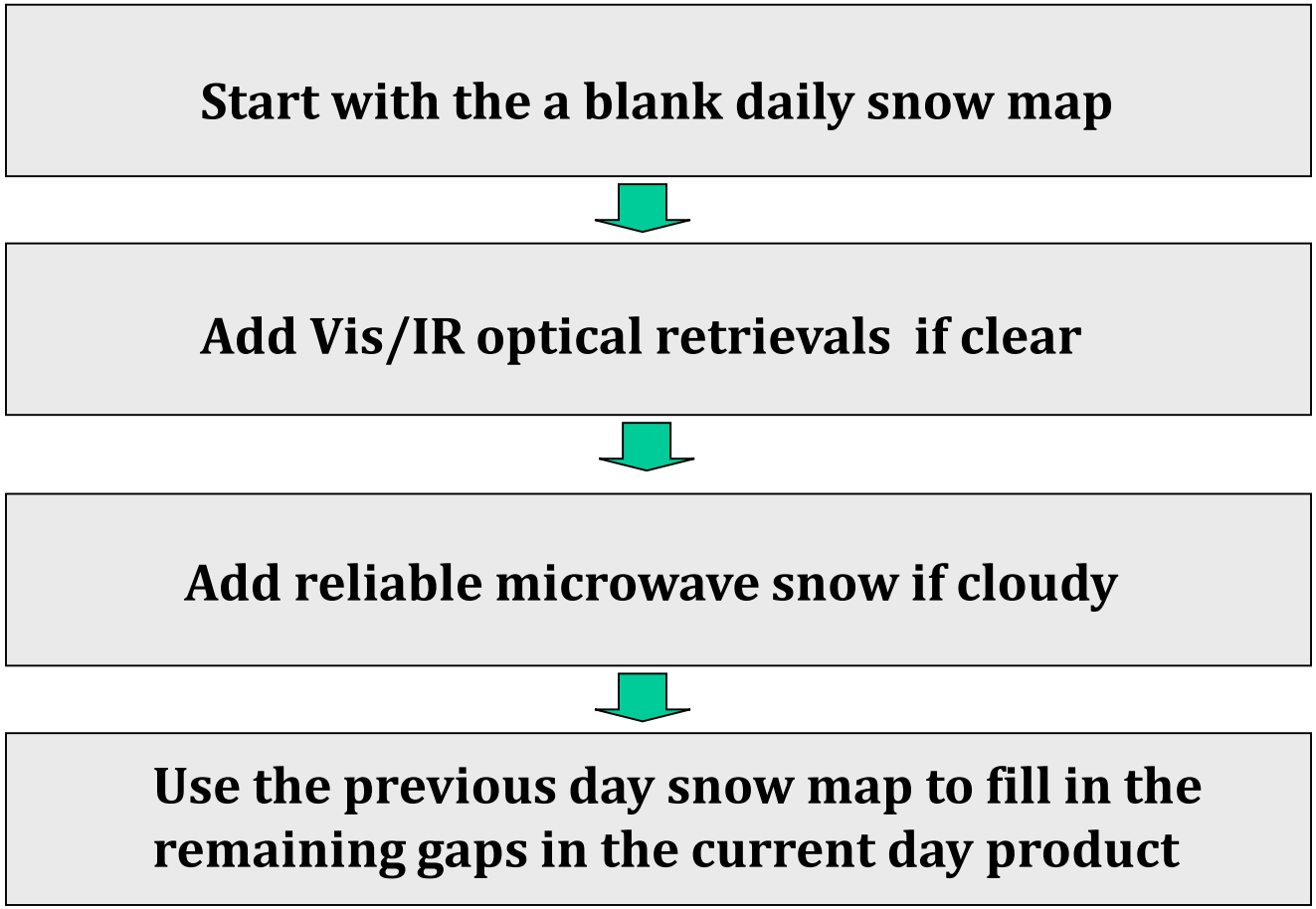
NOAA MSPPS system

4 satellites (4 daily products)

