# A Summary of NOAA Satellite-Derived Snow Products

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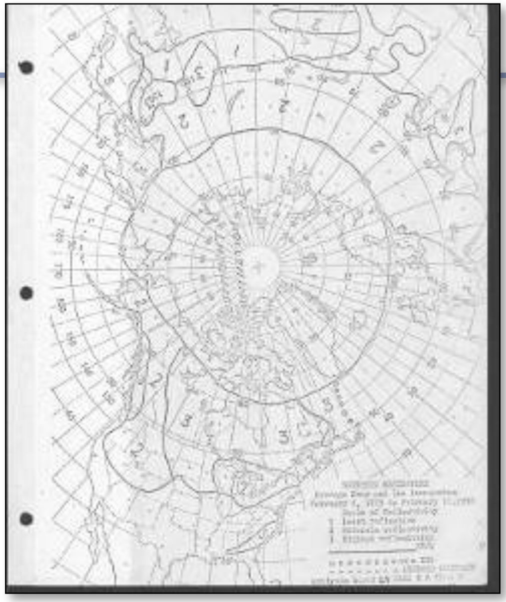
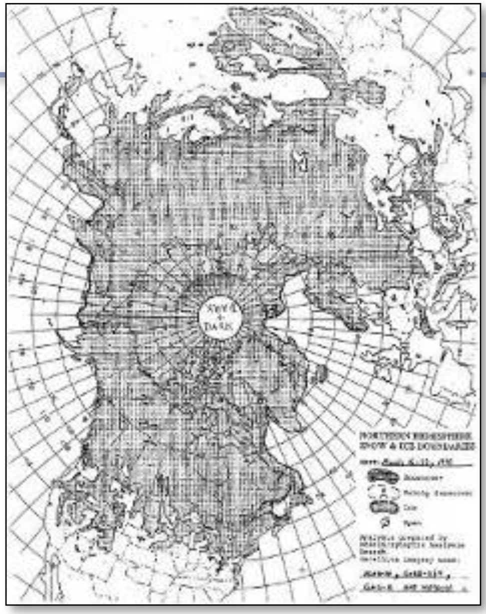
# OUTLINE

- **Historic Product Overview**
- **Current Product Suite**
  - **IMS (v3) & AutoSnowIce**
  - **VIIRS Binary & Fractional Snow Cover**
  - **ATMS MIRS Snow Products**
- **Emergent NOAA Snow Products**

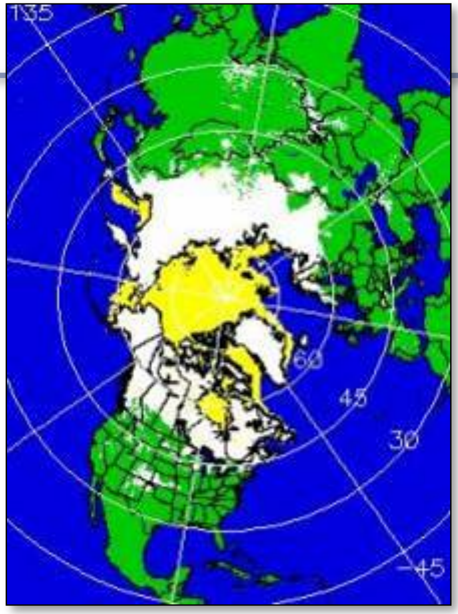
# Historical NOAA Snow Products



1973



1998



2007

| Nov 1966 | Oct 1972 | May 1975 | 1980-81 | | | 1990s May 1999 |
|---|---|---|---|---|---|---|

ESSA, NOAA, GOES Series

Weekly 190 km digitized

METEOSAT & GMS added

Reanalysis of 1966-71

| Feb 1997 | Feb 2004 |
|---|---|

Interactive Multisensor Snow & Ice Mapping System

IMS 24 km

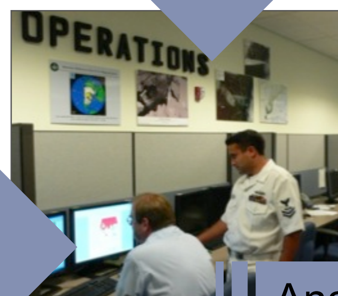
IMS 4 km

# Interactive Multisensor Snow and Ice Mapping System (IMS) Production

**Satellites**

GOES (E & W)
MeteoSat (MSG & 7)
MTSAT
NOAA Automated Snow & Ice
AVHRR (Channels 1 & 3)
MODIS (Channel 8)
ASCAT
AMSU (Derived snow, ice, rain)

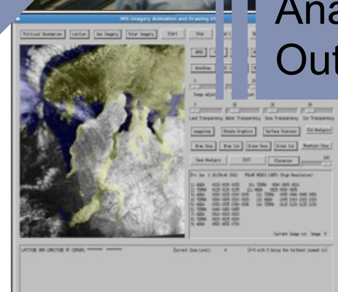
Pre-Processing




**Other Sources**

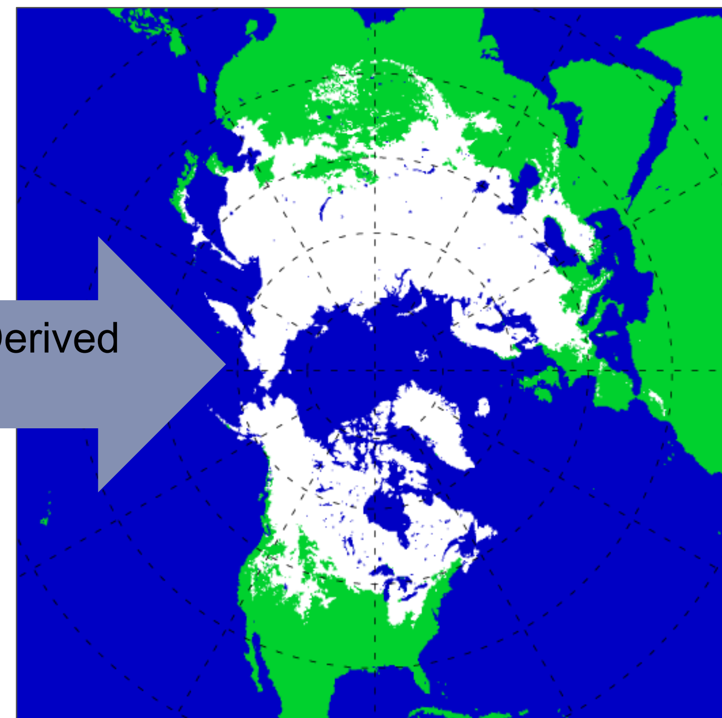
Radar
Models
Surface Observations
Webcams
Buoys
Charts

Indirect Sources

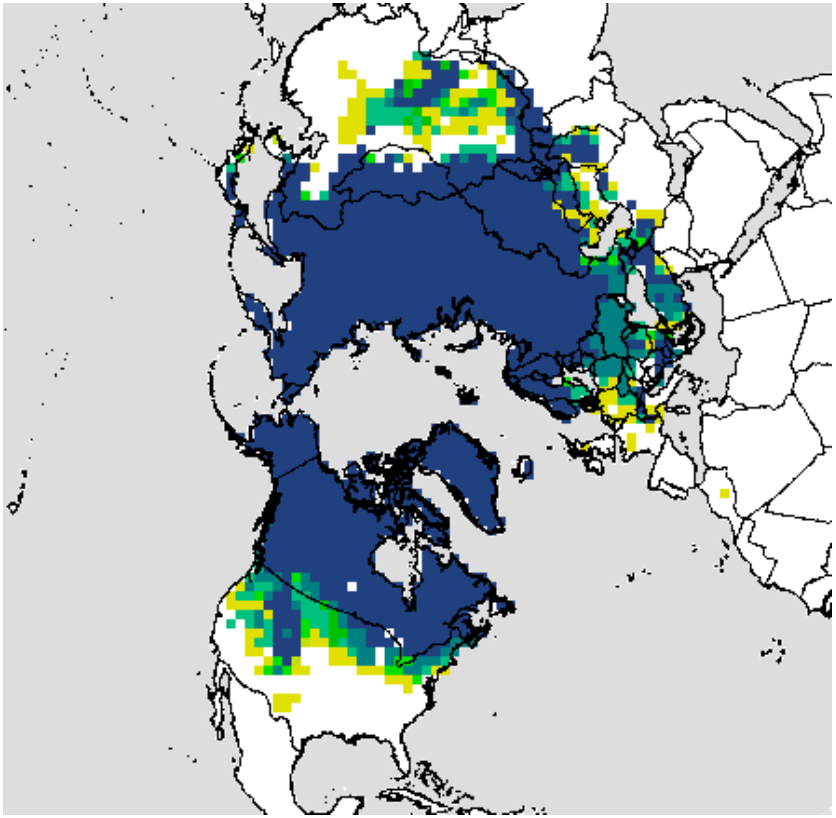


Analyst Derived Output

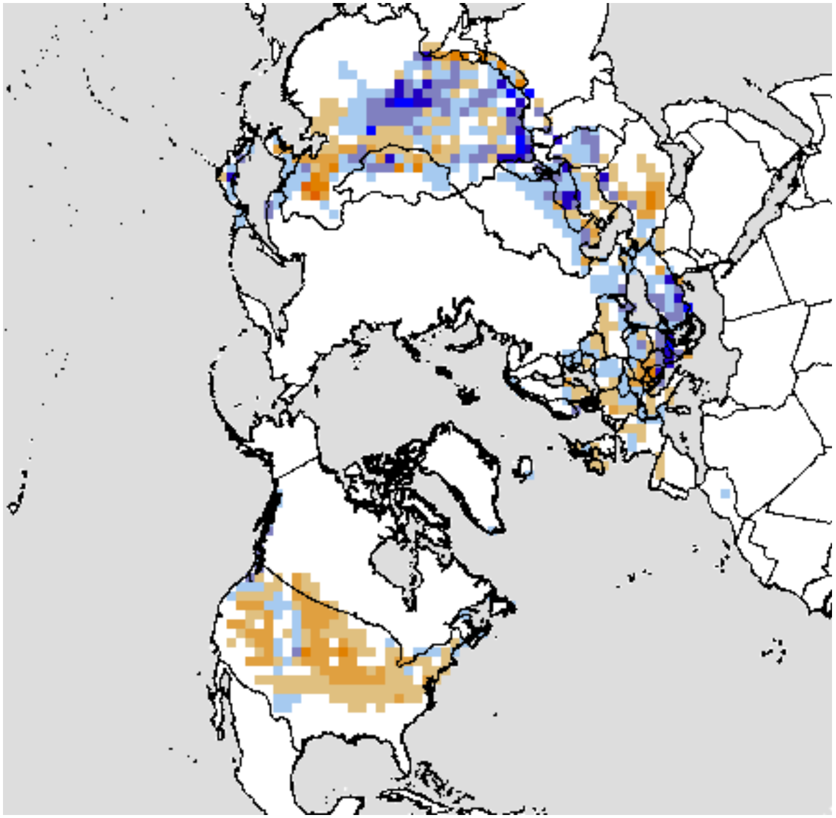
- 4 km & 24 km Northern Hemisphere Analysis
- Snow & Ice Cover
- Produced daily at U.S. National Ice Center



# N. Hem. Snow Cover
# Jan 2012



Extent

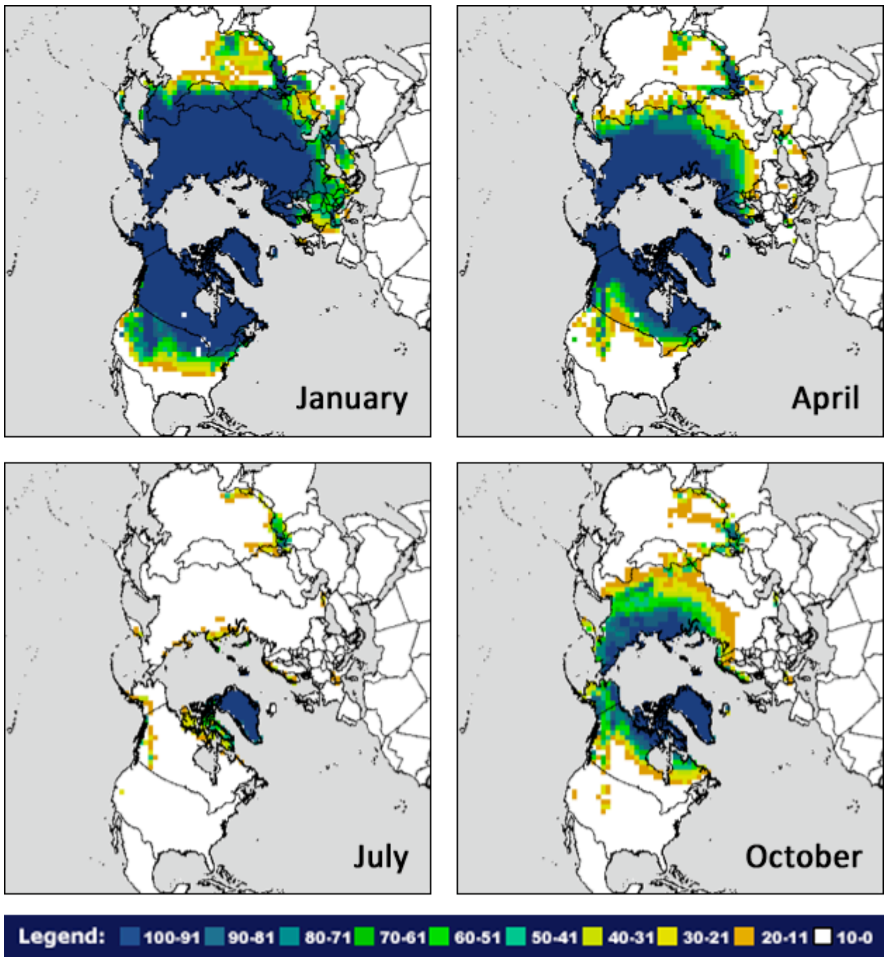


Departure
(blue: positive; tan: negative)

