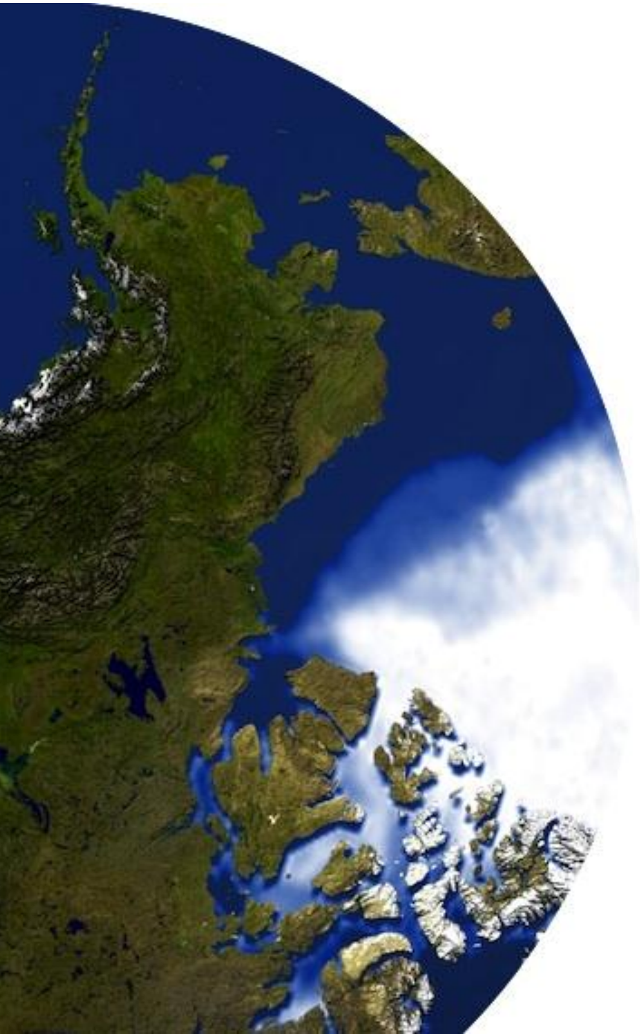
Cryosphere Products from ABI and VIIRS



Jeff Key

NOAA/NESDIS

Madison, Wisconsin USA

NOAA Satellite Science Week, 30 April – 4 May 2012, Kansas City



The **cryosphere** collectively describes elements of the earth system containing **water in its frozen state** and includes:


snow cover, solid precipitation, sea ice, lake and river ice, glaciers, ice caps, ice sheets, ice shelves, permafrost and seasonally frozen ground.

The cryosphere is **global**, ~100 countries



Snow and Ice Properties

Snow

There are at least 30 cryosphere properties that, ideally, would be measured. Of those, measurement techniques from space can be considered mature for only 8.

- freezeup/breakup, thickness, snow on ice

Sea Ice

- extent, concentration, type (age), thickness, motion, temperature, snow on ice

Glaciers, Ice Caps, Ice sheets

- mass balance (accumulation/ablation), thickness, area, length (geometry), firn temperature, velocity, snowline/equilibrium line, icebergs, snow on ice

Frozen Ground/Permafrost

- soil temperature/thermal state, active layer thickness, borehole temperature, extent, snow cover

(Green: mature capability; Blue: moderate/developing capability; Red: little or no capability)

The Cryosphere is Important

Changes in the cryosphere can have significant impacts on water supply, transportation, infrastructure, hunting, fisheries, recreation, and ecology.

Sea level rise threatens vital infrastructure.

Changes in sea-ice affect access to the polar oceans and resources, tourism, and security. Declining summer sea-ice affects ocean circulation and weather patterns.

Natural hazards such as icebergs, avalanches and glacier outburst floods create risks.

Permafrost thawing impacts infrastructure and is potentially a major source of methane, a greenhouse gas.

Changes in the cryosphere impact water supply, food production, freshwater ecosystems, hydropower production, and the risk of floods and droughts.

Retreating sea ice results in a loss of habitat for mammals such as polar bears and seals.

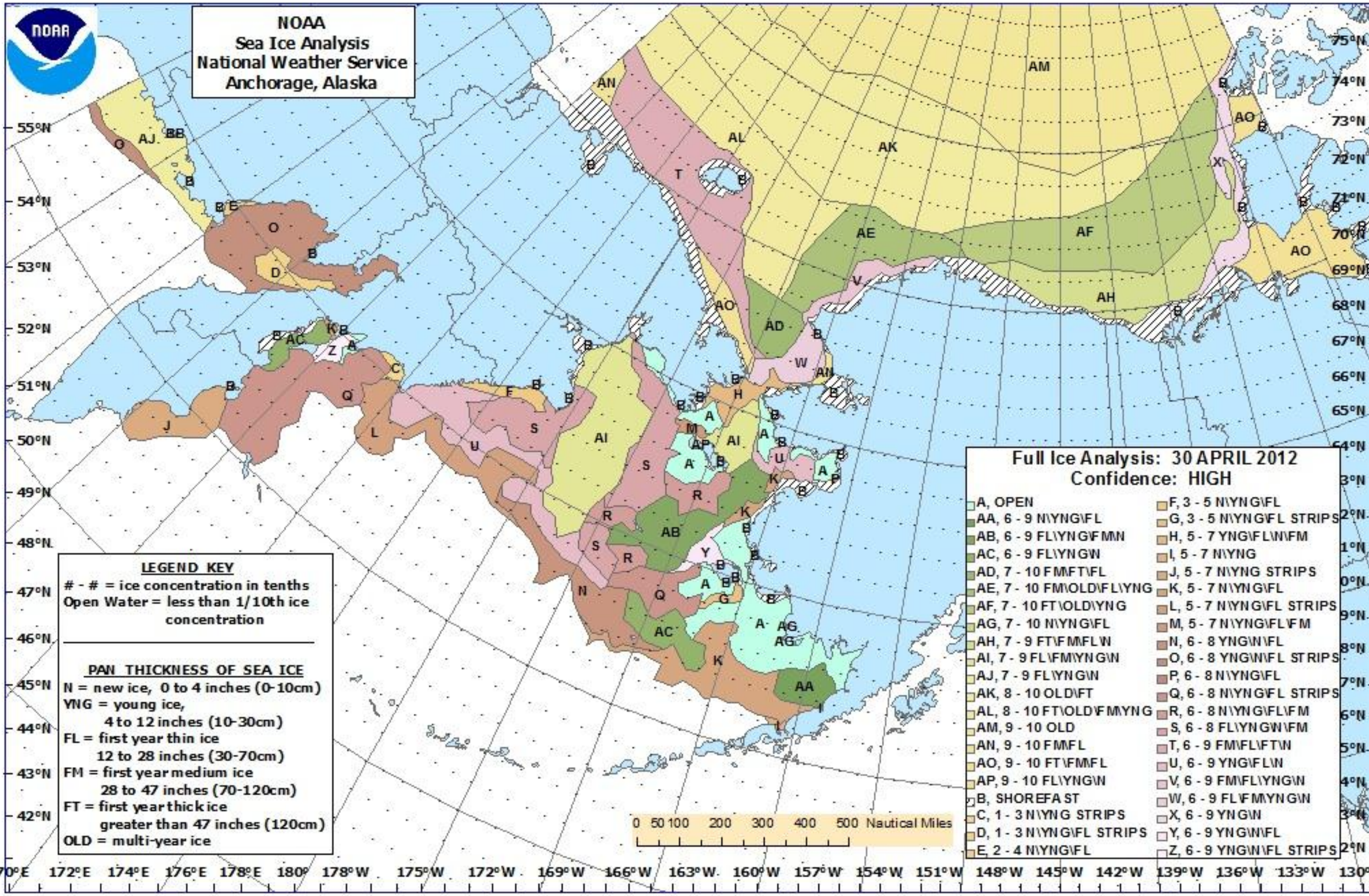
Uses and Users

- Numerical Weather Prediction (NWP centers)
  - Snow and ice cover are commonly used.
  - Ice thickness is used in some applications; should be used universally!
- Navigation and Transportation (National Ice Center, Alaska Ice Desk, local services)
  - Shipping, national security
  - Highway, railroad, municipal, and commercial snow removal services
- Hydrologic Modeling (NOHRSC, local services)

  Satellite-derived snow information is assimilated into spatially distributed snow models that forecast snow depth, snowpack water content, and snow melt