Snow maps are <u>different</u>

Larger difference in spring

Combining Vis/IR and Microwave



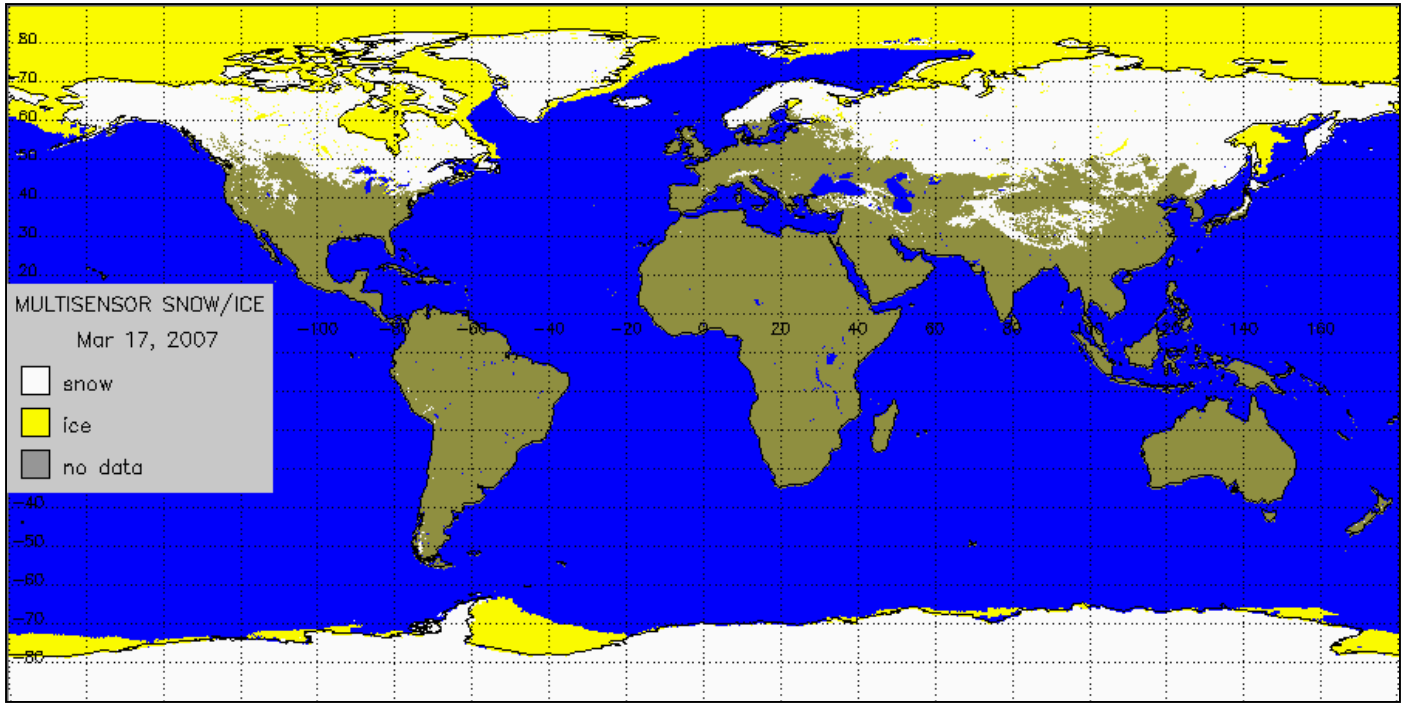
This results in a spatially continuous (gap-free) daily snow map

NOAA Global Multisensor Automated Snow and Ice Mapping System (GMASI)

Daily global continuous snow maps at 4 km spatial resolution

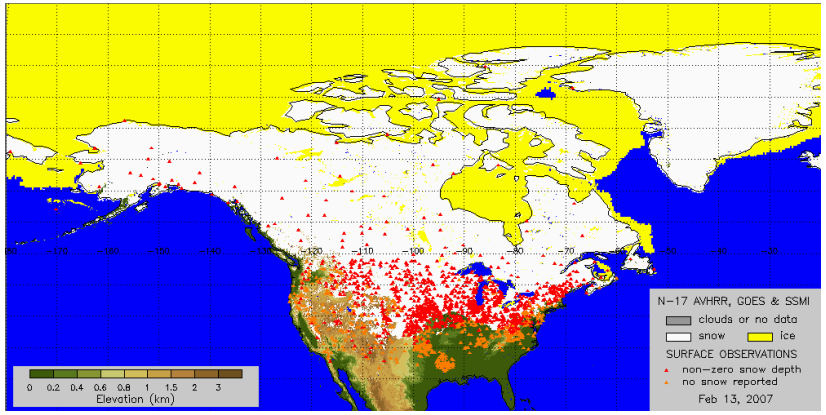
Based on combined AVHRR and SSMIS observations

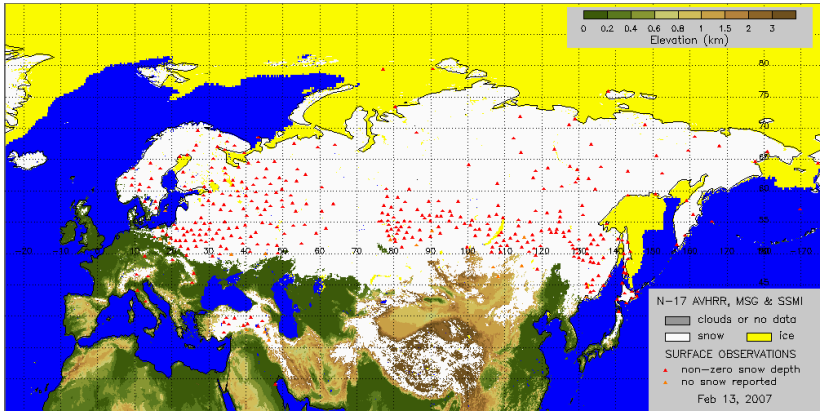
Available since 2006



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

Satellite snow maps vs surface observations





Most global/hemispherical satellite products agree to surface observations of snow in over 90% of comparisons