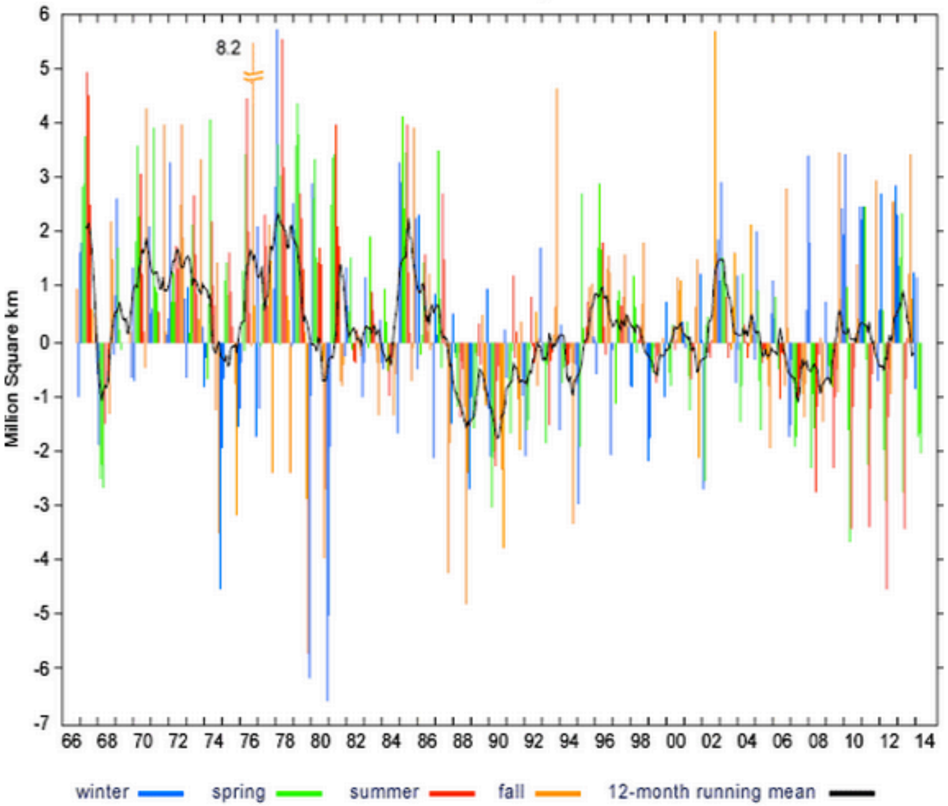
Rutgers Global Snow Lab data based on NOAA snow maps

# N. Hem. Snow Cover History

## Climatology Maps

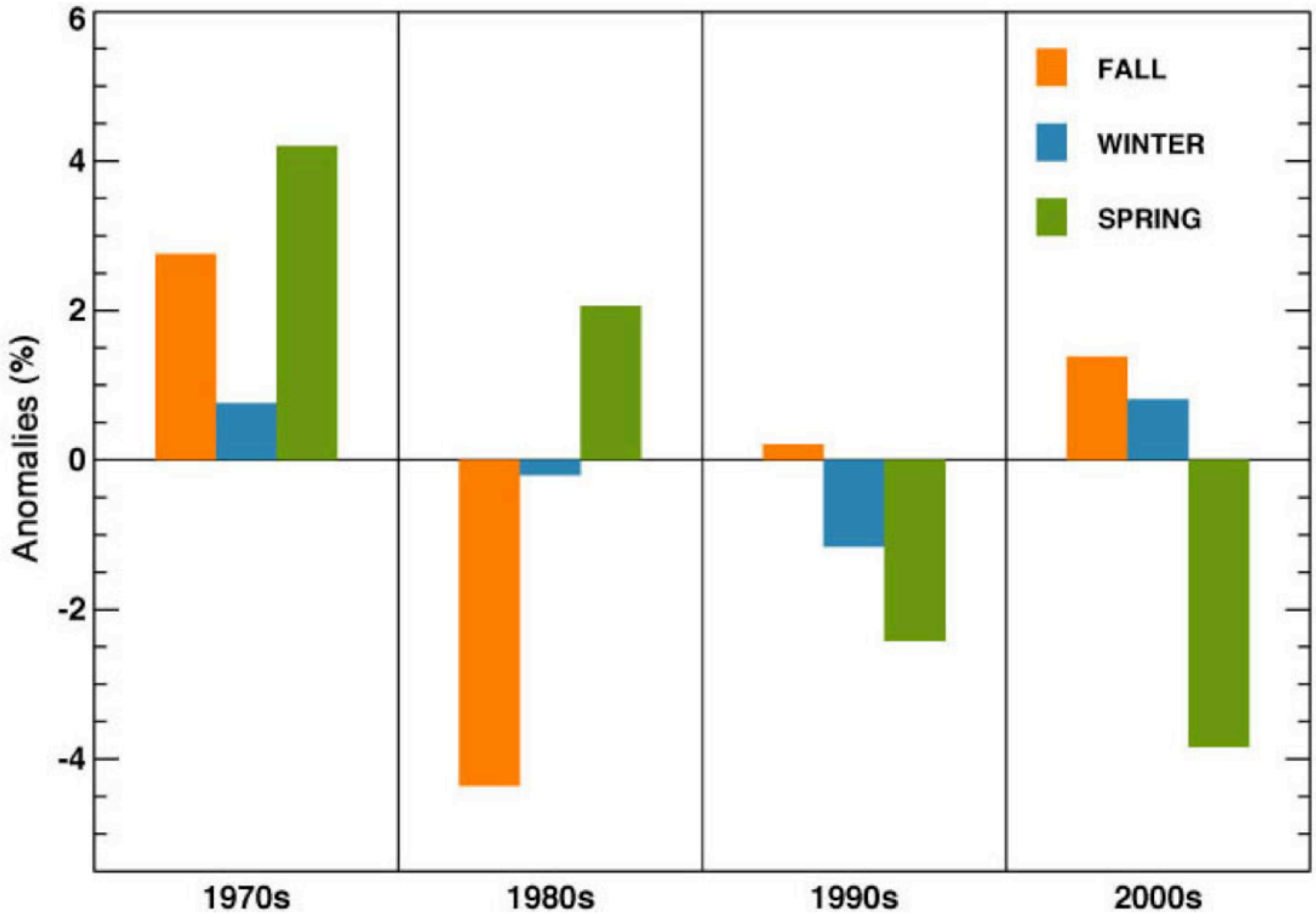



## Time Series



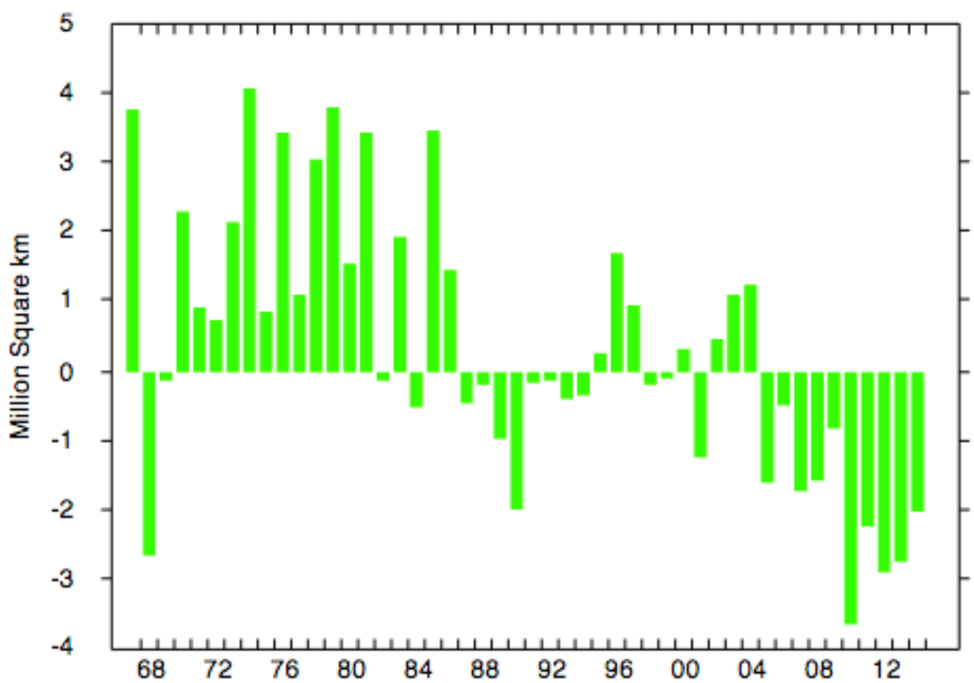

Rutgers Global Snow Lab data based on NOAA snow maps

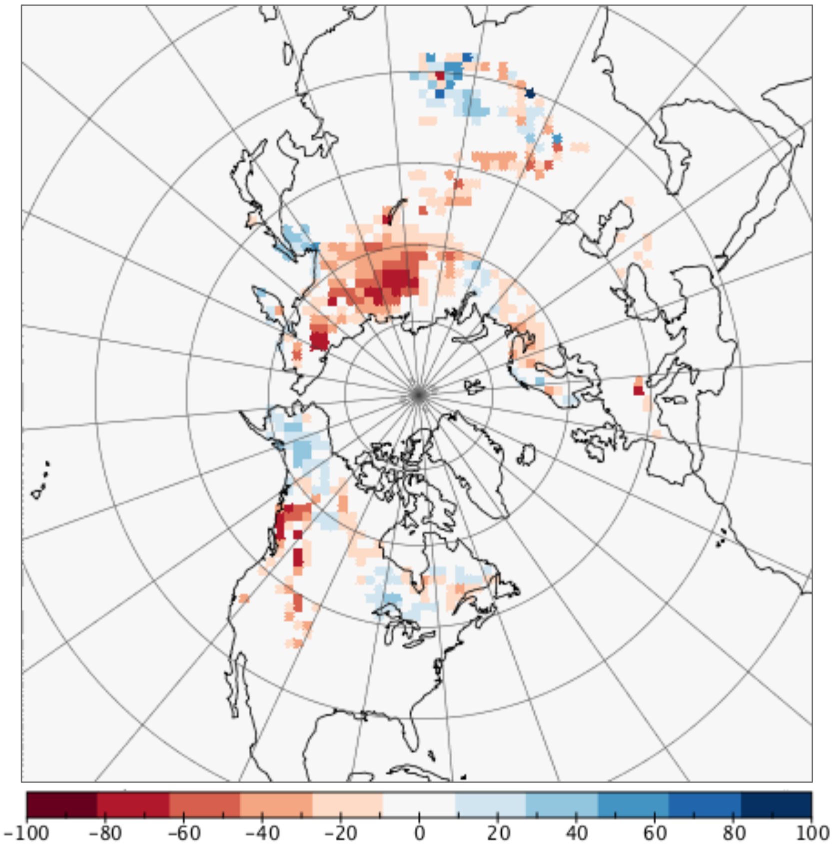
# NH Seasonal SCE Decadal Anomalies




Rutgers Global Snow Lab data based on NOAA snow maps

# May NH SCE Anomalies: 1967-2014




May 2013 Departure
from 1981-2010 Mean

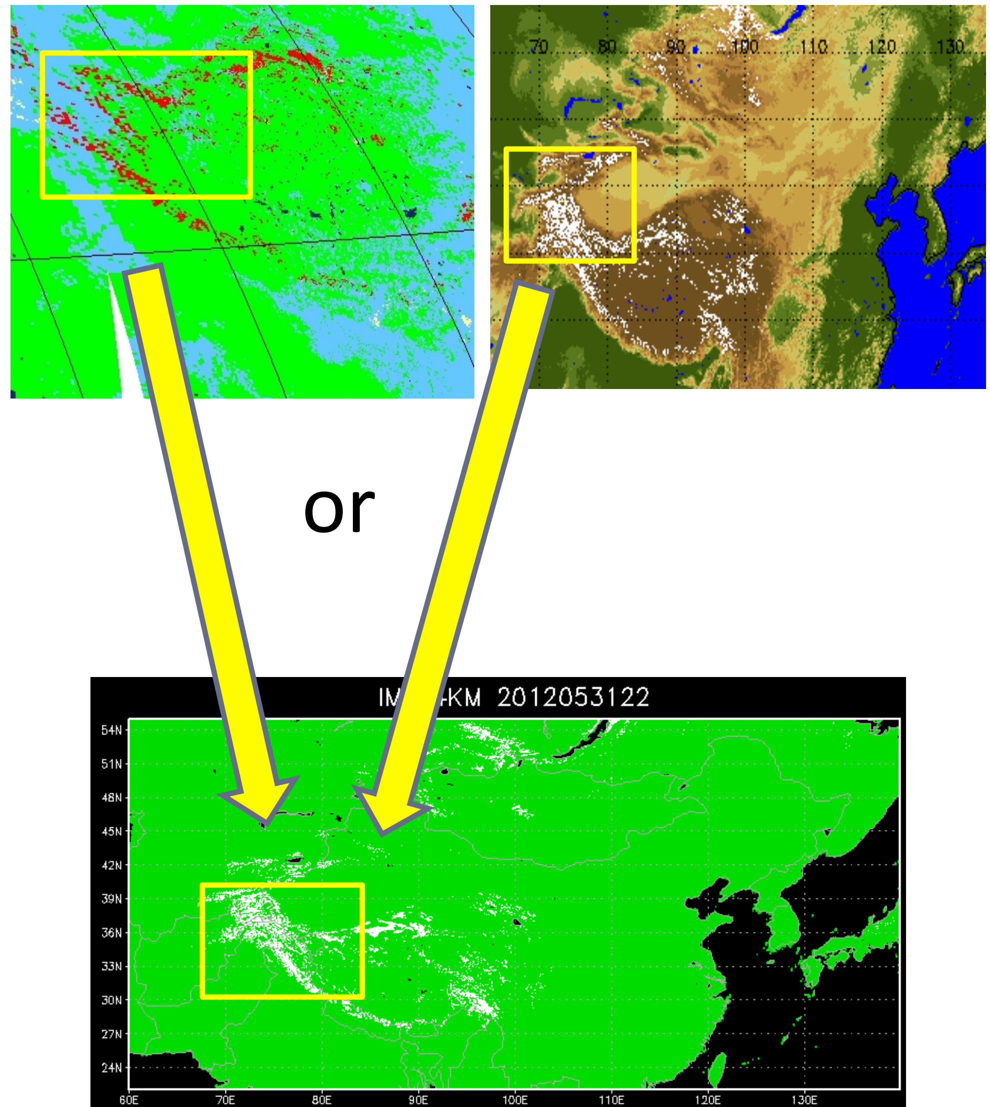
# IMS Version 3 Capacities – August 2014