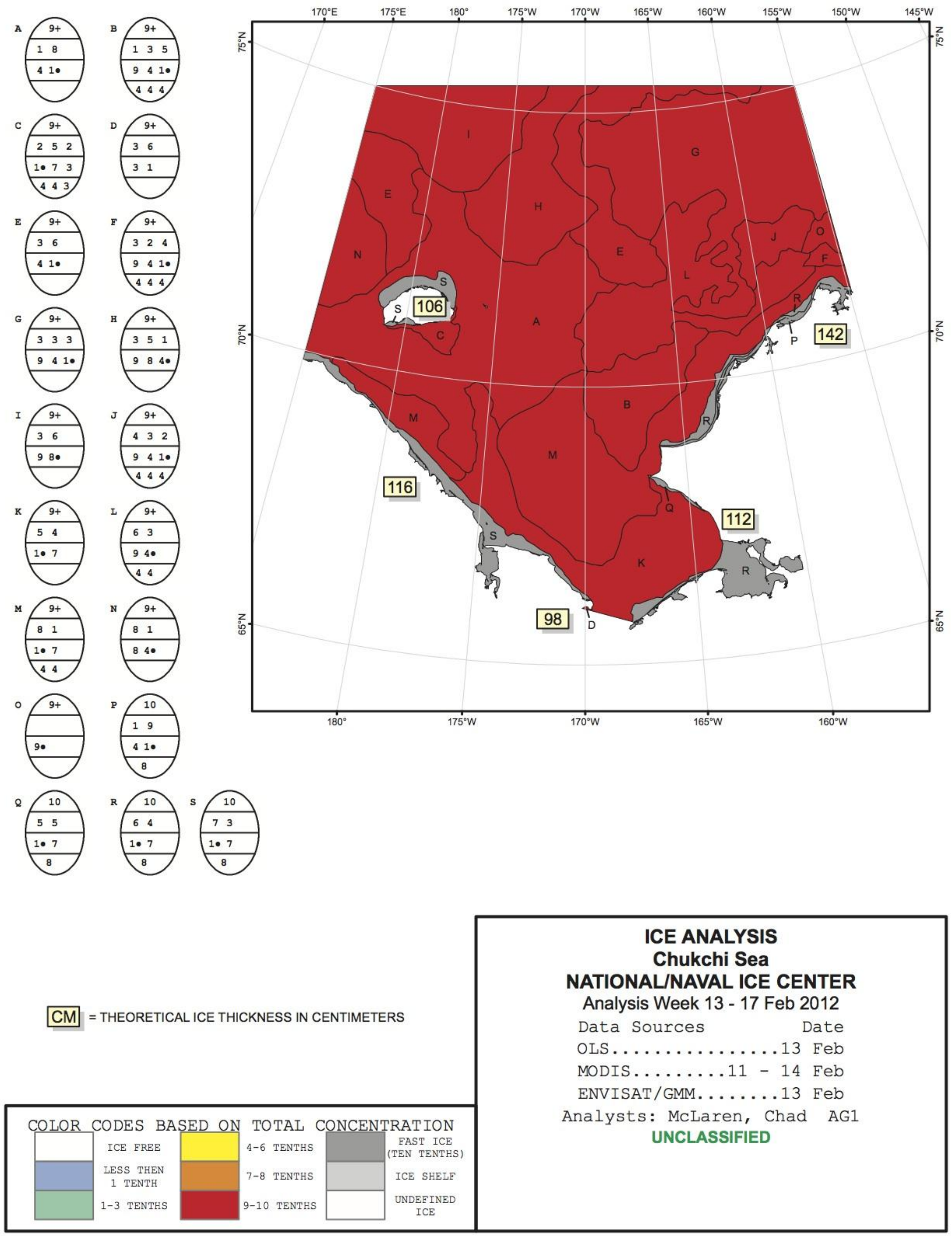
    - River flood forecasters – the protection of life, property, and commerce
    - Emergency managers and responders
    - Water supply forecasters – spring snow melt water is valued at ~$350 billion annually
    - Soil moisture forecasters and agriculture, forestry, and wildfire managers
    - Recreation industry
    - Business managers responsible for winter-product placement and market evaluation
- Climate Modeling, Monitoring, and Analysis (Reanalysis projects, science community)

Uses and Users, cont.



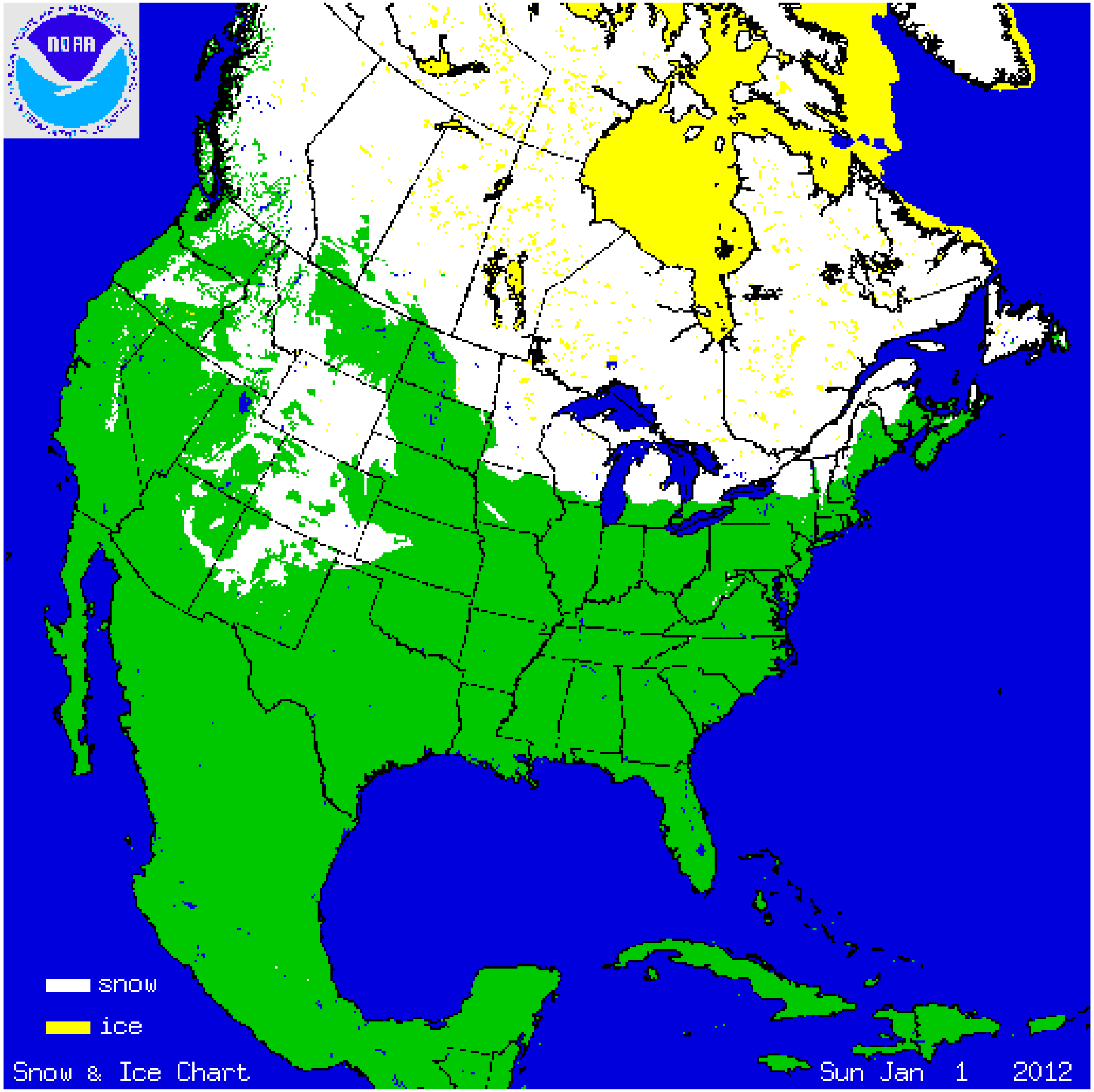
Sea ice analysis from the Alaska Ice Desk (NWS)

Uses and Users, cont.



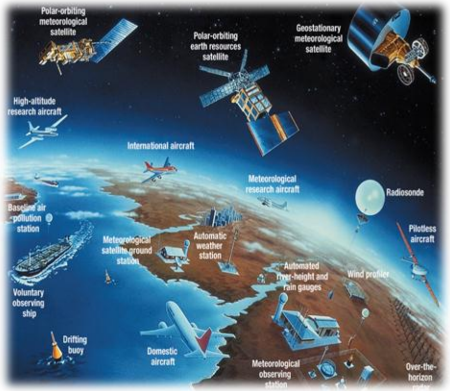
Ice chart from the National Ice Center

Uses and Users, cont.



Snow and ice from the IMS

GOES-R and JPSS **Products**



<u>GOES-R ABI</u>

- Fractional snow cover (baseline)
- Snow depth - plains only*
- Ice cover*
- Ice concentration*
- Ice thickness/age*
- Ice motion*

(*Future capabilities)

<u>NPP/JPSS VIIRS</u>

- Snow cover
- Ice characterization
  - Ice age
  - Ice concentration
- Ice surface temperature

<u>AMSR-2 on GCOM-W1</u>

- Launch: May 18, 2012
- Snow cover
- Snow depth
- Snow water equivalent (SWE)
- Ice characterization
  - Ice age
  - Ice concentration

<u>Near Future JPSS PG/RR</u>

- Sea ice leads (VIIRS)
- Blended ice concentration (VIIRS + passive microwave)