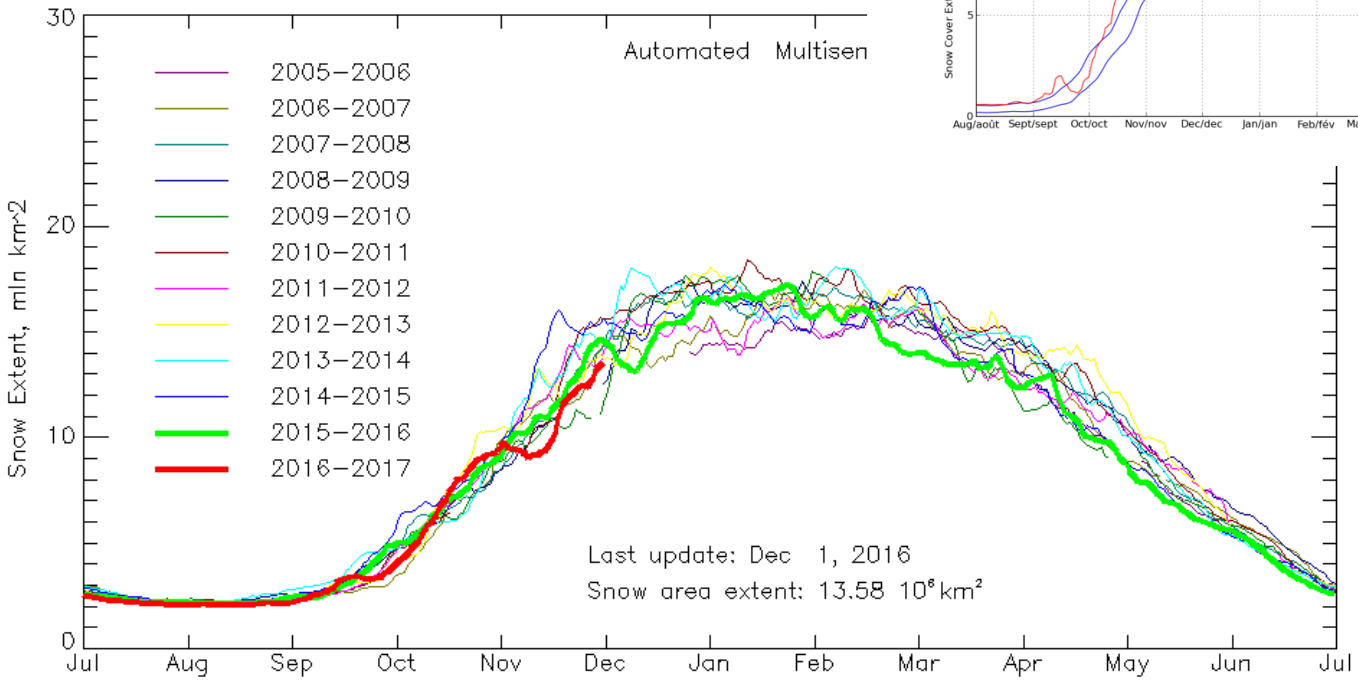
- Vis/IR: 93-98% agreement (but only for cloud-clear scenes)
- Interactive: 90-95%
- Combined: 90-95%
- Microwave: 80-90%

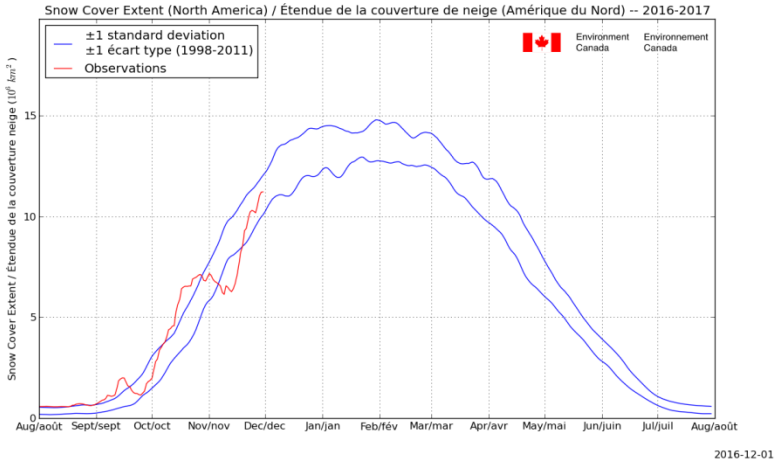
Agreement rates vary with time of the year and location