- 1, 4, & 24km Northern Hemisphere Analysis
- Snow & Ice Cover
- ASCII, BIN, GeoTiff, Grib2
- 2x day production
- Improved MetaData
- Automated 2km Southern Hemisphere Analysis
- Date since last confirmed observation
- Snow Depth (with uncertainty values)
- Sea Ice Thickness (with uncertainty values)
- VIIRS, SAR, MODELS, More Surface obs,
- Ability to import derived data sources
- Same underlying Snow & Ice cover resample algorithms - *Vital to keeping consistent record*

Legacy Version 2 New to Version 3

# Direct Import of Automated Snow & Ice Cover

- **Analysts will be able to selectively import the data from satellite derived products directly into the IMS analysis**
- **Analysis will have selection box to select snow cover and ice cover from the VIIRS, NOHRSC, and NH AutoSnowIce.**
- **Human data selection to optimize product use based on expert knowledge and imagery interpretation**
- **Combines the speed and reliability of automated products with the QC and flexibility of Human Analysts**

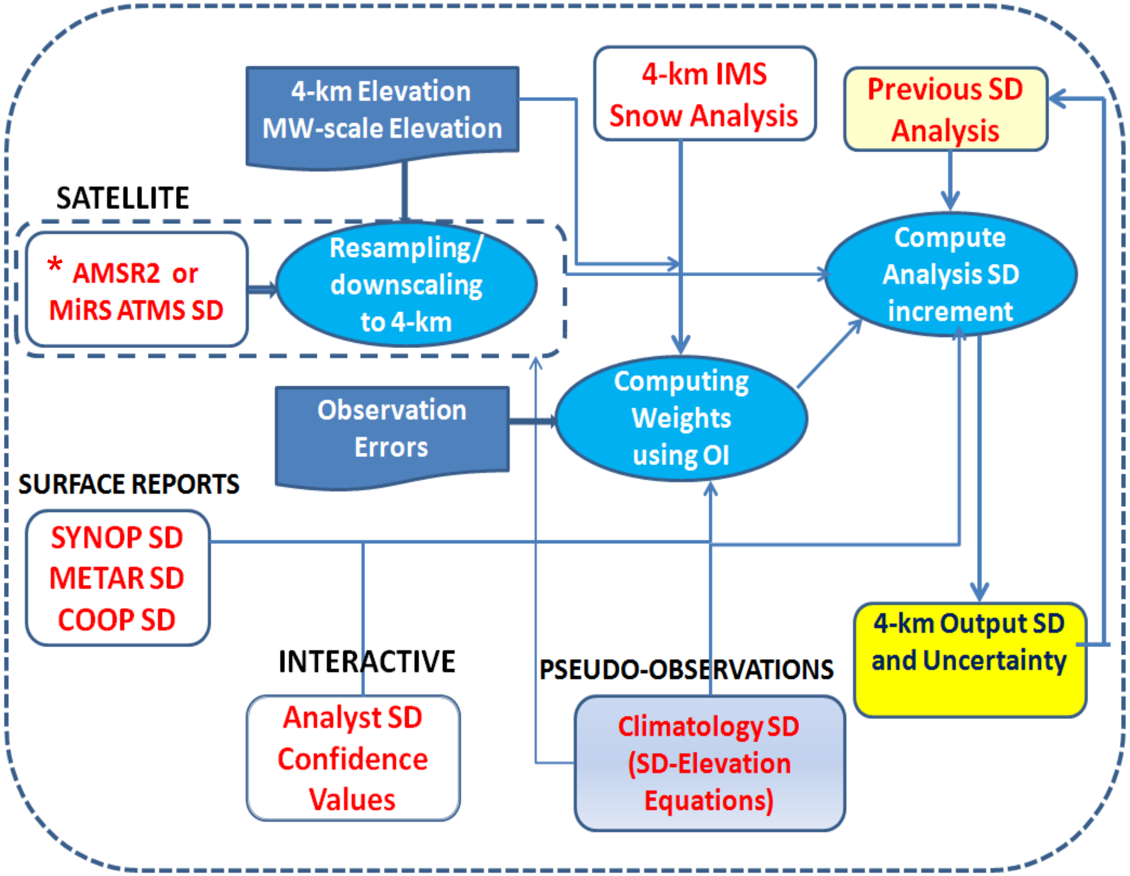



*Imagery Source: JCDAS*

# IMS Blended Snow Depth

**Key features**:

- 2-D OI Analysis integrated into IMS V3
- Multi-Source Scheme: MW+in-situ + Climatology + Analyst Updates
- IMS Analyst SD and Uncertainty estimates are also ingested into OI as independent data stream
- MW Downscaling based on elevation
- Applies previous day as initial guess

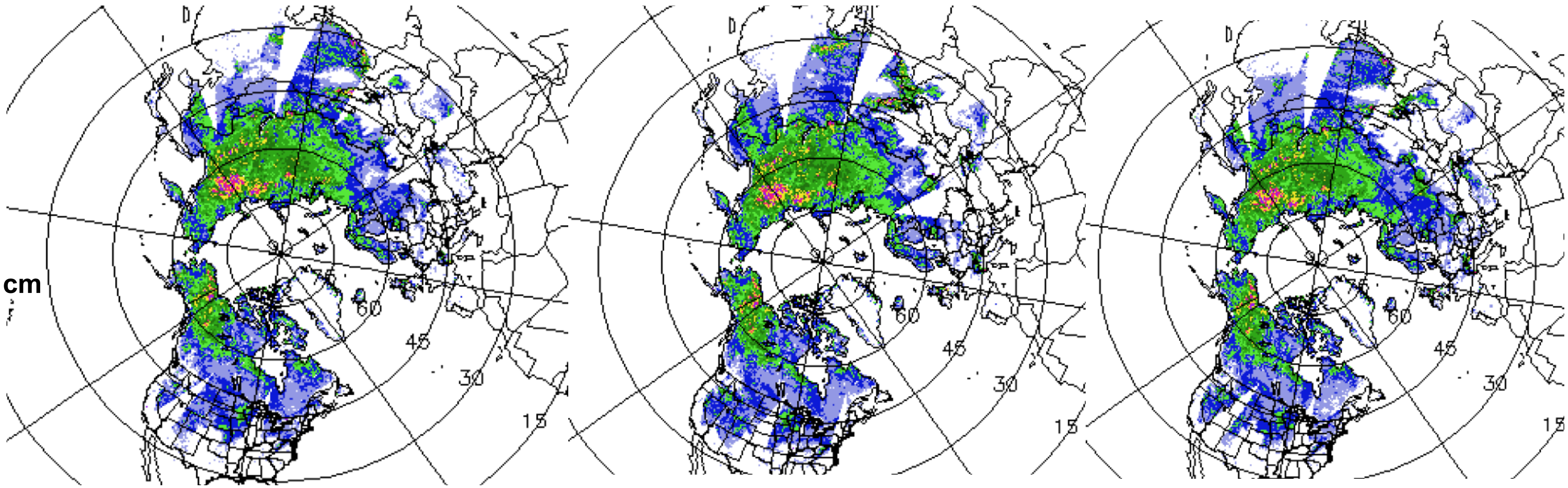


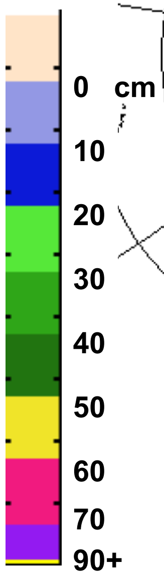

** NOAA's Global Change Observation Mission (GCOM) AMSR2 SD is first option and expected to go operational this year*

***Acknowledgement: Cezar Kongoli (NOAA CICS)***

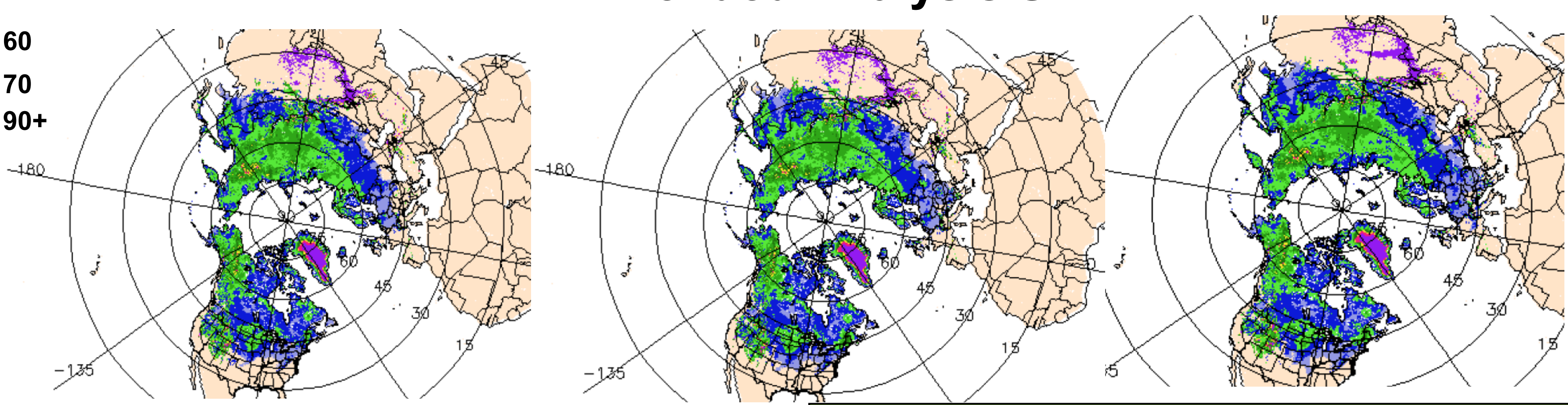
# IMS Blended Snow Depth

**NASA AMSRE-SD**




**Blended Analysis SD**



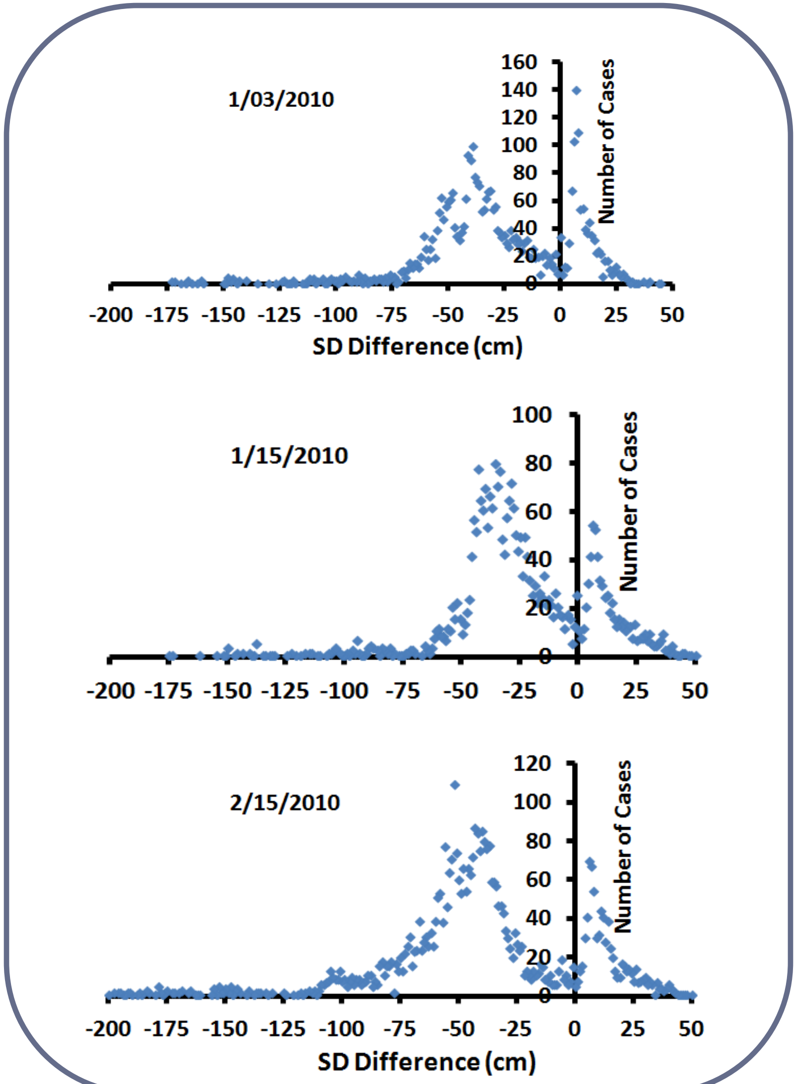

*Acknowledgement: Cezar Kongoli (NOAA CICS)*

# IMS Blended SD Evaluation

- In Jan 2010, SD Analysis within 20 cm of the GHCN-Daily measurements 86.9% in snow covered areas, while in Feb 2010 within 20 cm 85.1% of the time. This is a very good overall result considering large SD variability, 4-km res. and inclusion of high elevation areas.