GOES-R Cryosphere Team

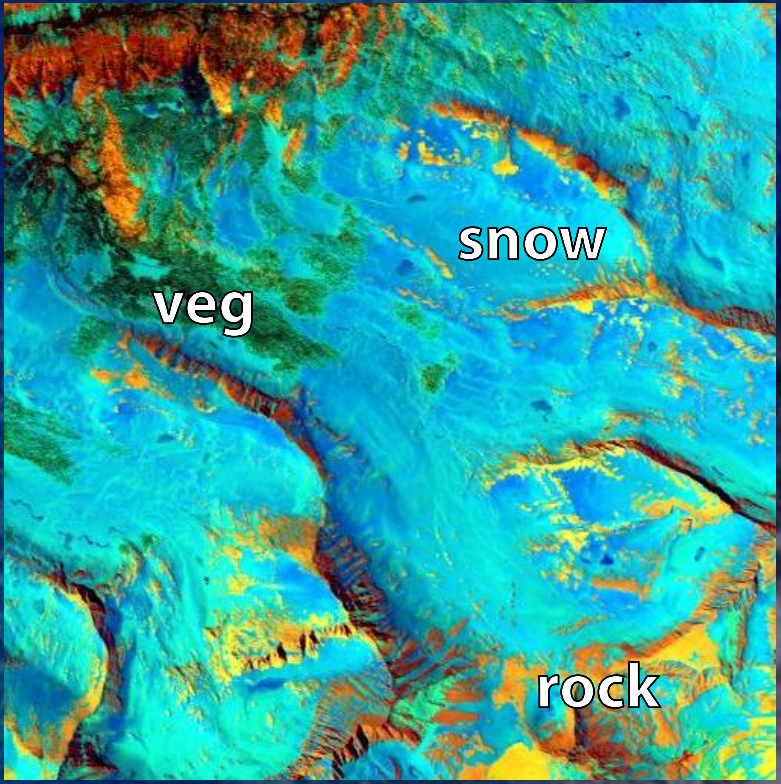
- Cryosphere Application Team
  - **Jeff Key (Lead; STAR/ASPB)**
    - Peter Romanov (CREST)
    - Kelley Eicher (NWS/NOHRSC)
    - Marouane Temimi (CREST)
- Fractional Snow Cover (baseline)
  - **Kelley Eicher (Lead; NWS/NOHRSC)**
  - Tom Painter (JPL)
  - Andy Rost (NWS/NOHRSC)
  - Chris Bovitz (NWS/NOHRSC)
- Snow Depth (Option 2)
  - **Peter Romanov (Lead; CREST)**
  - Cezar Kongoli (CICS)
- Ice Cover and Concentration (Option 2)
  - **Yinghui Liu (Lead; CIMSS)**
  - Xuanji Wang (CIMSS)
  - Jeff Key (STAR)
  - Marouane Temimi (CREST)
- Ice Motion (Option 2)
  - **Yinghui Liu (Lead; CIMSS)**
  - Jeff Key (STAR)
  - Xuanji Wang (CIMSS)
- Ice Age/Thickness (Option 2)
  - **Xuanji Wang (Lead; CIMSS)**
  - Jeff Key (STAR)
  - Yinghui Liu (CIMSS)

ABI Fractional Snow Cover

The pixel radiance from the surface that reaches the sensor is a mixture of contributions of radiances from snow, vegetation, soils, lake ice, etc.

2 km

2 km



AVIRIS

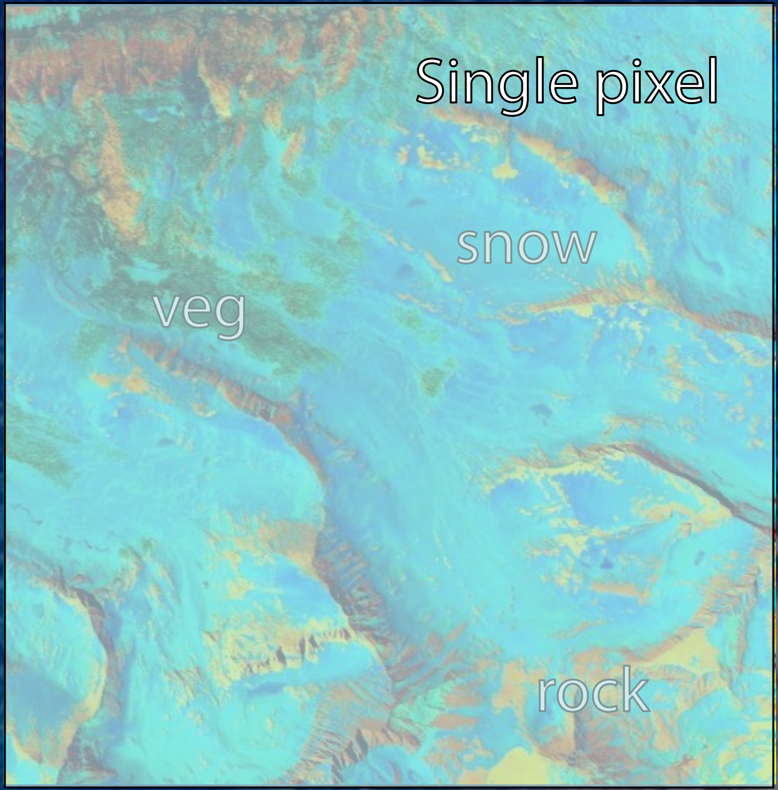
This scene is from the Sierra Nevada with 17 m imaging spectrometer data with the vast majority of radiances within a single pixel coming from a single surface

ABI Fractional Snow Cover

The pixel radiance from the surface that reaches the sensor is a mixture of contributions of radiances from snow, vegetation, soils, lake ice, etc.

2 km

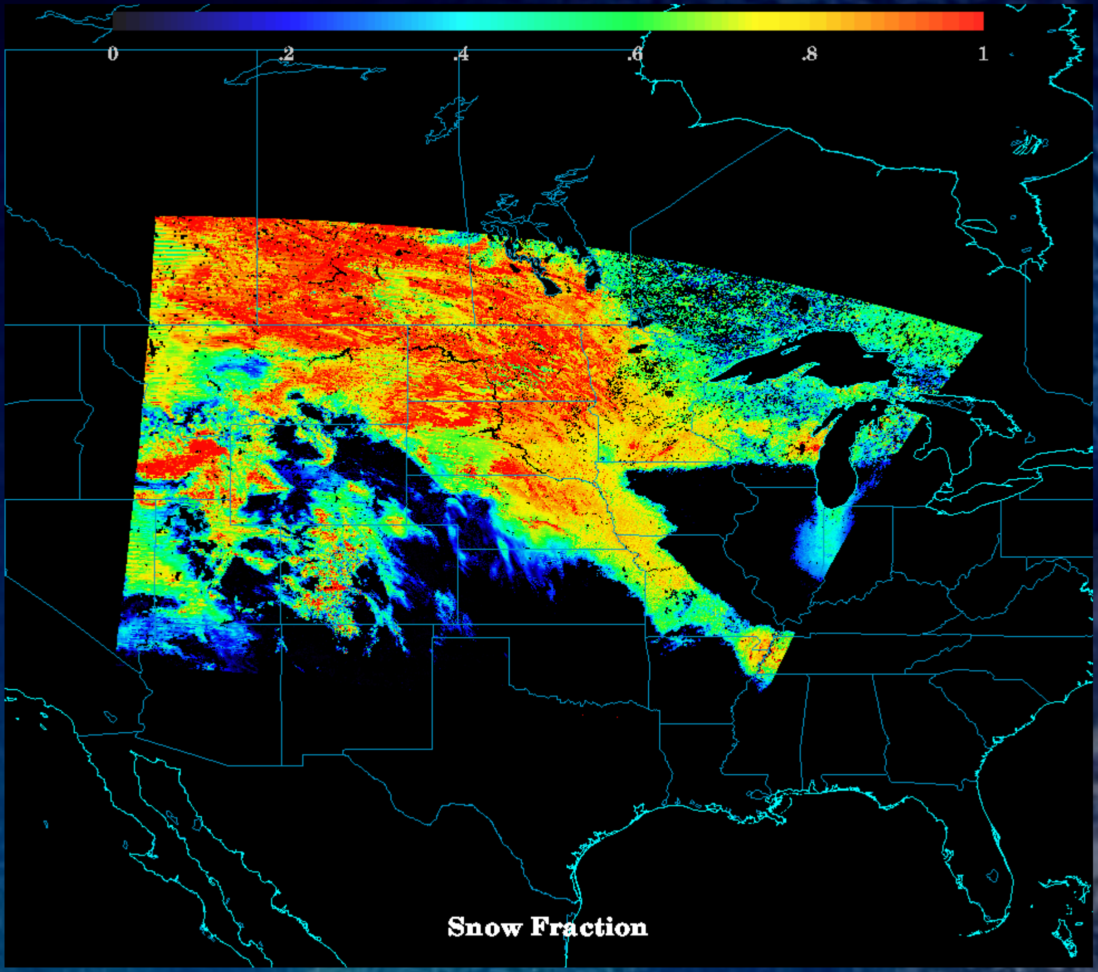
2 km



GOES-R ABI

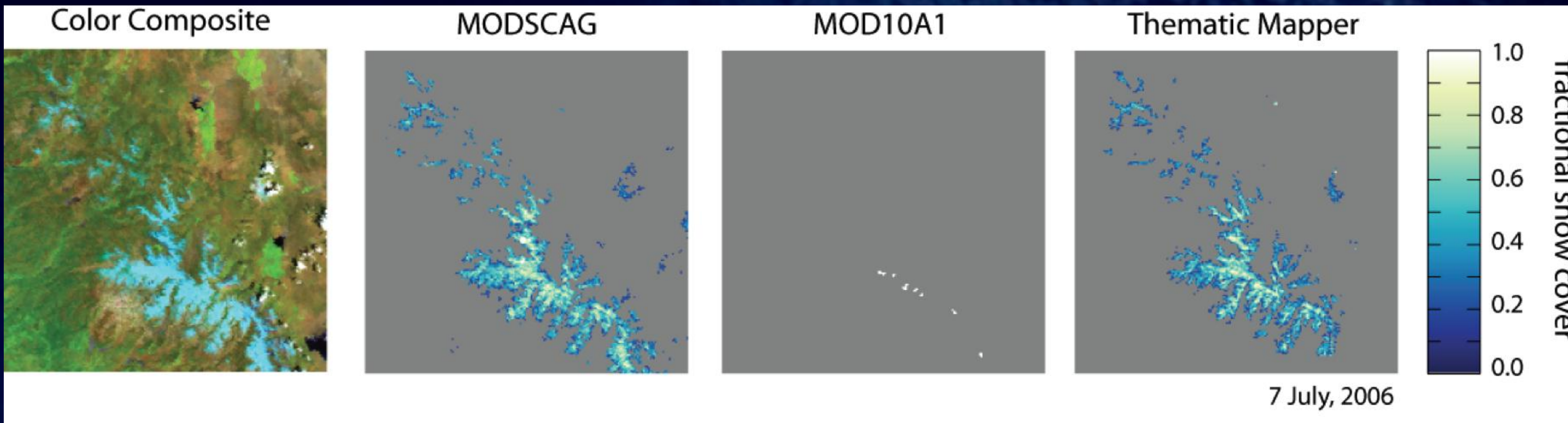
In this case, a single GOES-R ABI pixel is presented showing the underlying mixture of radiances from snow, vegetation, and exposed rock