Most disagreement is in the snow /no-snow transition zone

Contribution to snow climatology

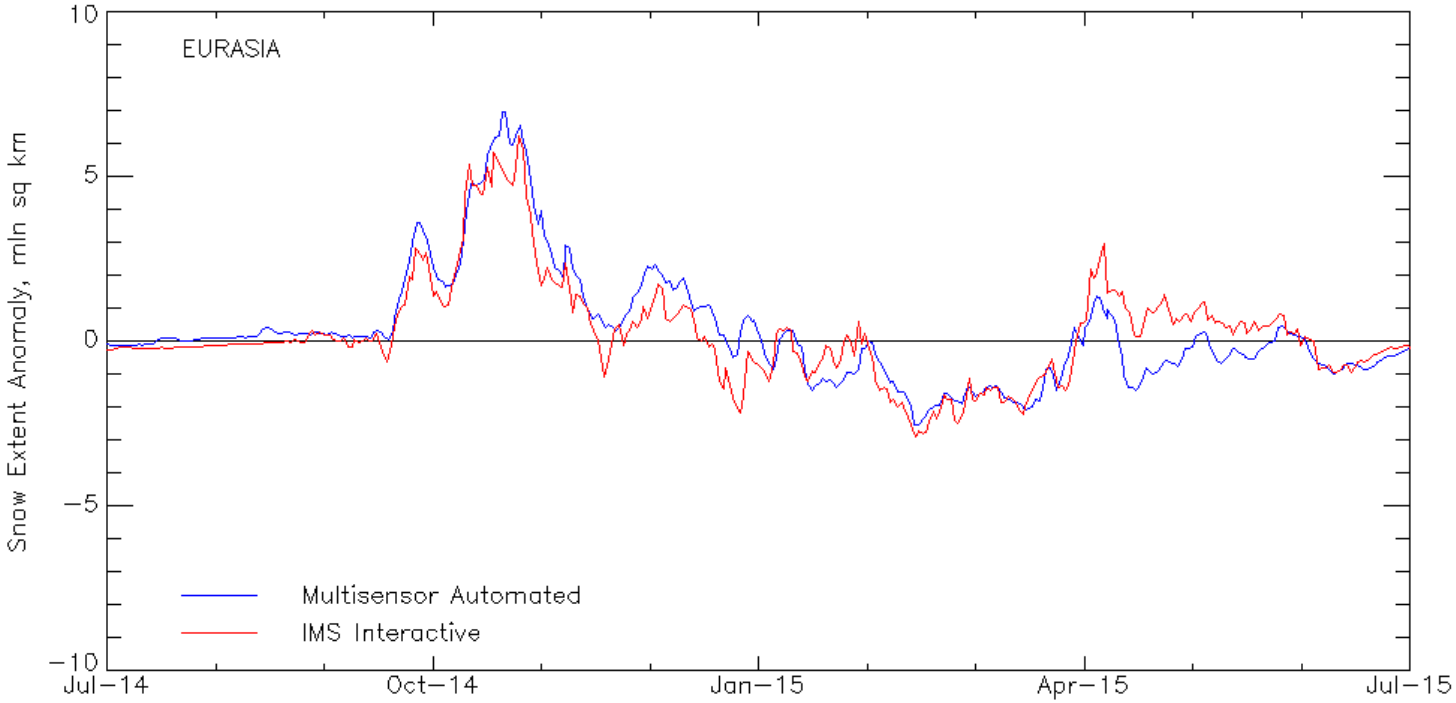
North America daily snow exte





Snow extent daily anomalies

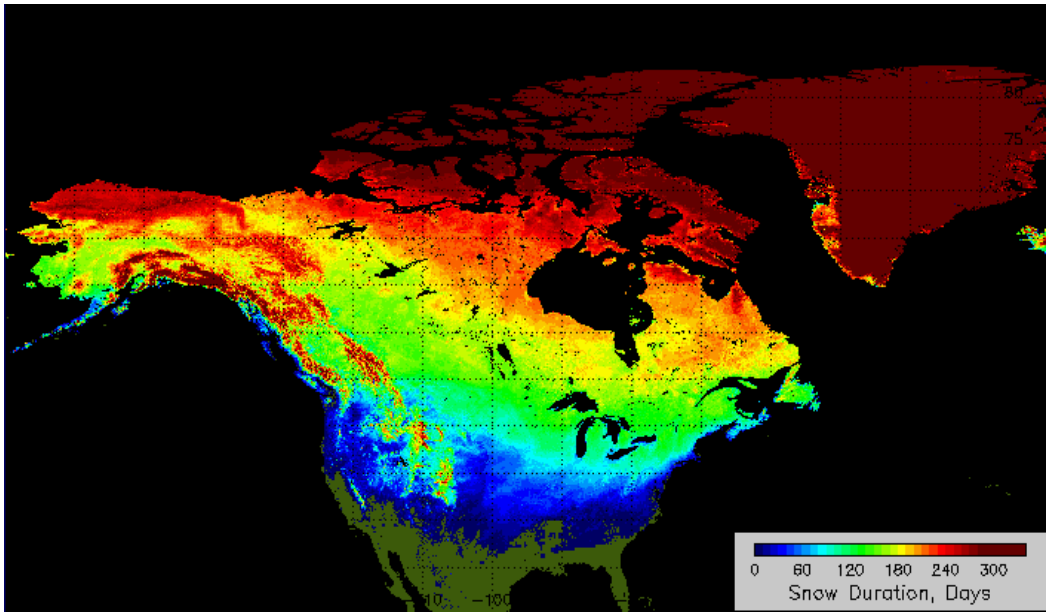
Snow area extent daily anomalies, AutoSnow and IMS



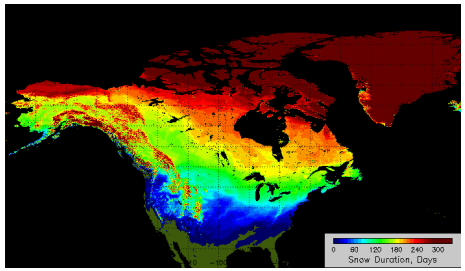
Autosnow vs IMS daily continental snow extent