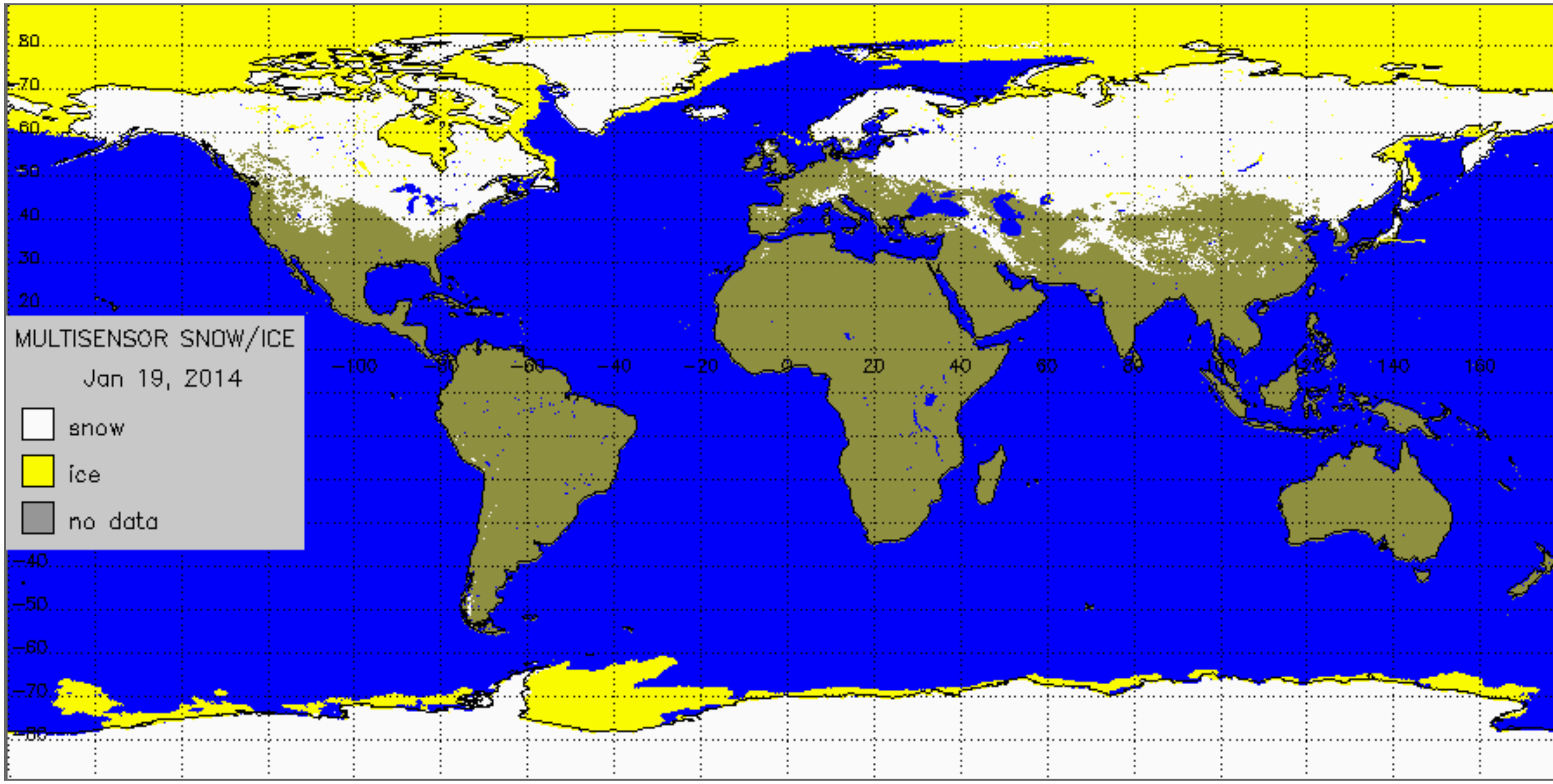
- *Bi-modal distribution of errors – low bias/RMSE in low-elevation areas (4/7cm) and larger bias/RMSE in high elevation areas (35 cm/45 cm)*

- *RMSE still reasonable over high elevation terrain considering large SD values*




***Acknowledgement: Cezar Kongoli (NOAA CICS)***

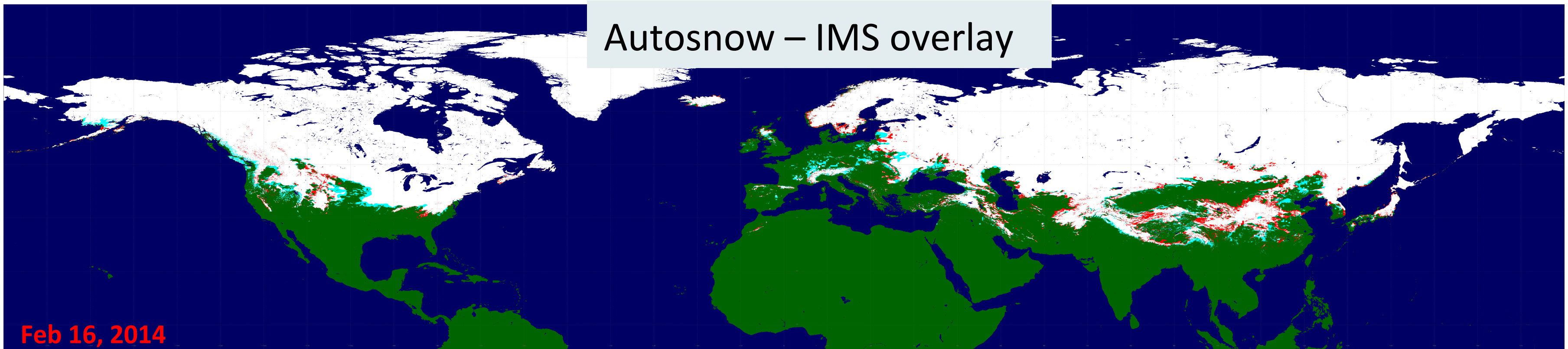
# Global AutoSnowIce Products



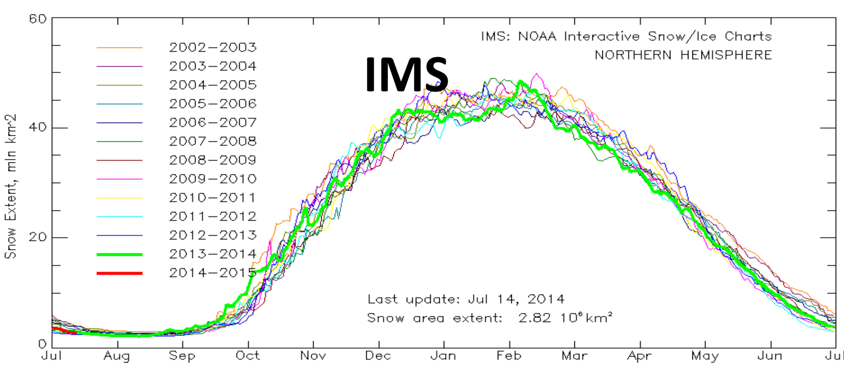

- Automated algorithm
- Multiple satellite sensor data used (optical and microwave)
- Global continuous (gap-free) coverage
- Operational since 2006

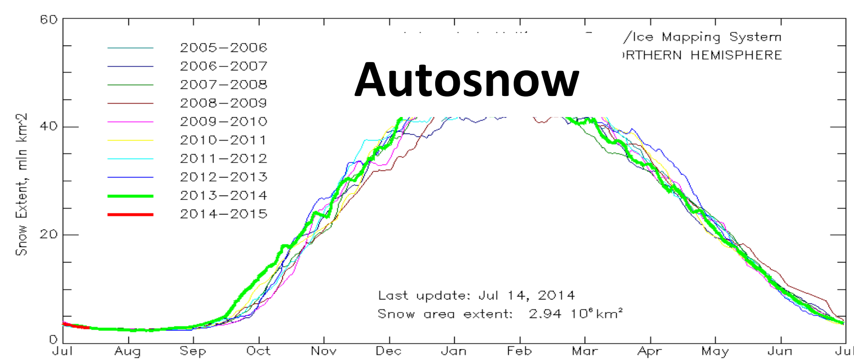
*On the Web: http://www.star.nesdis.noaa.gov/smcd/emb/snow/HTML/multisensor_global_snow_ice.html*

# IMS vs AutoSnow: Snow Covered Area




IMS: snow, Autosnow: land    IMS : land , AutoSnow: snow

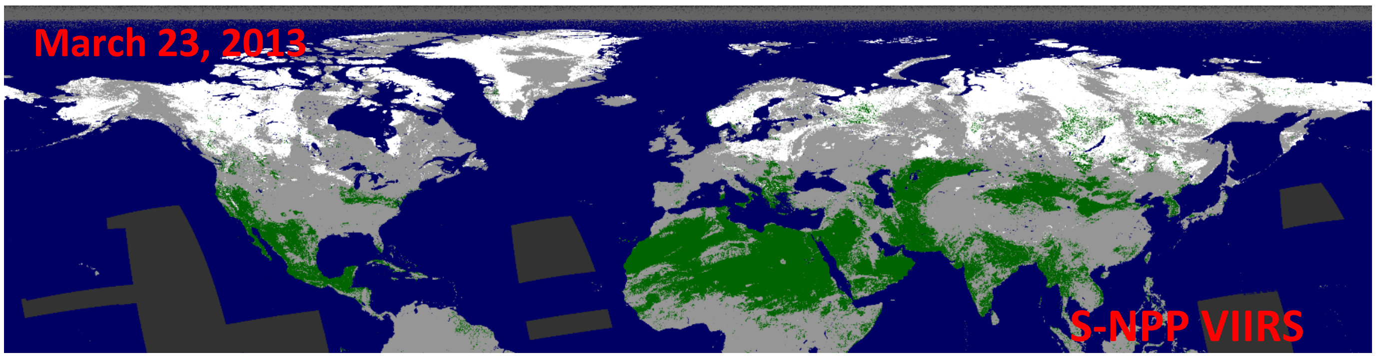


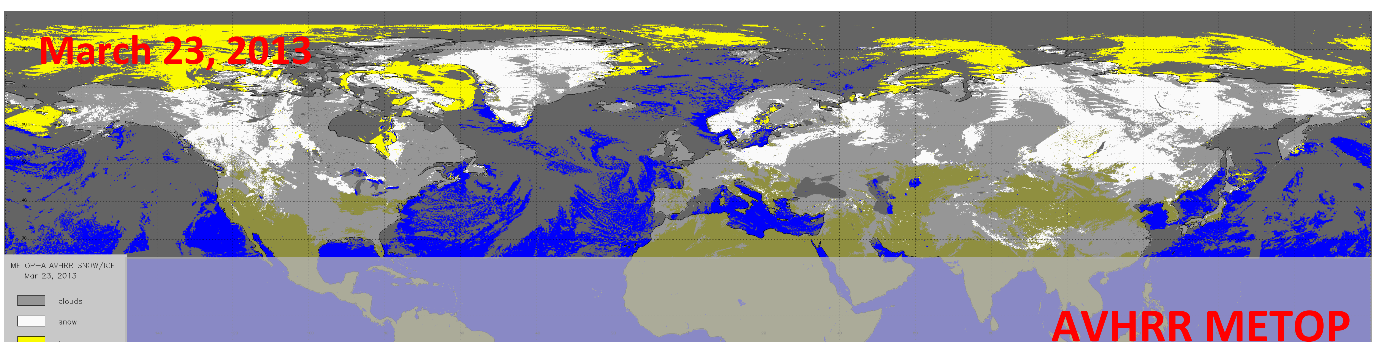

- Over 95% yearly average rate of agreement on the continental-scale binary snow extent
- Most differences are in the mountain regions and occur at the time of fast changes in the snow extent
- IMS has higher daily variability

# VIIRS Binary Snow Cover

***Description:*** Snow Cover is defined to be the horizontal and vertical extent of snow cover. The binary product gives a snow/no-snow flag.




snow land cloud No data



# VIIRS, AVHRR, MODIS Snow vs IMS

Mean agreement to IMS and cloud-clear fraction of daily automated snow products in 2013 Northern Hemisphere

| | *Agreement to IMS (%)* | *Cloud-clear(%)** |
|---|---|---|
| **VIIRS** | **98.0** | **38.6** |
| MODIS (T) | 97.3 | 49.1 |
| MODIS(A) | 97.1 | 48.3 |
| AVHRR | 97.9 | 55.0 |

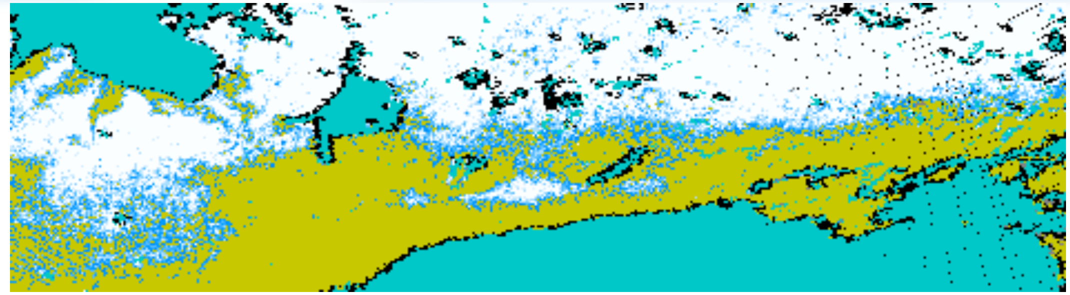
*Cloud-clear fraction is estimated in 25-60$^0$N latitude band

- Binary snow cover meets the accuracy requirement.
- Most issues are related to cloud masking; e.g., somewhat overestimated cloud extent and corrupted land/water mask.
- Some potential exists to improve the algorithm and the product, e.g., geometry-dependent threshold values.