Snow Cover Products



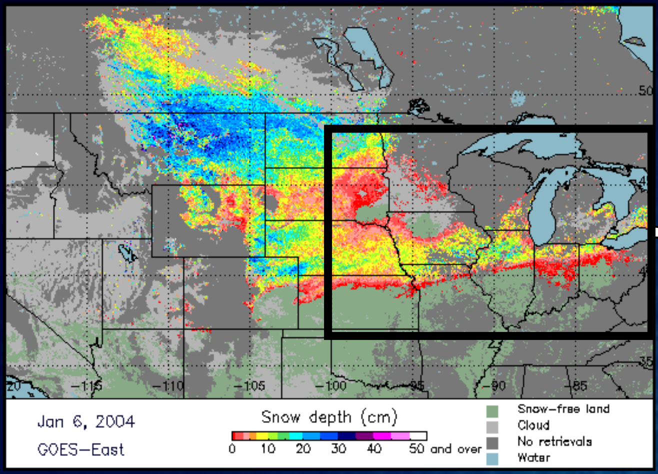
Simulated GOES-R ABI Snow Fraction from GOESRSCAG processing of proxy ABI data from MODIS, March 1, 2009.

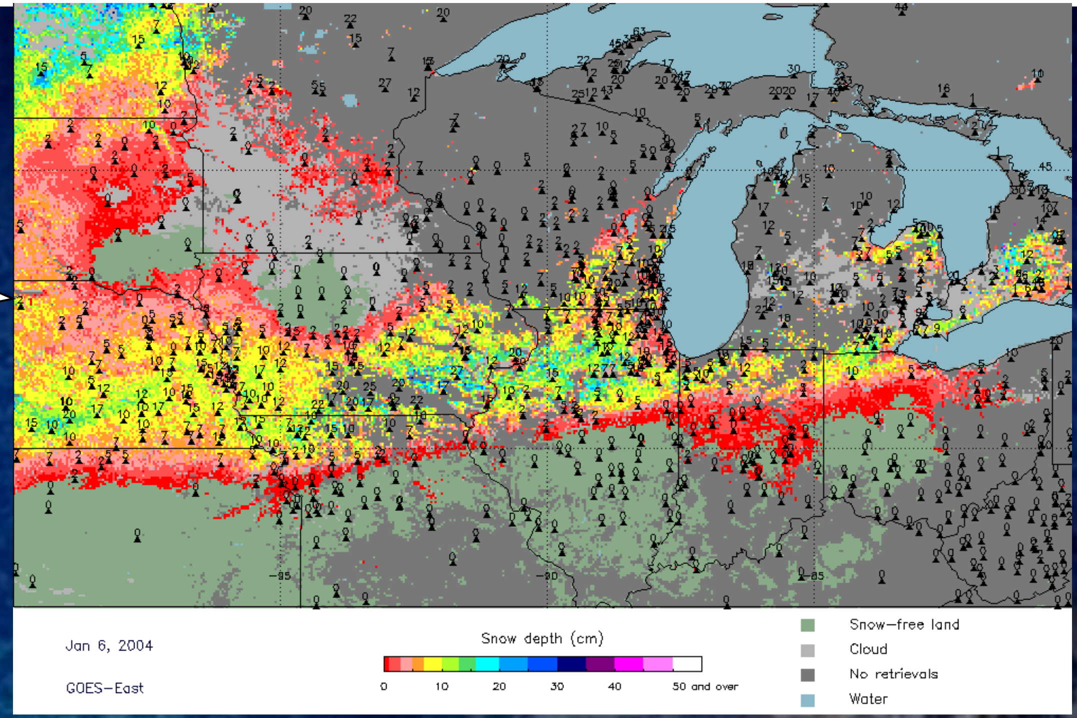
Validation Results Summary



Validation Configuration	Accuracy (spec)	Precision (spec)
Landsat TM vs. Ground Observations	3%	6%
Fractional Snow Cover 7-band MODIS vs. Landsat TM	-1.0% (<15%)	8.9% (<30%)
Fractional Snow Cover 5 band vs. 7-band MODIS	4.67% (<15%)	12.34% (<30%)

ABI Snow Depth (Plains only)





	Accuracy (spec)	Precision (spec)
Snow Depth (GOES) 2010-2011 winter season Depth < 30 cm	1.7cm (9 cm)	8.5 cm (15 cm)

Ice Cover and Concentration

Ice concentration over Great Lakes

Lake ice concentration (%) with MODIS Aqua data (left), MODIS true color image (middle), and from AMSR-E (right) over Great Lakes on February 24 2008.

Ice Cover and Concentration Validation

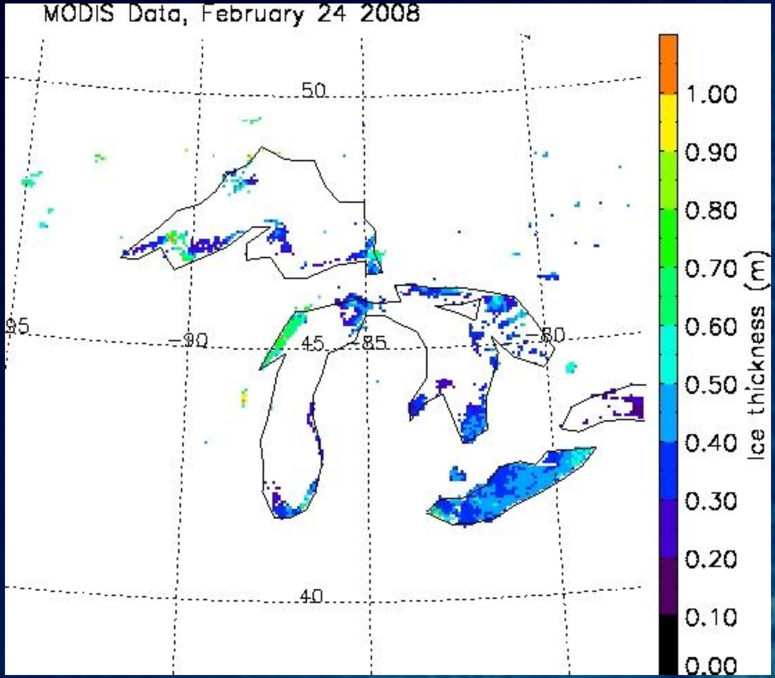
Case number Total pairs: 1576298	Sea/Lake ice cover determined from AMSR-E	Water determined from AMSR-E
Sea/Lake ice cover	1075124	
Water		305872
Correct detection ratio = (1075124+305872)/1576298 = 87.6%		

Spec: 85%

Ice concentration difference of AMSRE product and MODIS	Mean bias (%)	Standard deviation (%)
Over Arctic Ocean	4.0	15.7
Over Great Lakes	-4.0	25.6
Required measurement accuracy	10	
Required measurement precision		30

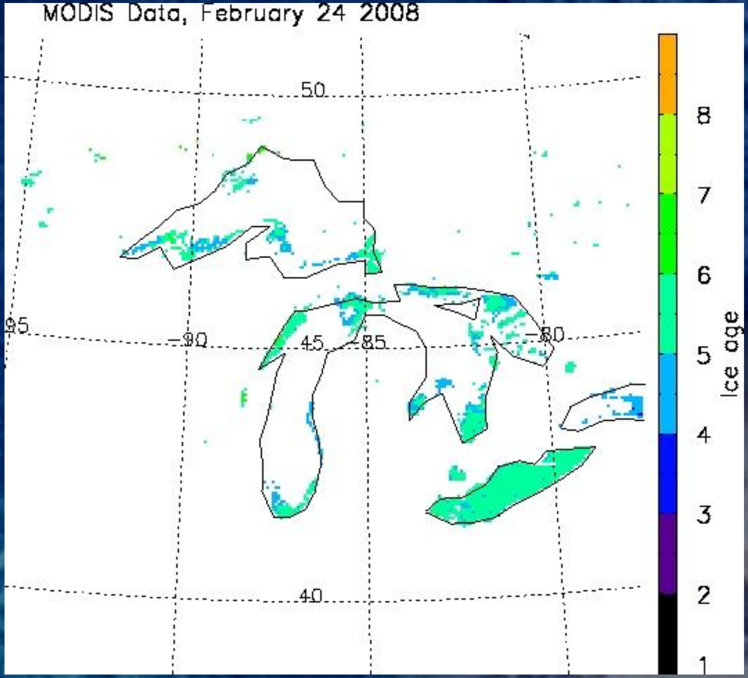
ABI Ice Age/Thickness

Ice Thickness



Ice Thickness (m) over Great Lakes area, February 24, 2008 using MODIS data.