- **Correlation 0.85-0.89**
- **RMSD 3-4%**

Snow cover duration



Snow Duration 2013-2014, Automated



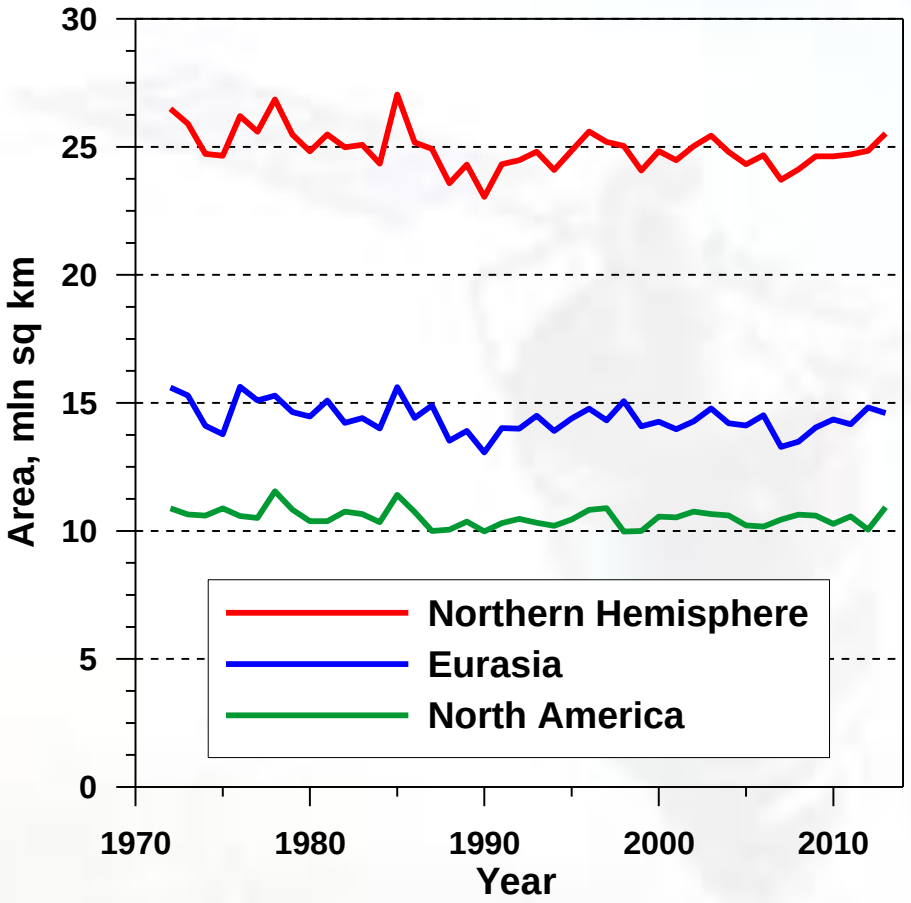
Snow Duration, Interactive

<u>Autosnow vs IMS duration, NH</u>

Mean bias : -1.1 days
Mean abs difference: 11.2 days

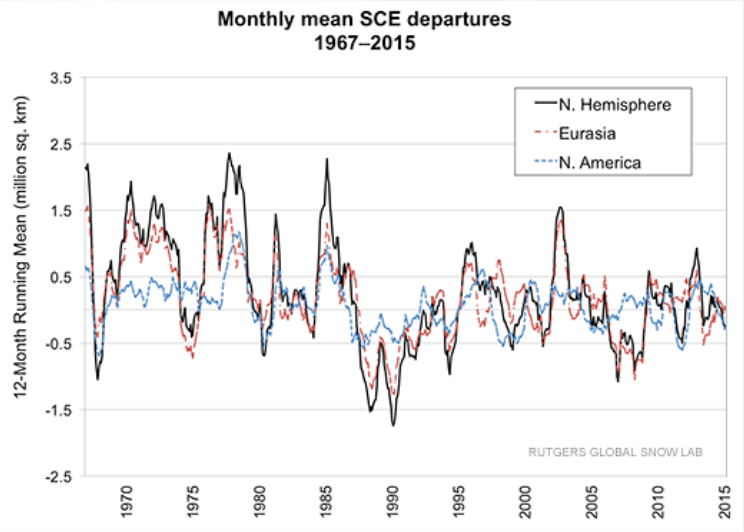
Largest differences are in the mountains

Snow extent change



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

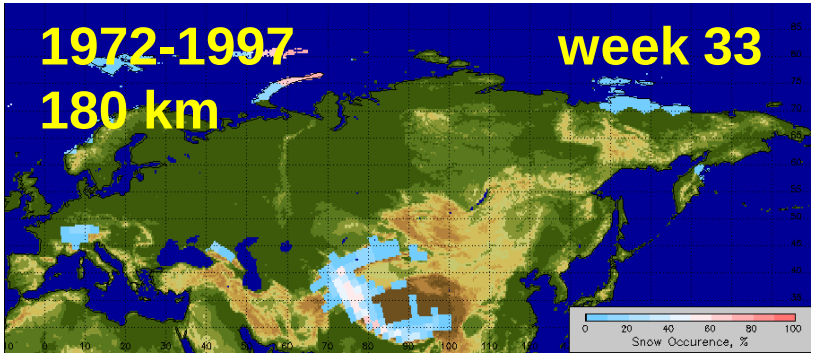
Estimated yearly mean snow extent decrease rate in NH is ~2% per decade since 1970