# VIIRS Snow Fraction

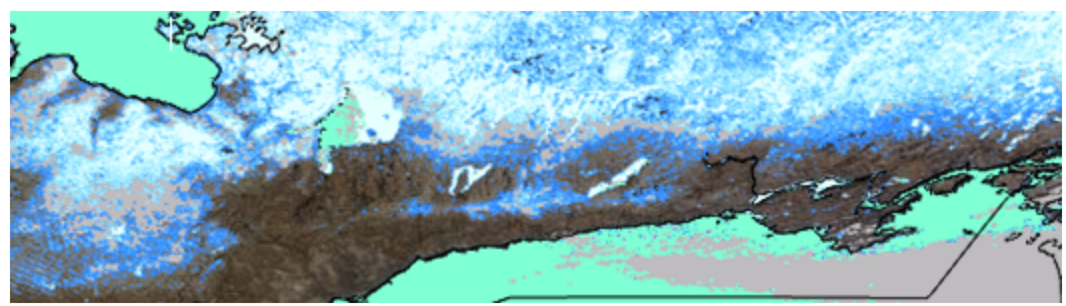
***Description***: VIIRS Snow Cover Fraction is derived from the Binary Snow Map as an aggregated snow fraction within 2x2 pixel blocks. The spatial resolution of the product is 750 m at nadir

VIIRS fraction



Image

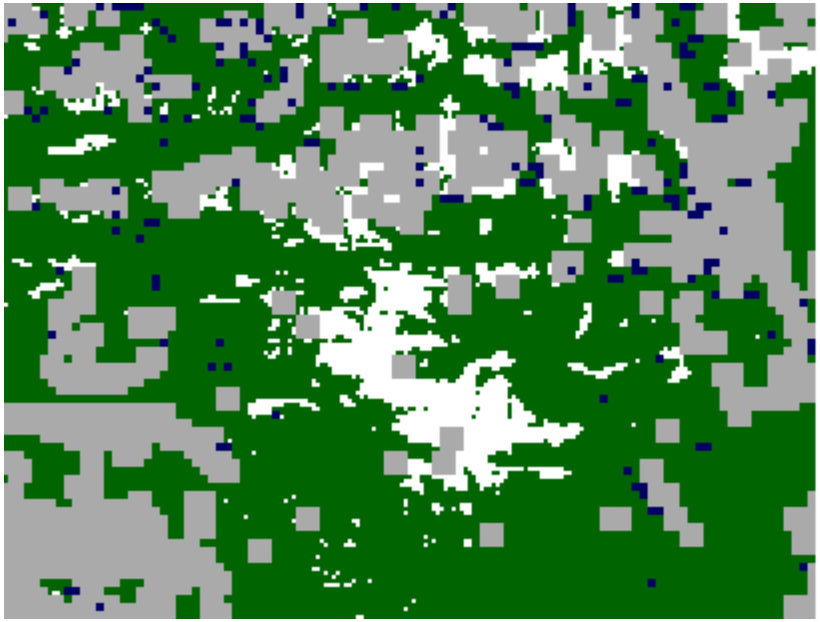
MODIS fraction



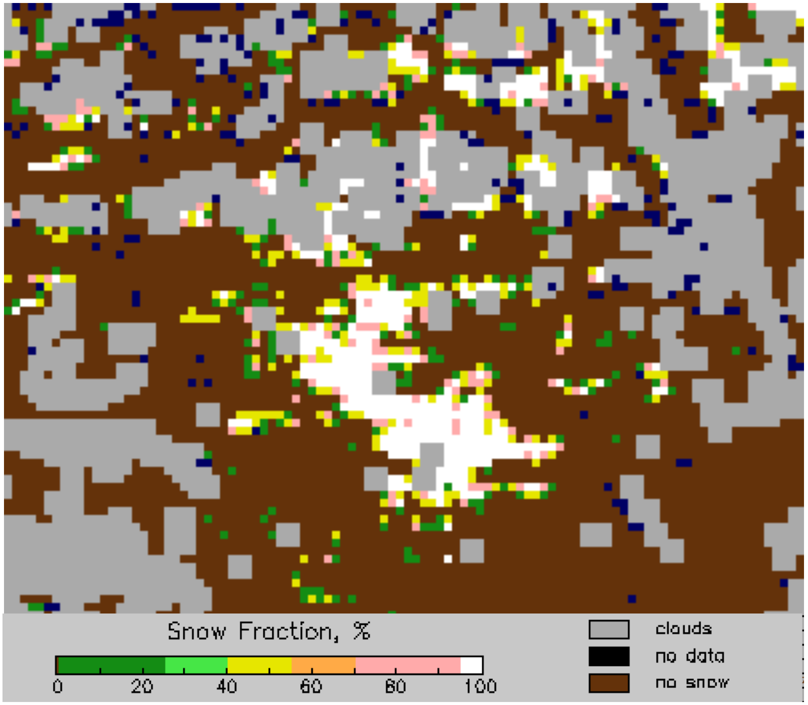
In 2x2 snow fraction (top) snow to no snow transition regions are unrealistically narrow compared to the MODIS based snow fractions.

# VIIRS Snow Fraction Results

**Granule date: 20130915 time: 0355267**



**Binary snow map (granule fragment)**
**375 m spatial resolution, white: snow, green: snow-free land, gray: cloud**




**Snow fraction map (granule fragment)**
**750 m spatial resolution, derived through 2x2 pixels aggregation**

This snow fraction algorithm has little added value and does not represent the viewable snow fraction and does not meet requirements.

# Microwave Integrated Retrieval System (MIRS): Snow Products

**MIRS Algorithm**

• MiRS is a 1-dimensional variational algorithm designed to operate on microwave measurements; entire state vector is retrieved simultaneously based on best fit to observed radiances, subject to additional background constraints

• State vector: T(p), q(p), CLW(p), RWP(p), IWP(p), Tskin, Emissivity

• Snow and sea ice properties retrieved in a post-processing step based on emissivity

• Official NOAA operational algorithm for 8 microwave satellites/sensors

**SWE Estimation**

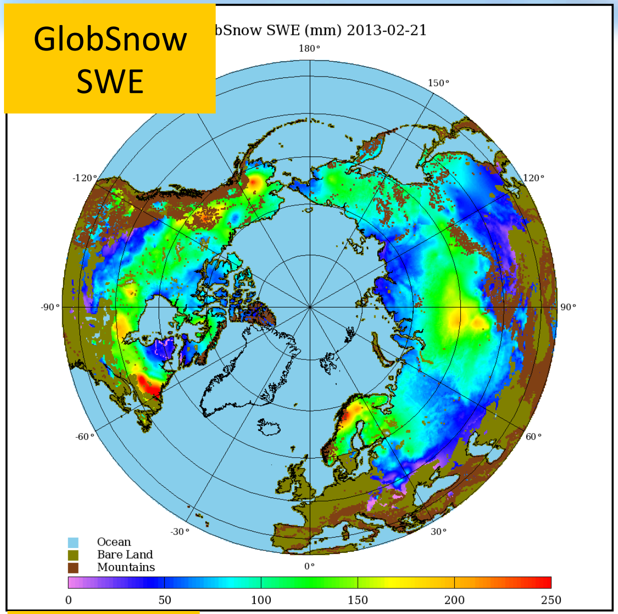
• Offline: Create emissivity catalog based on pre-specified sensor parameters; Based on work by Weng, Yan, and Grody (2001) modeling snow dielectric properties, etc.; Single-layer model

• Result is a sensor-specific lookup table with emissivity stored as a function of snow water equivalent and grain size

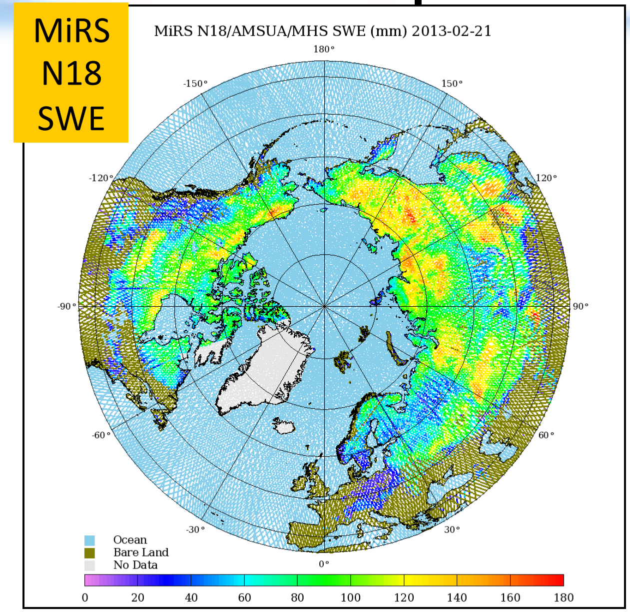
• Algorithm: quasi-variational search within lookup table, with cost function containing additional constraints (how far the solution can deviate from a BG SWE and GS ); emissivity spectral gradients used

# MIRS, AMSR 2 and GlobSnow Intercomparison

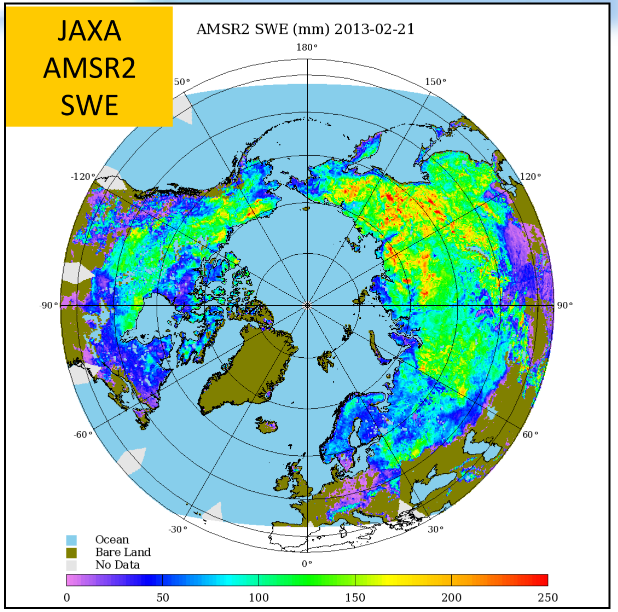
GlobSnow SWE



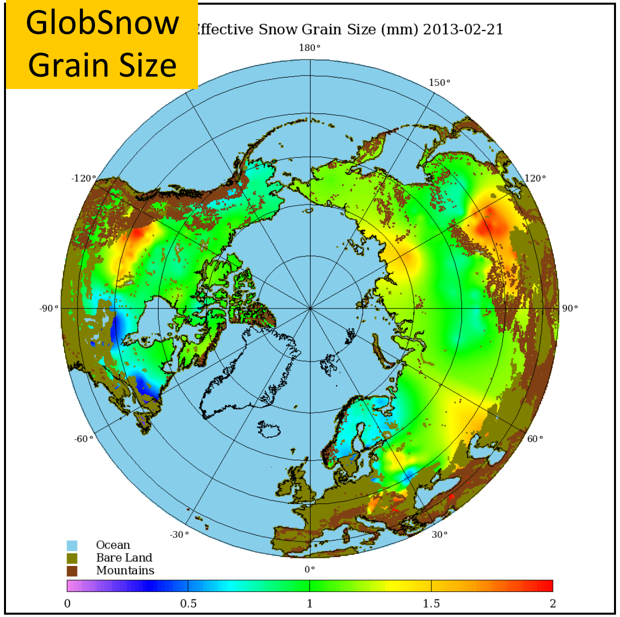

MiRS N18 SWE



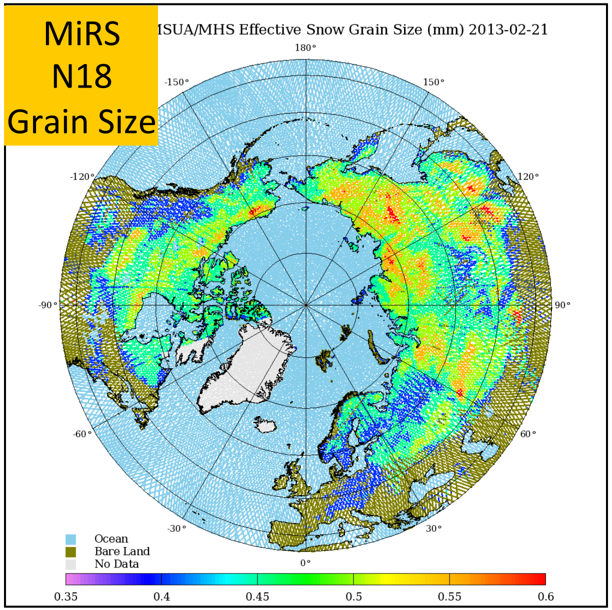

JAXA AMSR2 SWE




GlobSnow Grain Size




MiRS N18 Grain Size




2013-02-21

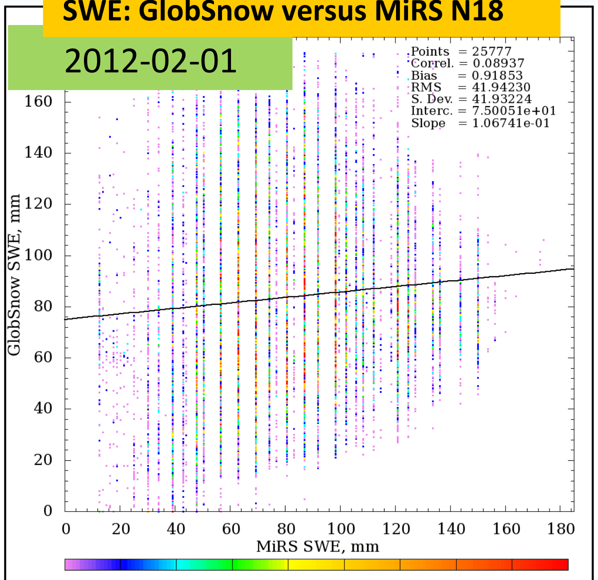
**Note:** GlobSnow grain size not considered an official product