Ice Age



Ice Age derived from Ice Thickness over Great Lakes area, February 24, 2008.

Ice Age Classification:

1: Free of ice (white)

2: New ice

3: Grey ice

4: Grey-white ice

5: Thin first-year ice

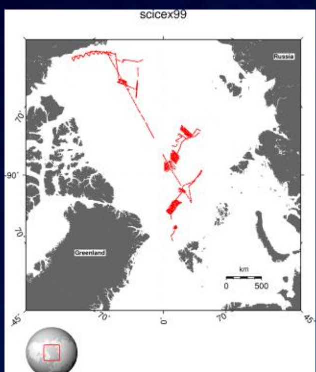
6: Median first-year ice

7: Thick first-year ice

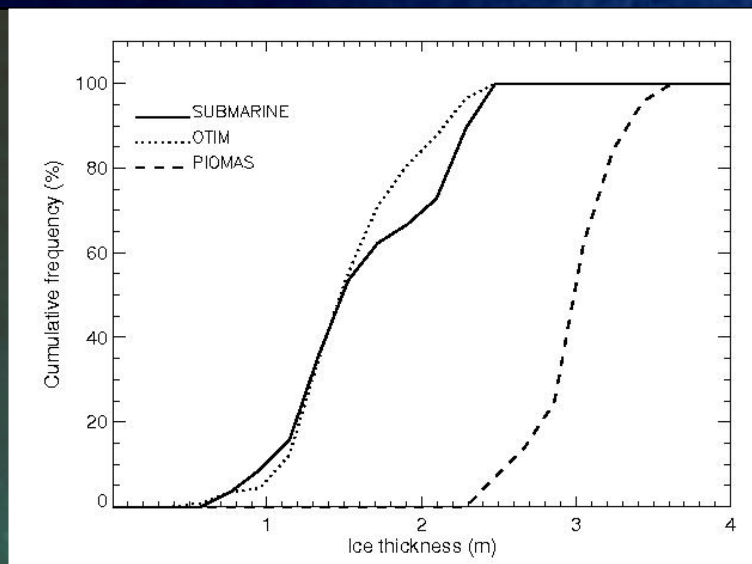
8: Old ice

Ice Thickness Validation

Comparison of AVHRR Ice Thickness with submarine ULS measurements and numerical model simulations

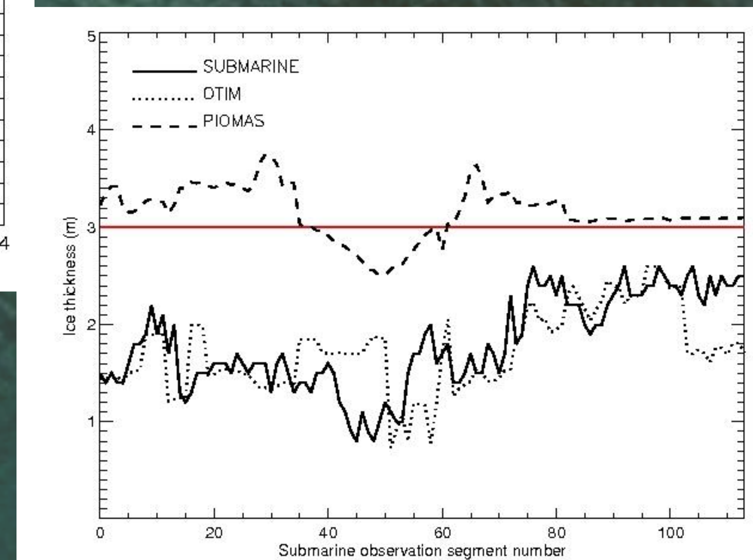


Submarine trajectory, 1999



Ice thickness cumulative distribution retrieved by OTIM with APP-x data, submarine sonar data, and simulated thickness from the PIOMAS model. Submarine ice draft (mean and median only) was converted to ice thickness by a factor of 1.11.

Ice thickness values retrieved by OTIM with APP-x data, submarine sonar data, and simulated thickness from the PIOMAS model along the submarine track segments. Submarine ice draft (mean and median only) was converted to ice thickness by a factor of 1.11.



Ice Age Validation

Ice Age (OTIM vs Microwave)	
Statistics	**Accuracy**
Ice Free	***D&N:93%, N:93%, D:~100%***
First-year Ice	***D&N:92%, N:92%, D:~100%***
Older Ice	***D&N:84%, N:84%, D:~100%***
All	***D&N:89%, N:89%, D:~100%***

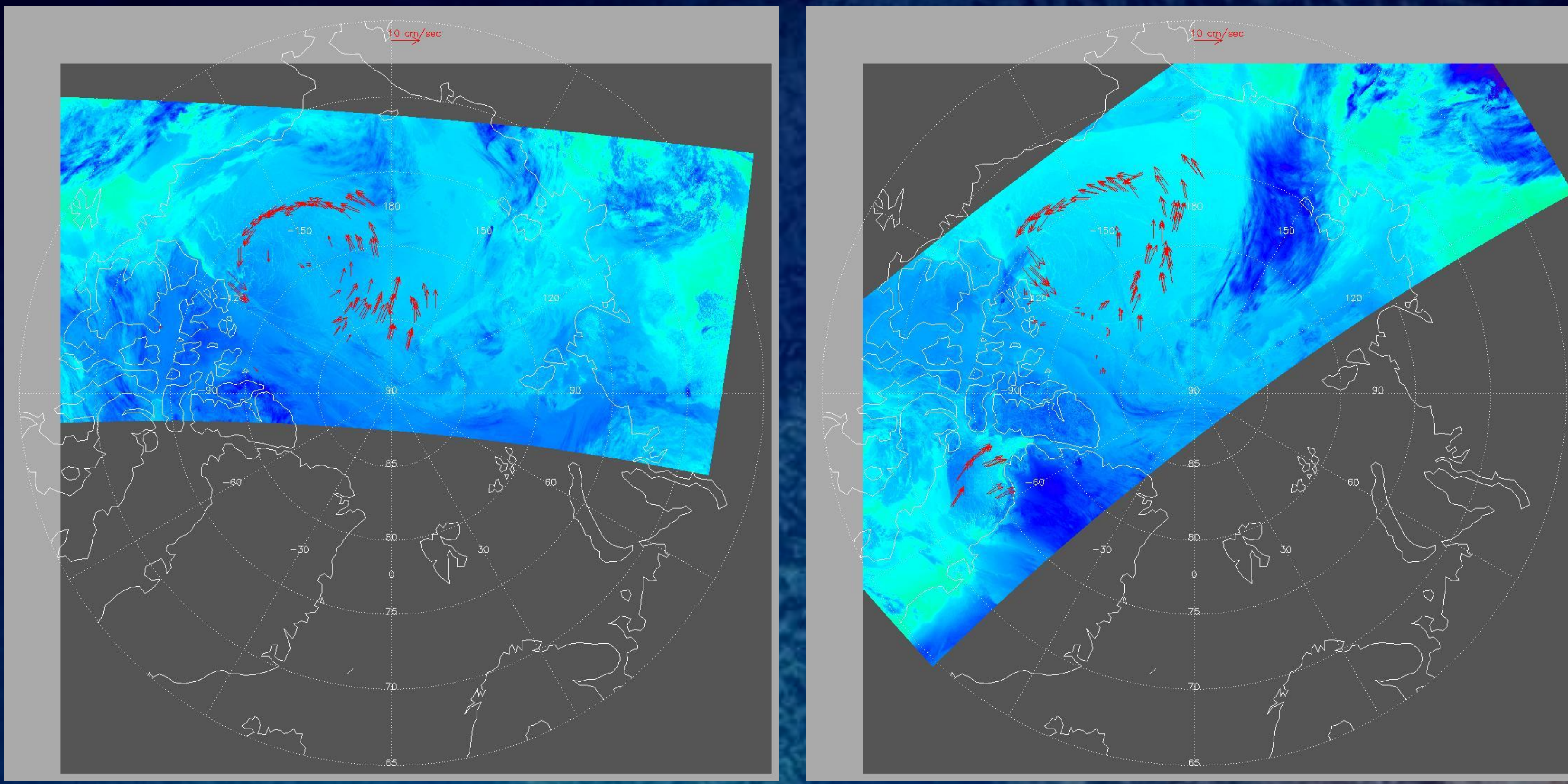
Spec: 80% correct classification

D=day; N=night

	Ice Age (OTIM vs Microwave)
Precision	**(D&N:0.34 Category)** **(N:0.34 Category)** **(D:0.03 Category)**

Spec: 1 category

Ice Motion



Ice motion over the Arctic from MODIS for May 5, 2008 (left), and for May 7 (right).