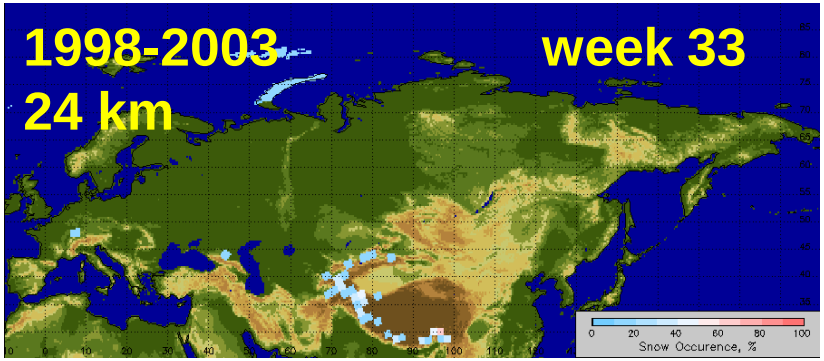


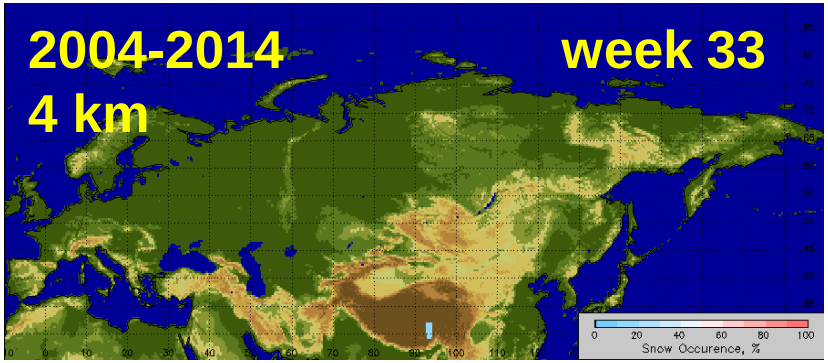
Scaling issue

- 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

Snow occurrence from interactive maps





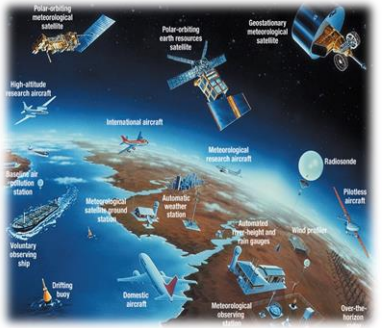


Decrease in the snow occurrence in mountainous areas is mostly spurious

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)



Product	Spatial Resolution	Coverage	Frequency	Notes
VIIRS snow cover and snow fraction	375 m	Global	Every orbit	
AMSR2 snow cover, snow depth, SWE	10 km	Global	Every orbit	All-sky
GOES-R ABI snow fraction	2 km	Western Hemisphere	Hourly	Not yet available
GMASI	4 km	Global	Daily	Multisensor, all-sky
IMS	1-180 km	NH	Twice daily to weekly	Interactive, multisensor
MIRS	50 km	Global	Daily	All-sky

GCW Snow Product Assessment and Inventory

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

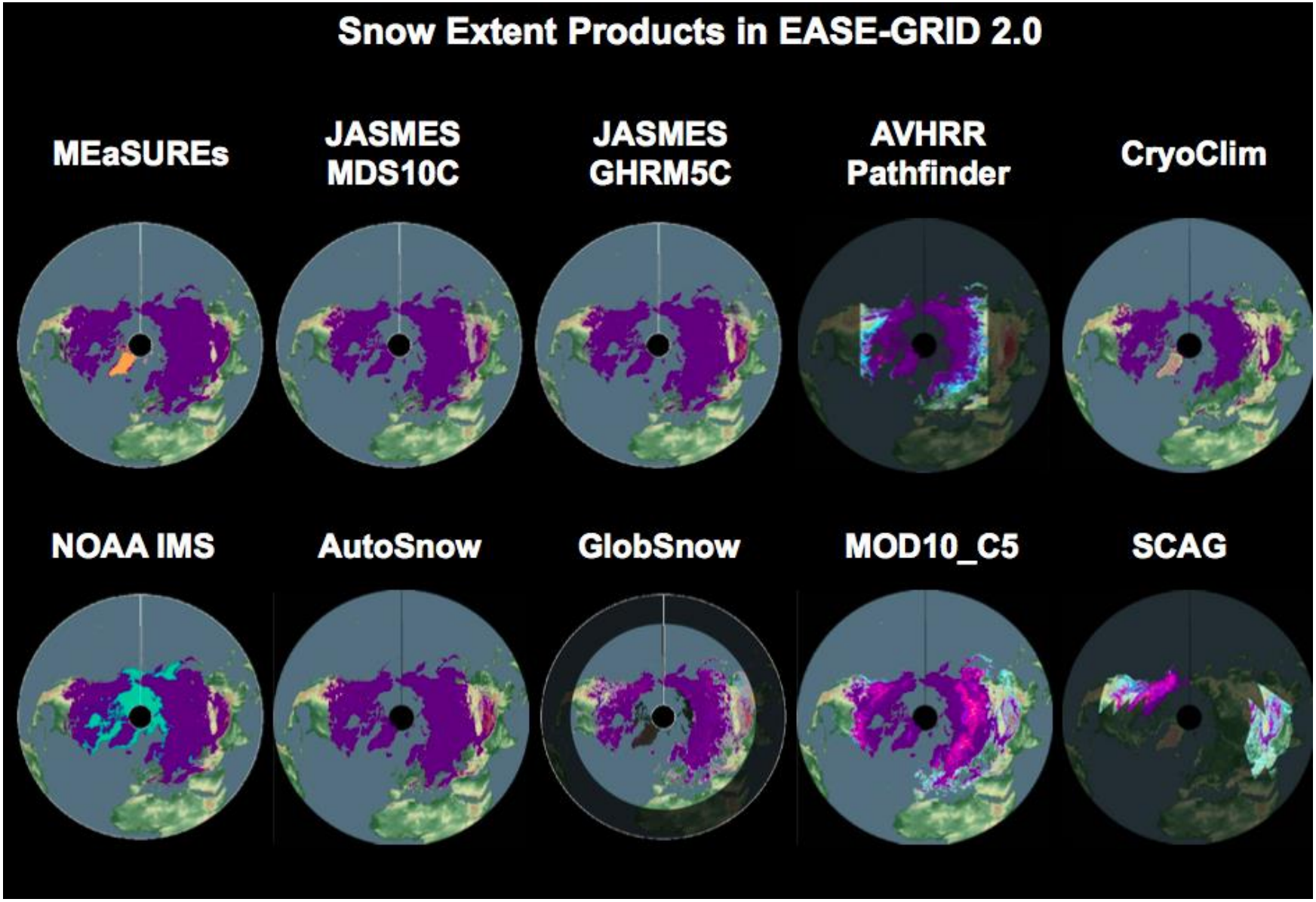
18 satellite-derived, 22 in situ, and 20 analysis/reanalysis