***Acknowledgement: GlobSnow data courtesy of Kari Luojus (FMI)***

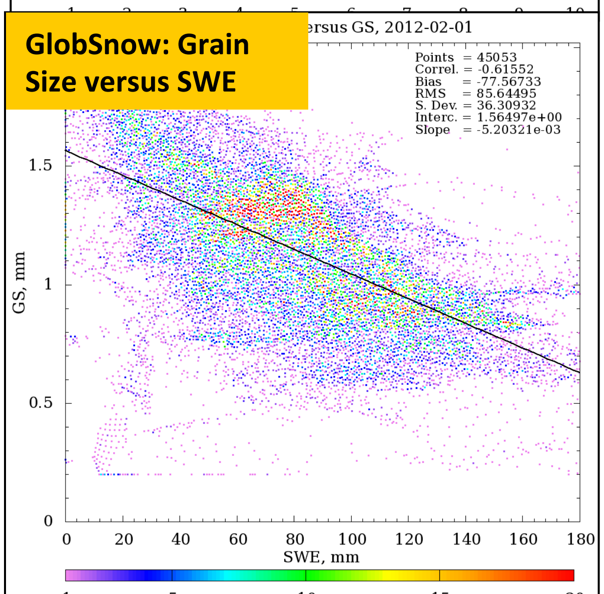
# MIRS, AMSR 2 and GlobSnow Intercomparison

**SWE: GlobSnow versus MiRS N18**

2012-02-01

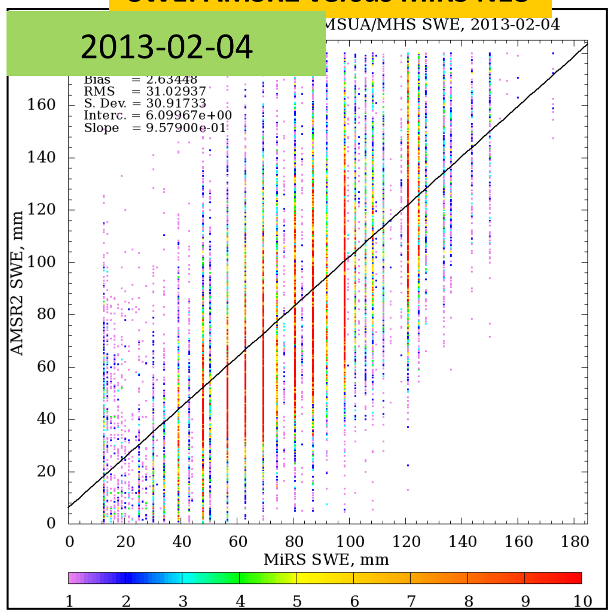



**GlobSnow: Grain Size versus SWE**




**SWE: AMSR2 versus MiRS N18**

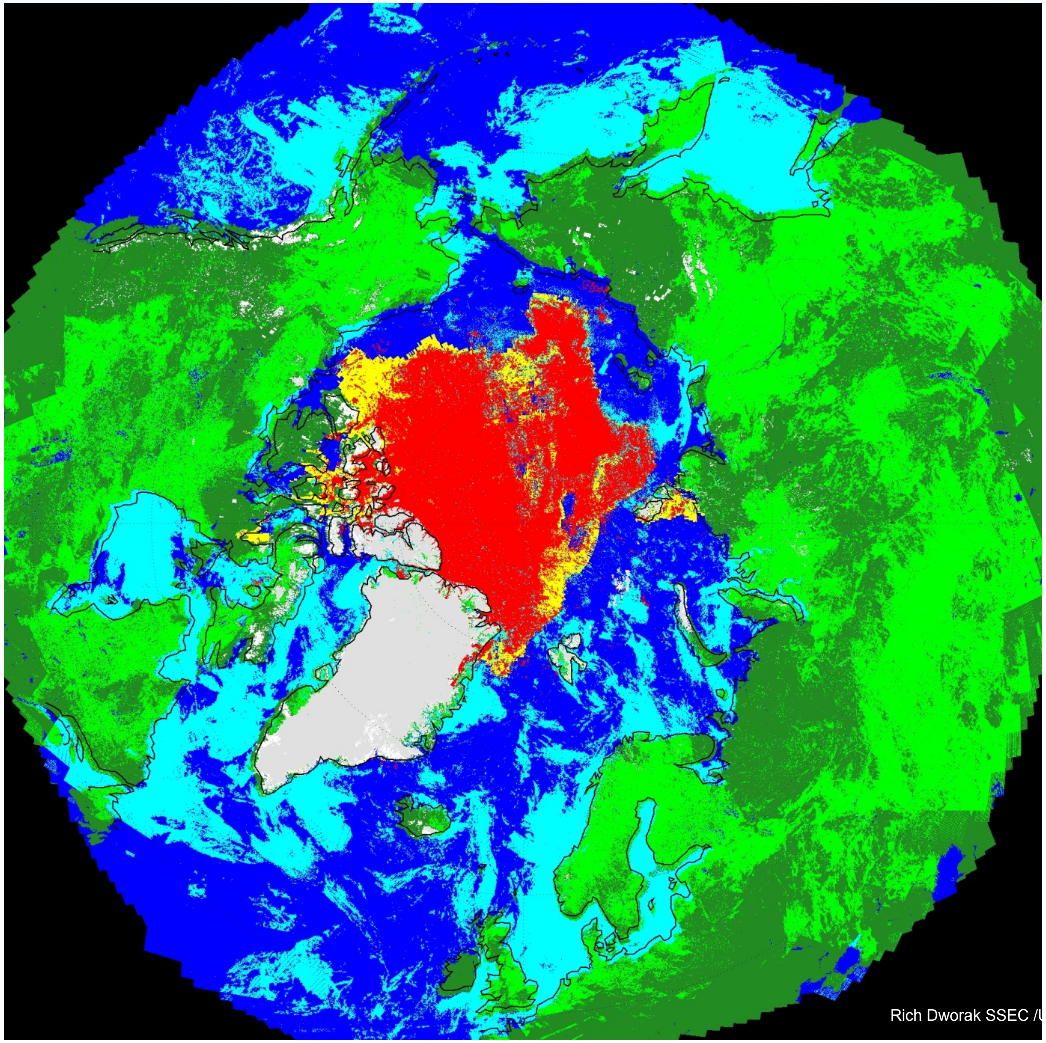
2013-02-04




- MIRS SWE better agreement with JAXA AMSR2 SWE than GlobSnow (both microwave algorithms sensitive to similar snowpack properties)
- GlobSnow SWE tends to be anti-correlated with Grain Size
- **Note:** GlobSnow grain size not considered an official product

***Acknowledgement: GlobSnow data courtesy of Kari Luojus (FMI)***

# VIIRS Snow/Ice Gridding Tests




**GMASI**

- Ice over water
- Snow over land
- No Snow over land
- No Ice over water

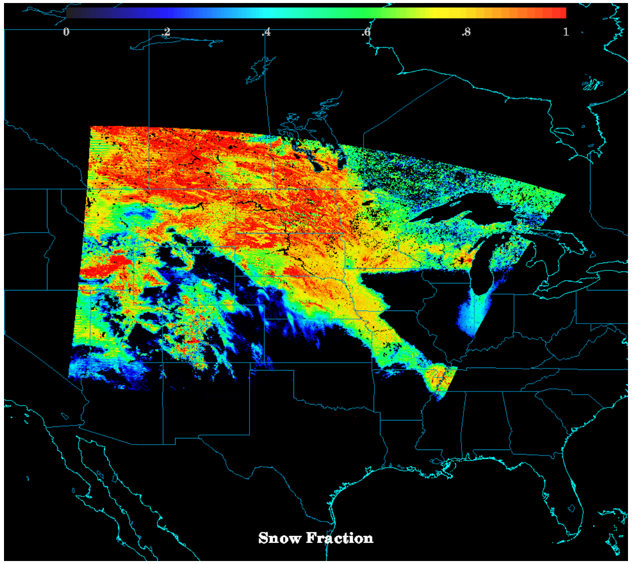
**VIIIRS Updated**

- Ice over water
- Snow over land
- No Snow over land
- No Ice over water

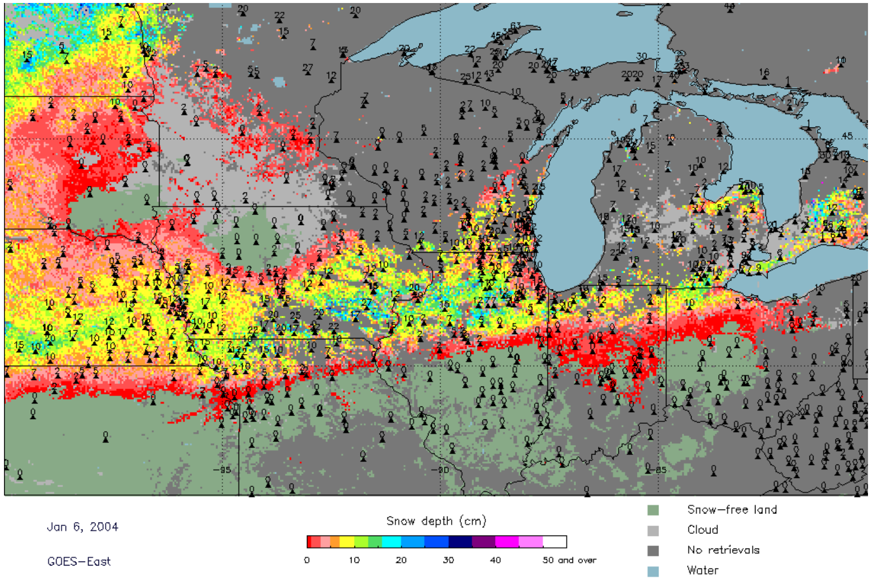
# GOES R ABI algorithms

**SNOW FRACTION: Multiple endmember multispectral approach (Painter)**

**SNOW DEPTH: Snow Fraction based approach for shallow snow depth detection (Romanov)**




*Snow Fraction ABI Simulation: From ATBD, Painter Et al 2010*



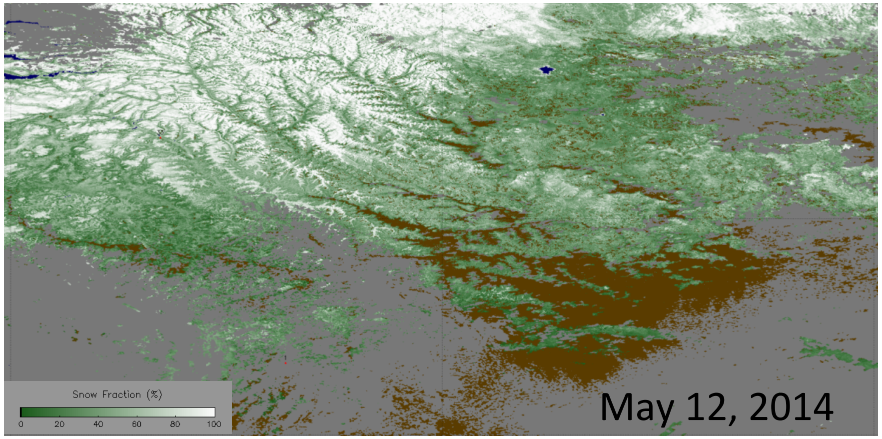

*Snow Depth Simulation: From ATBD, Romanov & Kongoli 2010*

# Revised VIIRS Snow Fraction Approaches

The 2x2 pixel aggregation scheme can only provide a small set of values (0, 25, 50, 75, 100% if no missing pixels) and therefore cannot meet the 10% accuracy requirement throughout the measurement range.

A number of different snow fraction algorithms are available; first 2 being tested:

1. **NDSI-based (Solomonson/Appel, Hall/Riggs)**
2. **Visible reflectance –based (Romanov/Tarpley)**
3. **Multiple endmember multispectral approach (Painter)**




*Visible Reflectance example: VIIRS , 375m gridded at 1 km*

# AMSR 2 Snow Algorithms for NOAA

## SNOW COVER

**Enhanced Grody SSMI algorithm**

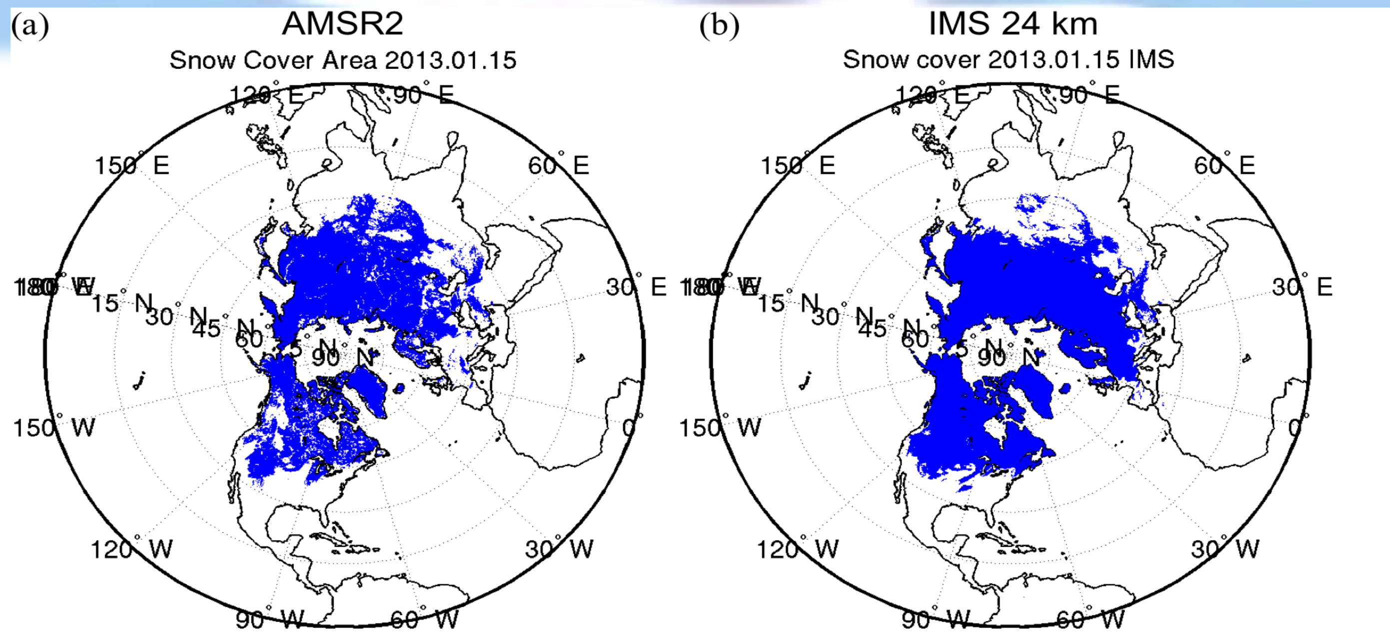
- Uses the Grody 1991 approach as the base
- A climatology test: probability of snowfall occurrence derived and updated from IMS snow cover data
- Adapt the algorithm to AMSR2 configuration
- Investigate the utility of the lower frequency channels (10 GHz and below)
- Investigate the utility of TB atmospheric corrections