Sea and Lake Ice Motion Validation

Validation of Ice Motion Product with Buoy Data (1654 pairs)

Ice motion product performance by comparison with buoy data: 1654 pairs	Mean bias (cm/second)	Root mean squared error (cm/second)
Ice motion speed	0.25	3.4
Required measurement accuracy and precision	3.5 (3 km/day)	3.5 (3 km/day)
	Mean bias (degree)	Root mean squared error (degree)
Ice motion direction	2.9	30.0
Required measurement accuracy and precision	22.5	30.0

JPSS VIIRS Cryosphere Team

- JPSS Cryosphere EDR Team
  - Ice, STAR and U. Wisconsin:
    - Jeff Key (team lead), STAR
    - Pablo Clemente-Colón, STAR and National Ice Center (team co-lead)
    - Xuanji Wang, CIMSS
    - Yinghui Liu, CIMSS
    - Tony Schreiner, CIMSS (incoming)
  - Ice, University of Colorado
    - Jim Maslanik, CU/CCAR
    - Mark Tschudi, CU/CIRES
    - Dan Baldwin, CU/CCAR
  - Snow, CREST and IMSG
    - Peter Romanov, CREST
    - Igor Appel, IMSG
- JAM
  - Paul Meade
- NGAS
  - Robert Mahoney
- NASA NPP Science Team
  - Mark Tschudi, CU
- Users
  - Sean Helfrich, NIC
  - Mike Ek, NWS/EMC/Land Hydro Team
  - David Kitzmiller, NWS/OHD
  - Joseph Sienkiewicz, NWS/OPC

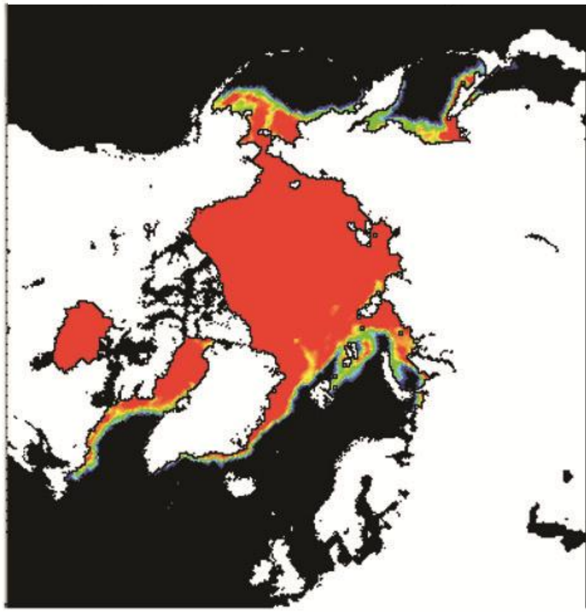
Imagery

VIIRS IR (11.5 m) animation from consecutive overpasses of Suomi NPP over Prince Patrick Island (located in the far northwestern portion of the Canadian Arctic Archipelago) on 28 April 2012.

Ice Cover

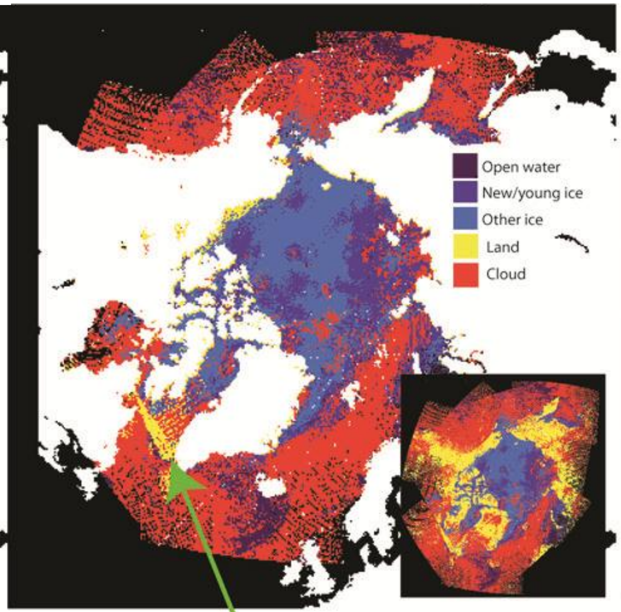
Sea ice extent is realistic, but with some false ice over open water, misclassification of new/young vs. other ice, and some misplacement of land values

SSM/I Ice Concentration



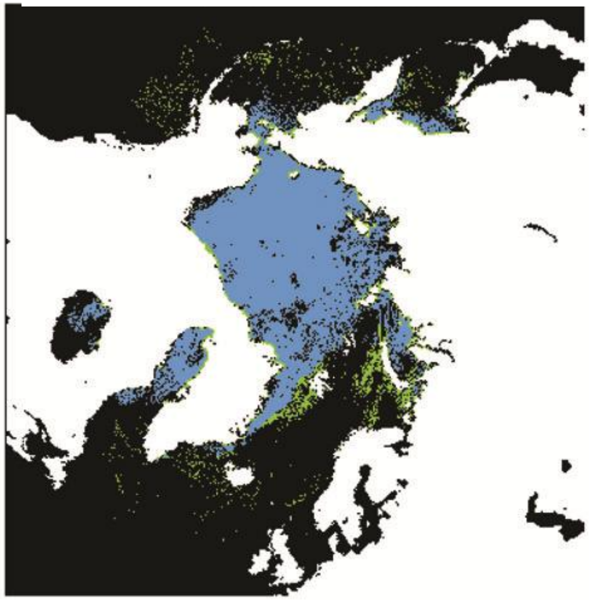
1 Feb 2012

VIIRS Ice Characterization



Land mask pixels in incorrect locations

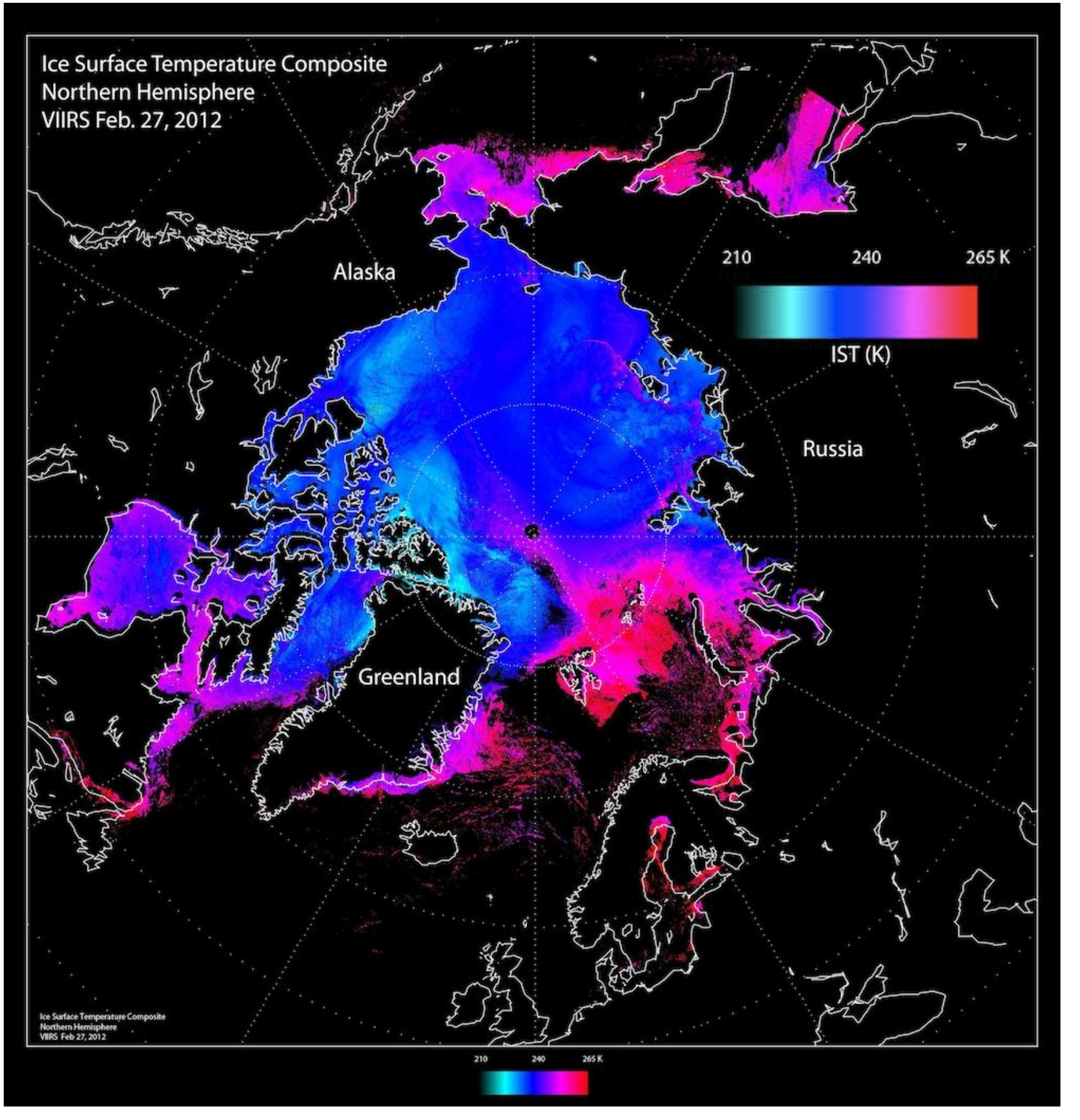
SSM/I vs VIIRS Ice Extent



Green = pixels indicated as ice by VIIRS but not by SSMI
Likely due to cloud mask classifying cloud as clear sky