globalcryospherewatch.org

SnowPEx – Snow Extent Products

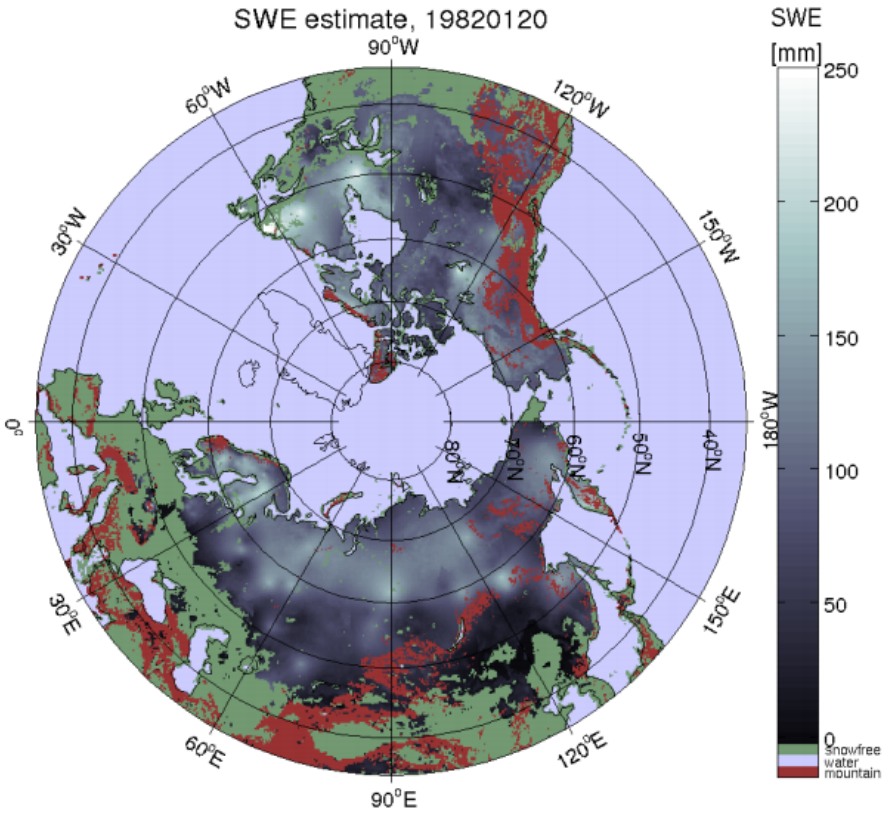
SnowPEx PROD. ID	Product Name	Thematic Parameter	Frequency	Period	Pixel Sp.	Contact
ASNOW	Autosnow	Binary, Global	daily	2006 – present	4 km	P. Romanov / NESDIS
CRCLIM	CryoClim	Binary, Global	daily	1982 – present	5km	R. Solberg / NR
CRYOL	CryoLand	Fractional, PanEU	daily	2000 – present	0.5 km	T. Nagler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