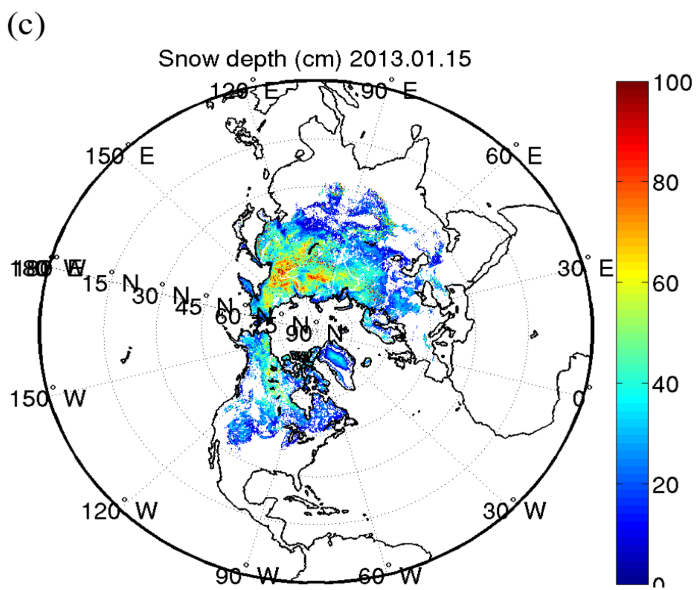
## SNOW DEPTH / SWE

**NASA AMSR-E SD/SWE approach (Kelly, 2009; Tedesco and Narvekar, 2010)**

- Brightness temperature differences at 10, 18 and 37 GHz (the Chang et al. approach) but with non-linear spatially and varying coefficients computed from brightness temperatures at horizontal and vertical polarizations
- Use of 10 & 18 GHz channels over non-forest fraction of the AMSR-E pixel for deeper snow retrievals
- Retrievals of pixel SD are weighted between forest and non-forest fractions
- Algorithm coefficients are tuned to SD, and SWE is estimated using a spatially and seasonally varying snow density climatology.

# AMSR 2 Snow Products

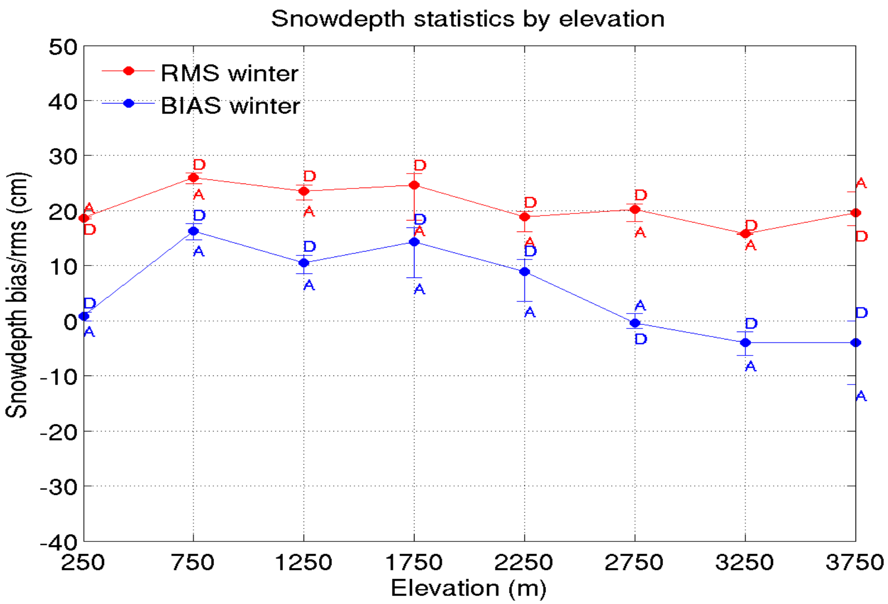


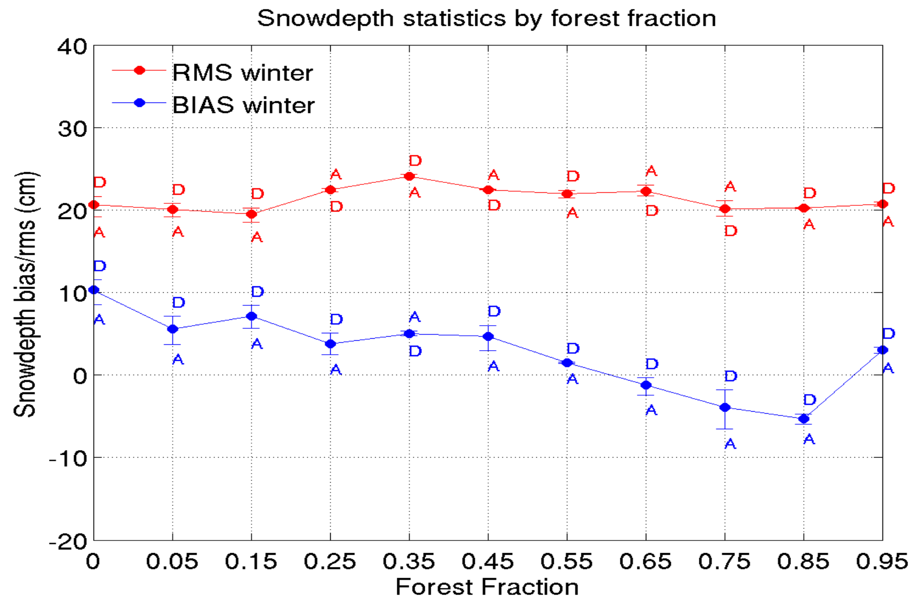



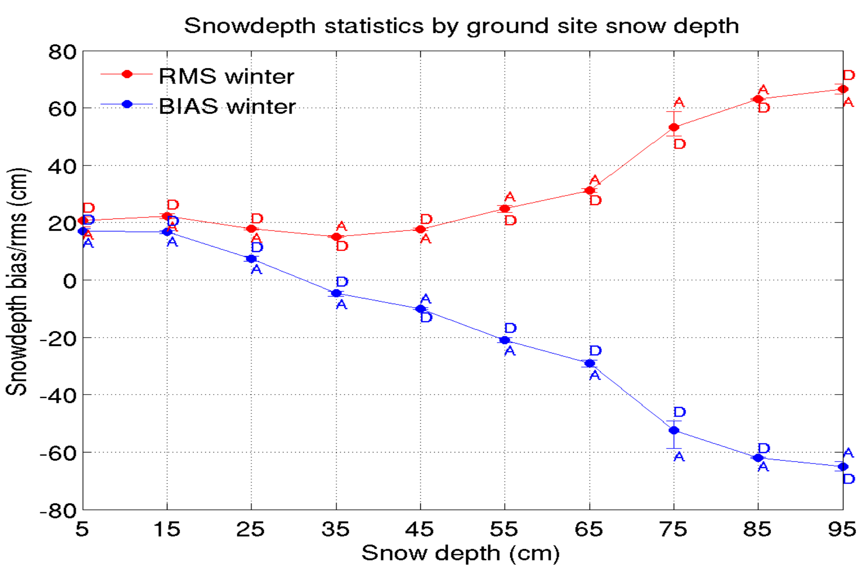

Snow cover area (SCA) detection and snow depth (SD) using AMSR2 measurements (January 15, 2013). (a) AMSR2 SCA, (b) IMS 24 km SCA, and (c) AMSR2 SD.

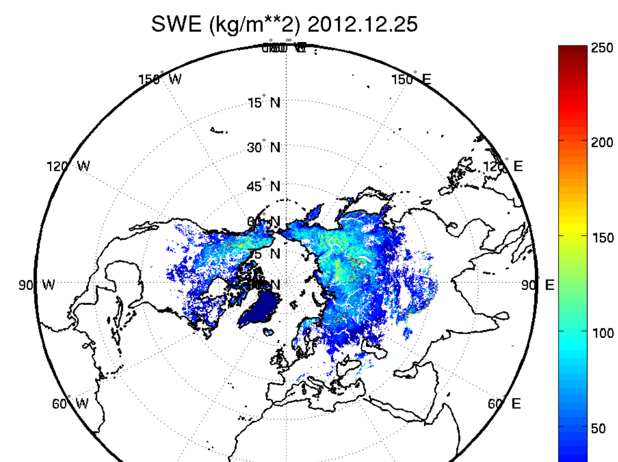
***Acknowledgements: Yong-Keun Lee & Cezar Kongoli***

# AMSR 2 Snow Depth



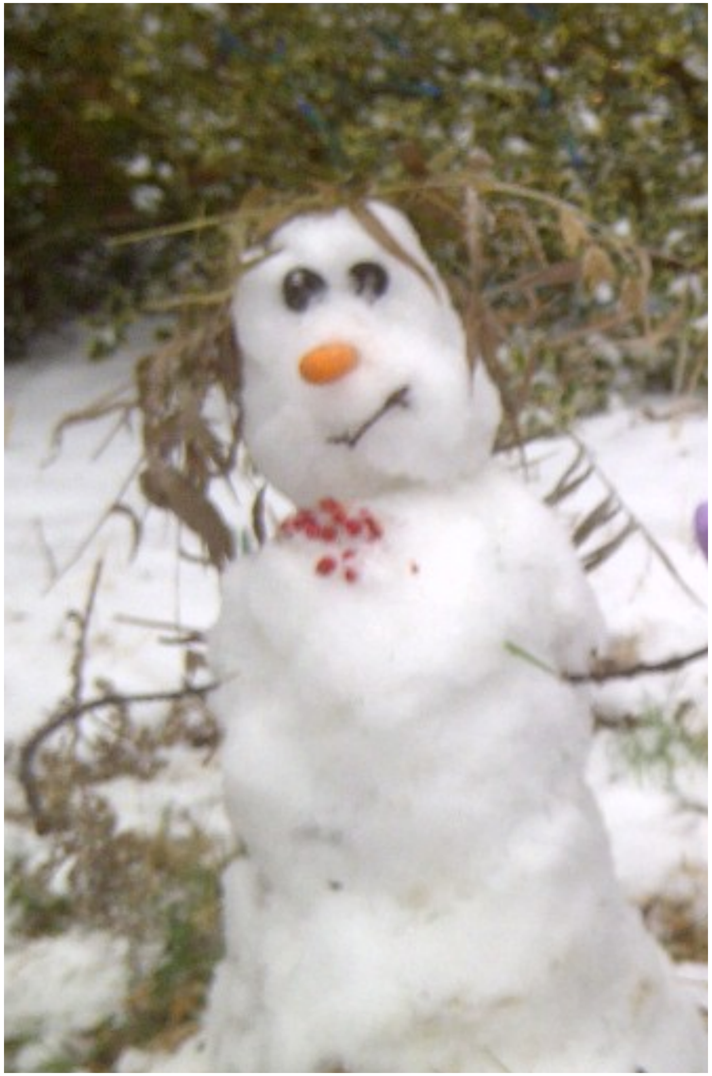




***Acknowledgement: Yong-Keun Lee & Cezar Kongoli***

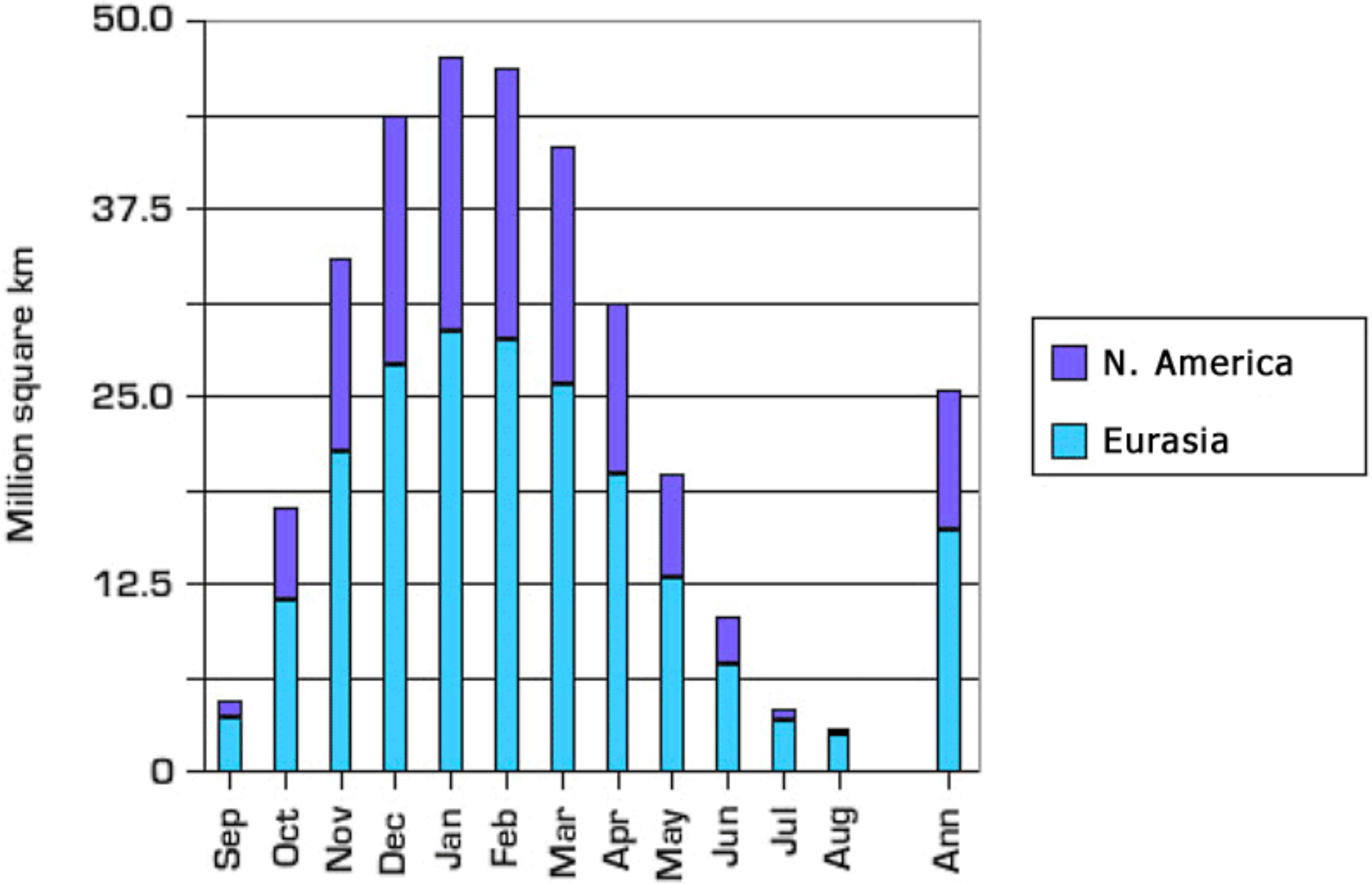
# Questions?