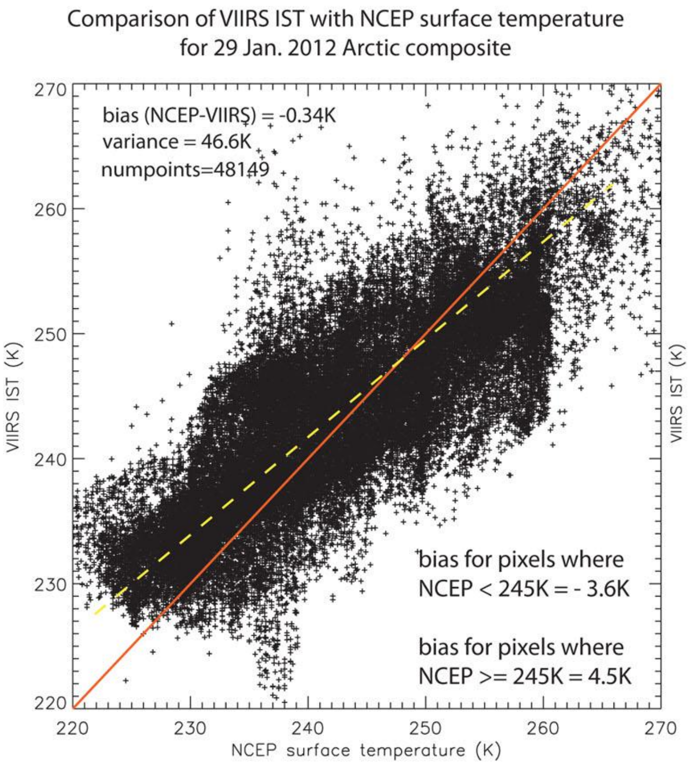
Ice Surface Temperature

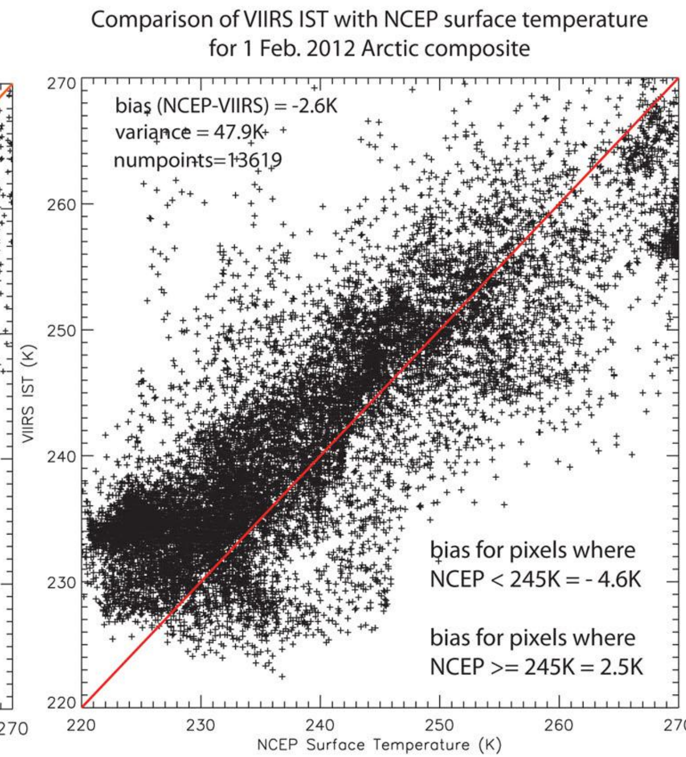
VIIRS Brightness temperature (BT) at 11 um (upper left), IST (upper right), MODIS IST (lower left) from 1440 to 1500 UTC, and NCEP surface air temperature at 1200UTC, March 7, 2012.



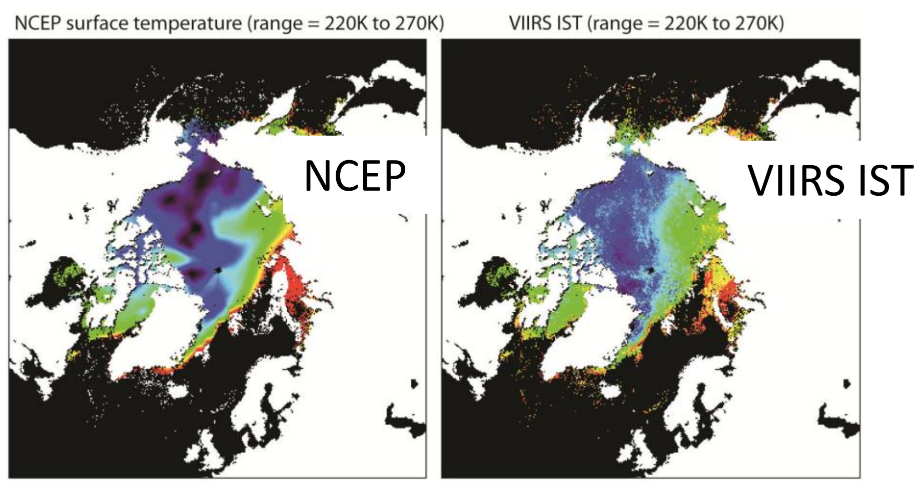
VIIRS IST has a 1-2 K cold bias relative to MODIS. The bias for VIIRS Land Surface Temperature over the ice sheet (not shown) is less than for IST. Compared to drifting ice buoy near-surface air temperatures, the **mean difference (buoy minus VIIRS IST) is 4.8K.**

VIIRS IST vs NCEP Reanalysis Surface Temperature





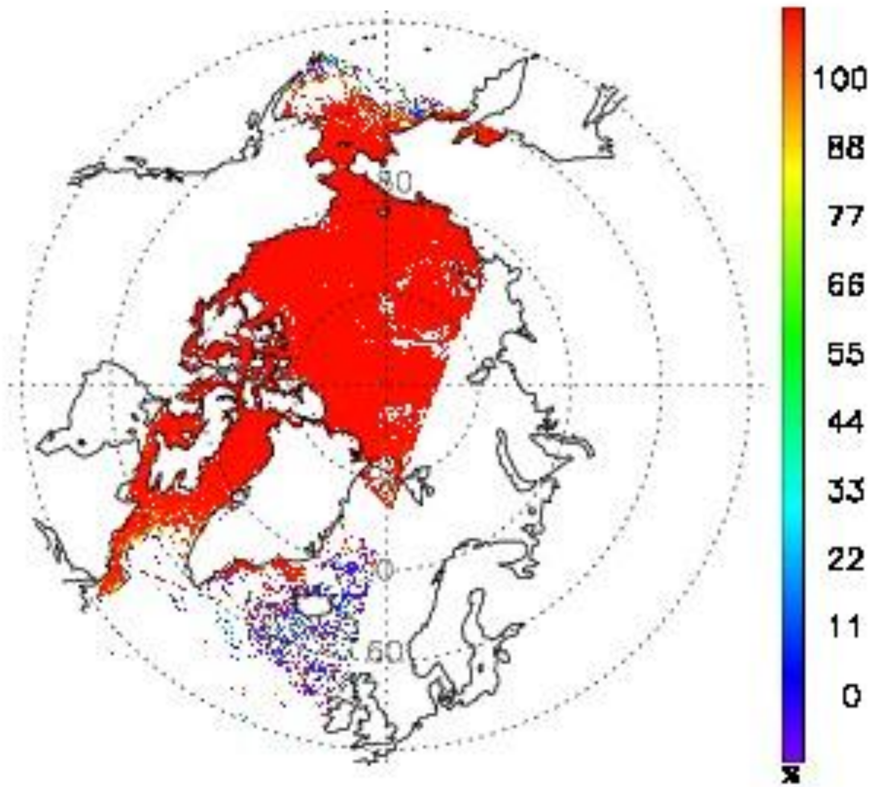
VIIRS is biased high (too warm) compared to NCEP reanalysis (opposite of the MODIS results). Bias increases with decreasing temperature.



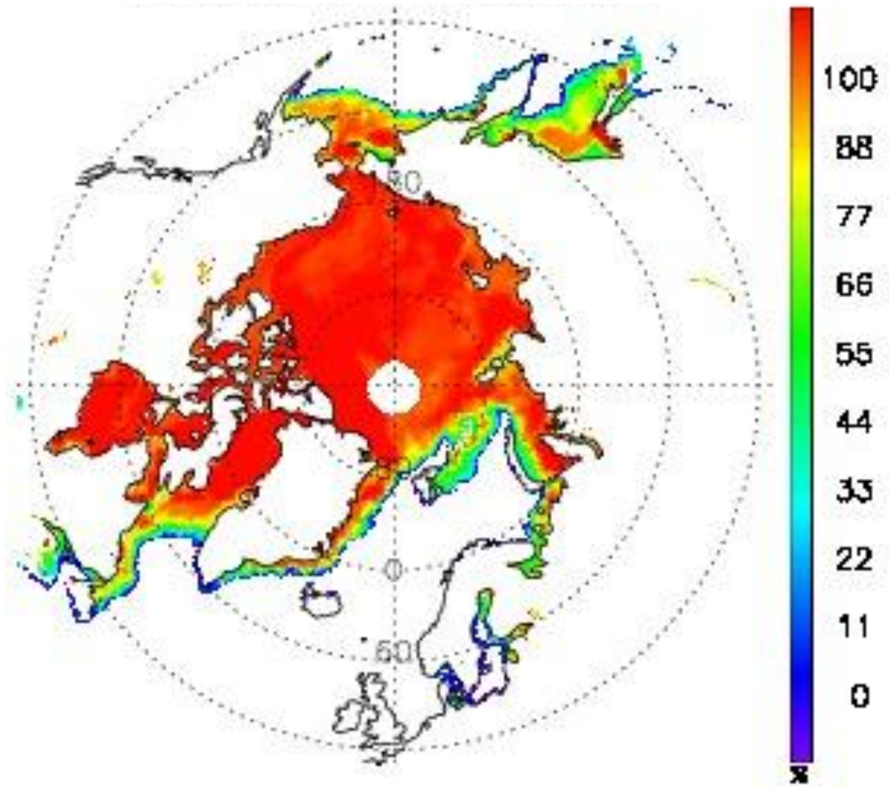
Spatial patterns of IST vs. surface temperature are consistent.