SnowPEx – Snow Extent Products

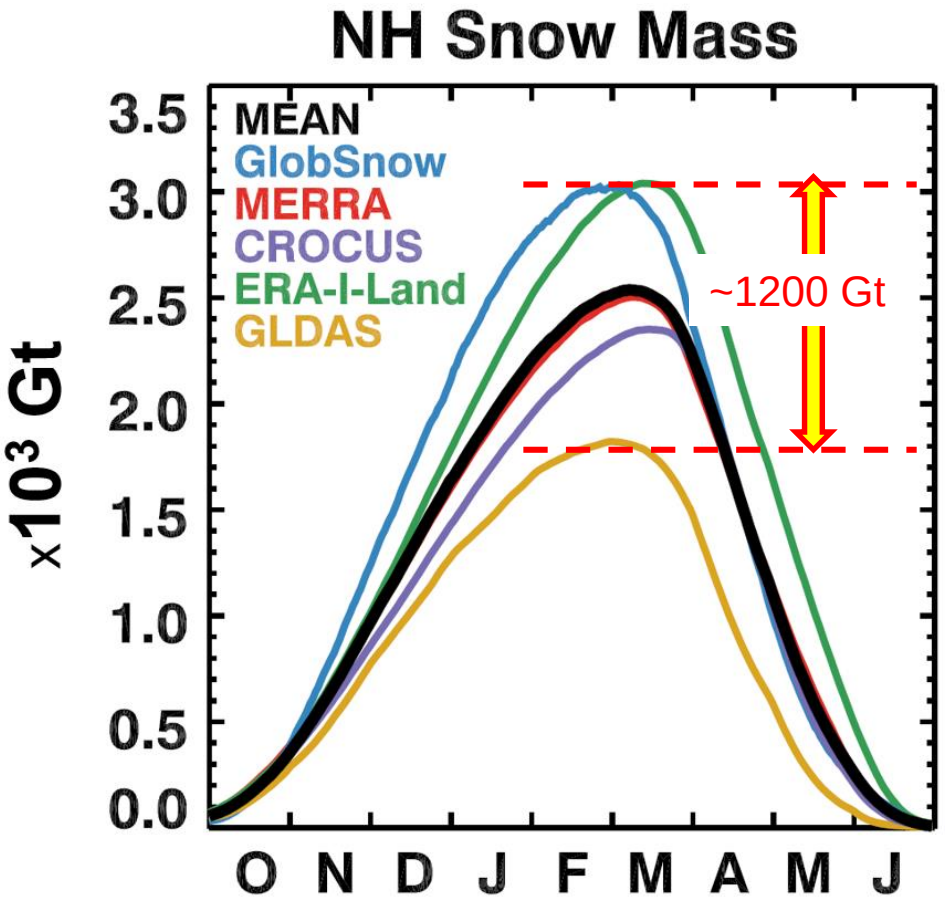


Uncertainty in NH Seasonal Snow Mass

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



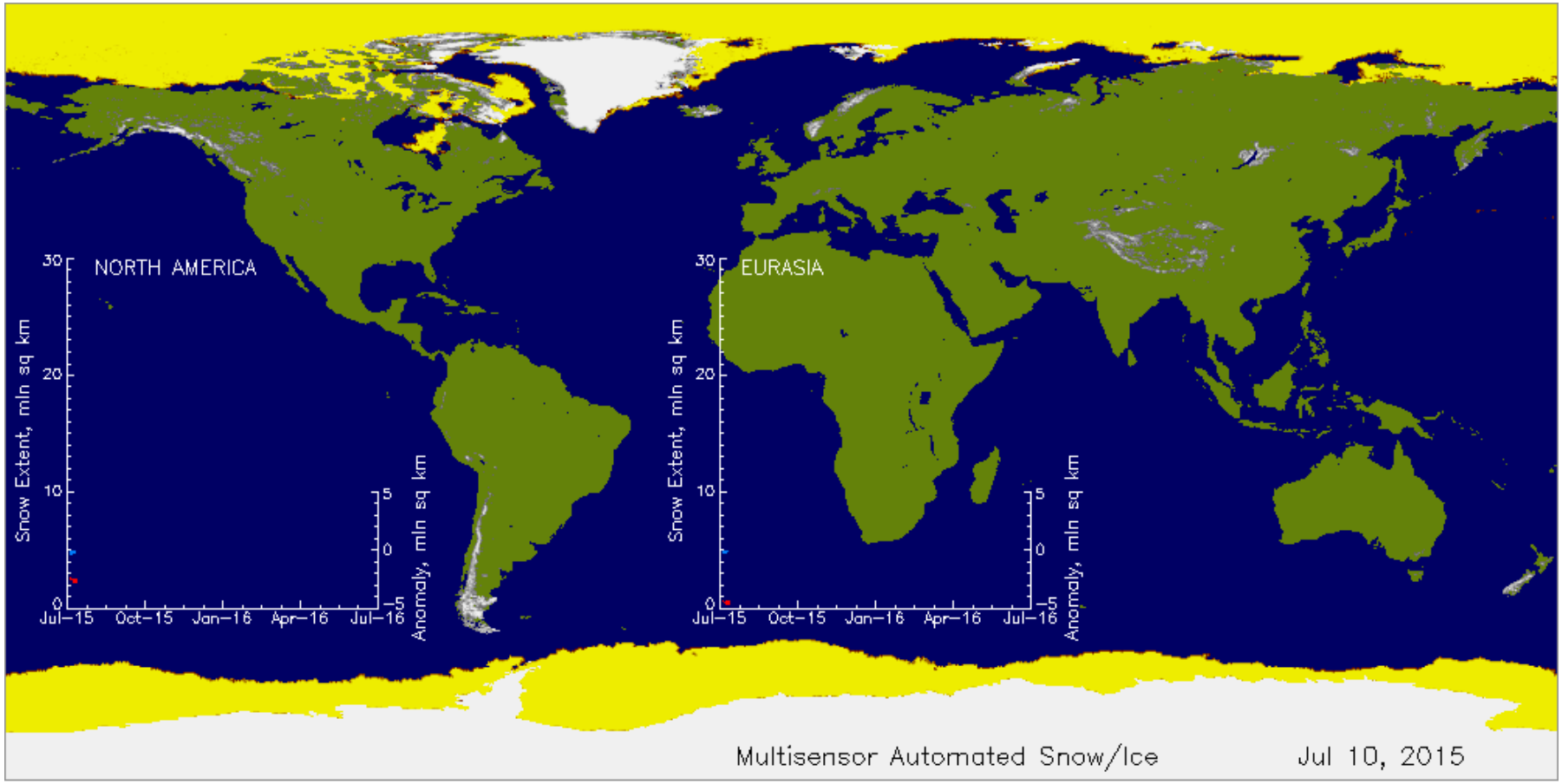
"Satellite-based" GlobSnow SWE estimate



Models vs. satellite-based data

Final notes

- 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


NORTH AMERICA
Snow Extent, mln sq km
30
20
10
0
Jul–15
Oct–15
Jan–16
Apr–16
Jul–16
Anomaly, mln sq km
5
0
−5
EURASIA
Snow Extent, mln sq km
30
20
10
0
Jul–15
Oct–15
Jan–16
Apr–16
Jul–16
Anomaly, mln sq km
5
0
−5
Multisensor Automated Snow/Ice
Jul 10, 2015


0
20
40
60
80
100
Snow Area Fraction, %


0
20
40
60
80
100
Ice Area Fraction, %