# Extra Slides

Extra Slides

# N. Hem. continental SCE climatology




Rutgers Global Snow Lab data based on NOAA snow maps

# IMS V3 Input Direct Data

GOES (E & W)
MeteoSat (MSG (ch 1,2,3) & 7)
MTSAT
NOAA Automated Snow & Ice
AVHRR (Channels 1,2,3)
MODIS (Channels 1,2,7,8)
ASCAT
AMSU (Derived snow, ice, rain)
NIC Marginal Ice Zone
NIC & CIS Ice Charts
Surface Obs (METAR)
NOHRSC SNODAS
AFWA Snow Depth
SSMI/S (Derived snow, ice, rain)
MMAB Sea Ice Cons

ATMS MIRS Algorithm (SWE, Sea Ice Con, Snow Grain Size)
VIIRS Snow Cover
VIIRS Ice Age
VIIRS Imagery (I1, I2, I3, & I5)
RadarSat & Sentinel SAR imagery
US RADAR
COOP and SYNOP reports
CMC Snow Depth Analysis
CMC RIPS 3D var Ice Analysis
US Navy Arctic Cap (ACNFS) Ice Cons & Thickness
GFS Snow Depth Change (24hrs)

Legacy Version 2 New to Version 3

# VIIRS Binary Snow Cover

| Parameter | Specification Value |
|---|---|
| a. Binary Horizontal Cell Size, | |
| 1. Clear – daytime (Worst case) | 0.8 km |
| 2. Clear – daytime (At nadir) | 0.4 km |
| 3. Cloudy and/or nighttime | N/A |
| b. Horizontal Reporting Interval | Horizontal Cell Size |
| c. Snow Depth Range | > 0 cm (Any Thickness) |
| d. Horizontal Coverage | Land |
| e. Vertical Coverage | > 0 cm |
| f. Measurement Range | Snow / No snow |
| g. Probability of Correct Typing | 90% |
| h. Mapping Uncertainty | 1.5 km |

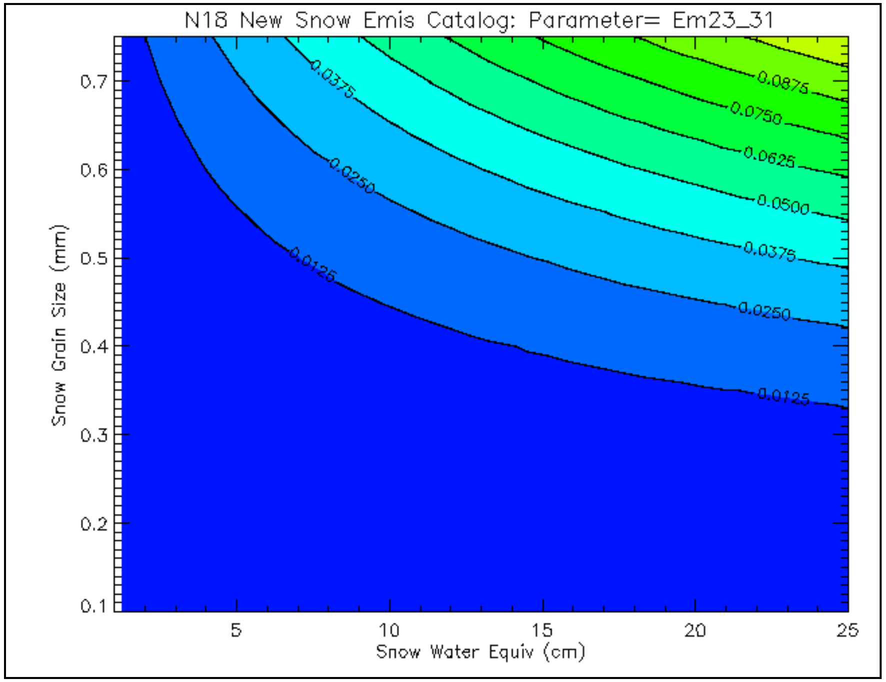
1. The probability of correct snow/no-snow detection applies only to climatologically snow-covered regions.
2. The accuracy of snow detection does not apply over forested/mountainous areas where snow may be hidden by vegetation or topographic shading.

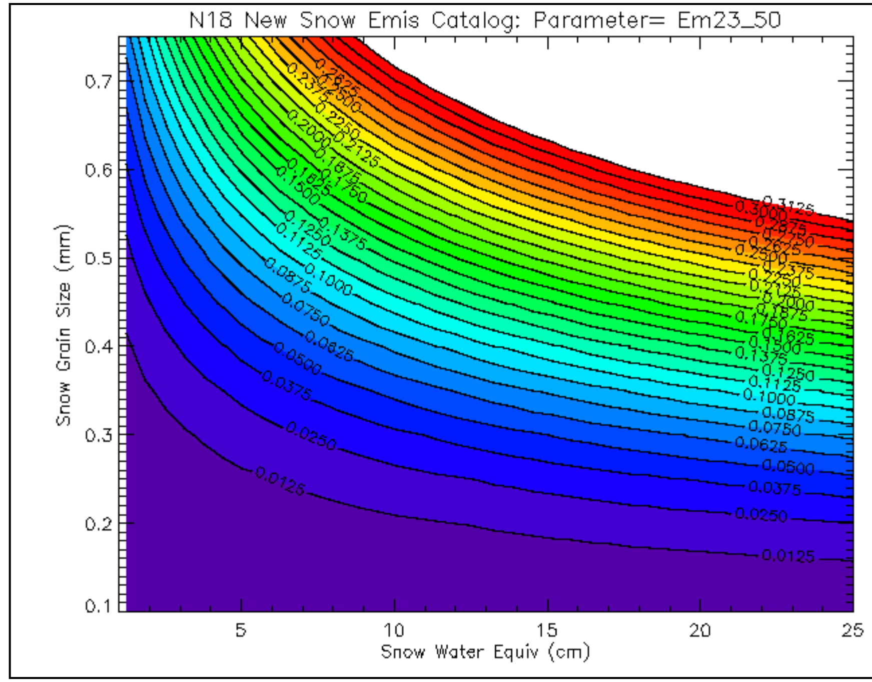
[Joint Polar Satellite System (JPSS) Program Level 1 Requirements SUPPLEMENT – Final Version: 2.9 June 27, 2013]

# VIIRS Snow Fraction Requirements

| Parameter | Specification Value |
|---|---|
| a. Horizontal Cell Size, | |
| 1. Clear – daytime (Worst case) | 1.6 km |
| 2. Clear – daytime (At nadir) | 0.8 km |
| 3. Cloudy and/or nighttime | N/A |
| b. Horizontal Reporting Interval | Horizontal Cell Size |
| c. Snow Depth Ranges | > 0 cm (Any Thickness) |
| d. Horizontal Coverage | Land |
| e. Vertical Coverage | > 0 cm |
| f. Measurement Range | 0 – 100% of HCS |
| g. Measurement Uncertainty | 10% of HCS (Snow/No Snow) |
| h. Mapping Uncertainty | 1.5 km |

# MIRS Snow Emissivity Catalog Example:
# N18, Spectral Gradients Em23-Em31 (left) and Em23-Em50 (right)

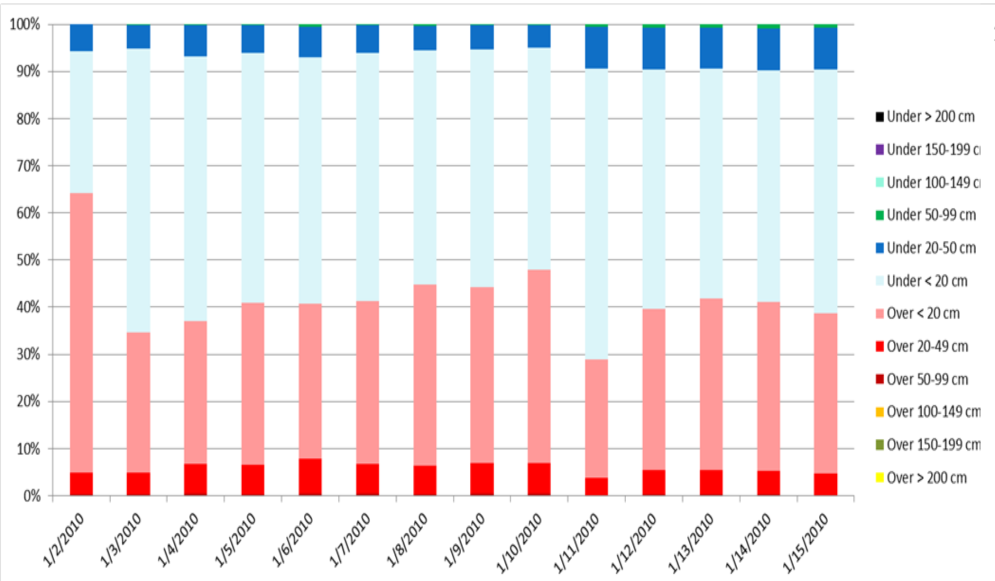


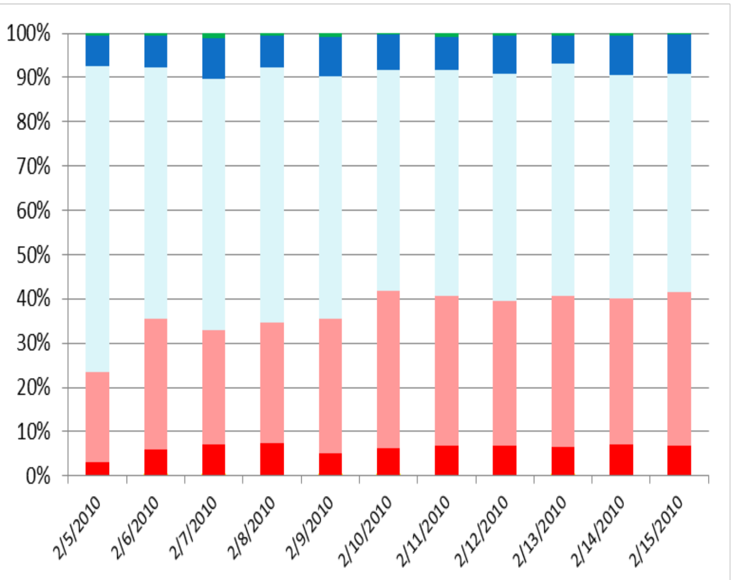

***Prepared by C. Grassotti, MiRS Team (NOAA/NESDIS/STAR)***

# Current Validation Results

January 2-15, 2010




February 5-15, 2010




Difference of IMS V3 snow depth versus GHCN-Daily measurements in cm. Underestimates of snow depth made up more than 60% of the values, though most IMS V3 estimates were within 20 cm of the measurements.

# Blending using ATMS

- ATMS output applies ***Microwave Integrated Retrieval System (MIRS)*** algorithm. MIRS is MIRS is based on an assimilation-type scheme (1DVAR) capable of optimally retrieving atmospheric and surface state parameters simultaneously.
- MIRS appears to saturation snow depth at about 20-30 cm. This is far under than observed at in-situ stations.
- MIRS does not have a vegetation correction.
- The differential of ATMS and in-situ measurement yields "bulls-eyes" in the NESDIS blended snow.
- *Bias correction could help*.

NASA AMSR-E Snow Depth algorithm
Description (Kelly, 2009)

# Snow Depth/SWE Algorithm Details

Adopted the current version of the Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E) algorithm based on Kelly (2009).

$$SD = ff * [p1 * (T18V - T36V)/(1 - b * fd)] + (1 - ff) * [p1 * (T10V - T36V) + p2 * (T10V - T18V)]$$

$p1 = 1/\log 10(T36V - T36H)$ , $p2 = 1/\log 10(T18V - T18H)$

ff: forest fraction product from MCD12Q1 (7km radius averaged)

fd: Vegetation continuous field product from MOD44B (7km radius averaged)

b = 0.6 from the SD comparison with 80 WMO snow measuring stations

T18V: Brightness temperature at 18 GHz, vertically polarized.

T18H: Brightness temperature at 18 GHz, horizontally polarized.

SWE = SD * snow density (snow density look-up table)
(Brown and Mote 2009; Sturm et al. 1995)