Ice Concentration (IP)

VIIRS Ice Concentration



Microwave Ice Concentration



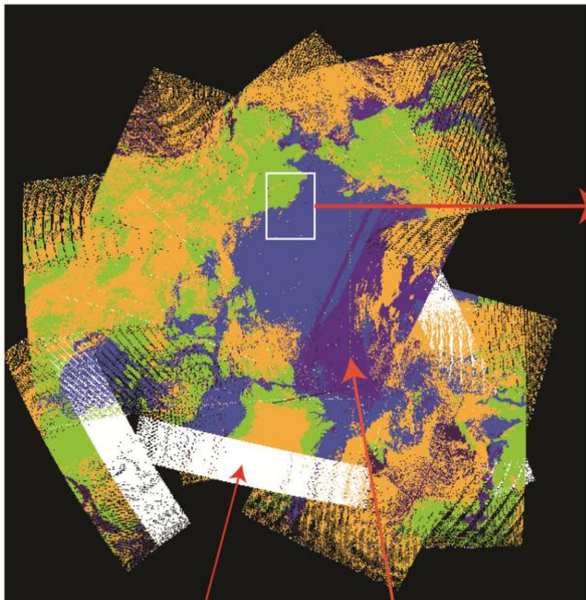
Ice concentration from VIIRS 1440 to 1500 UTC (left) and SSM/I daily mean (right) over Arctic on March 7, 2012.

VIIRS ice concentration is **biased high relative to passive microwave data** overall, but biased low at the low end.

Sea Ice Characterization

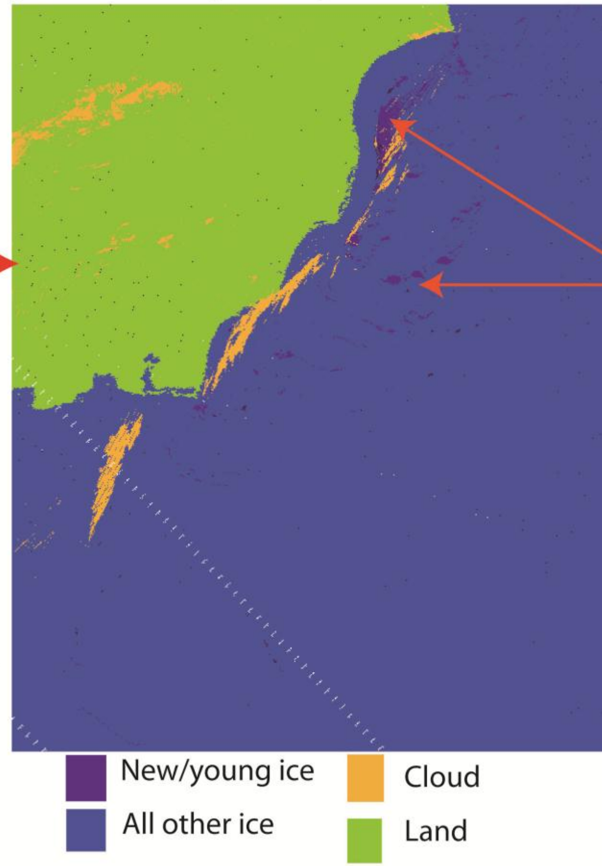
Ice type misclassification: Suggests that new/young ice vs. other ice classification may be working relatively well for daytime passes, but not for nighttime.

Sea Ice Characterization (30 March 12)

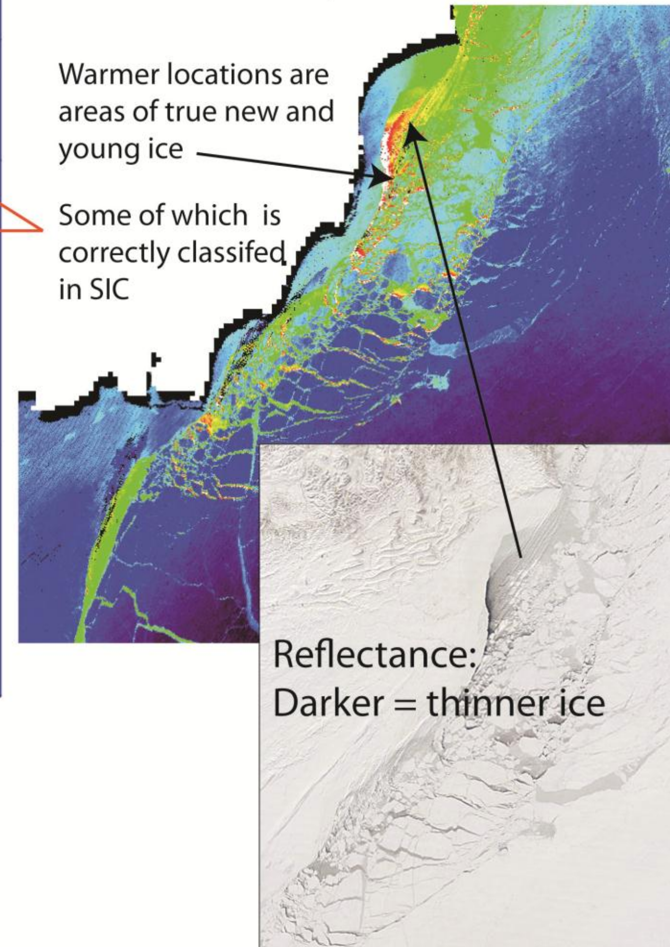


data value = 254 (ice free). Should be data value =1 (ice free) to be consisent with other values.

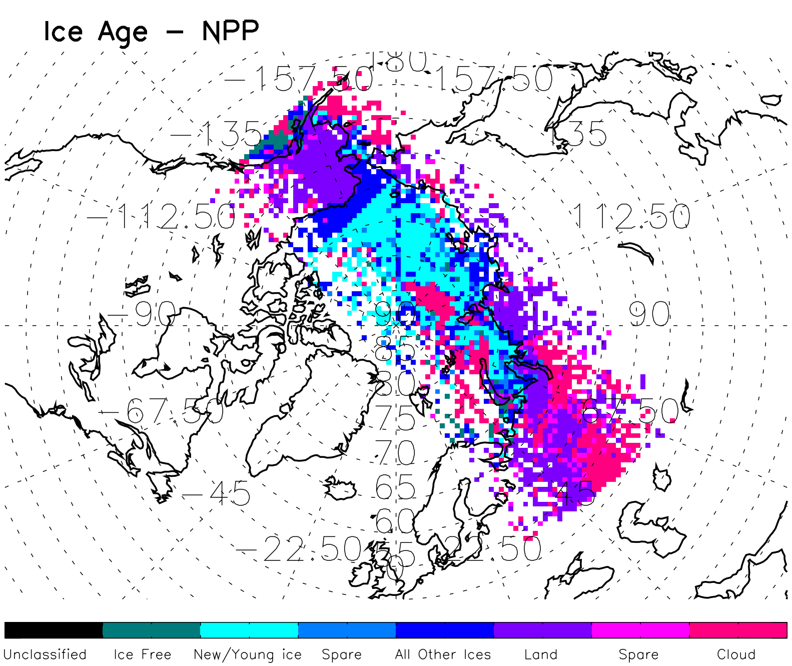
Large area incorrectly classified as new/young ice

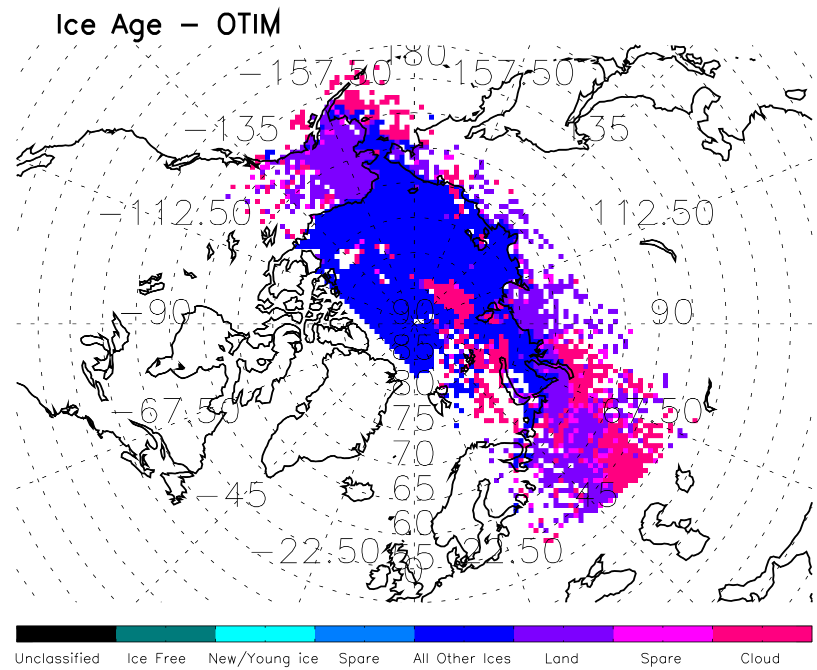


VIIRS Ice Surface Temperature (30 March 12)



Ice Age, VIIRS vs OTIM (GOES-R method)



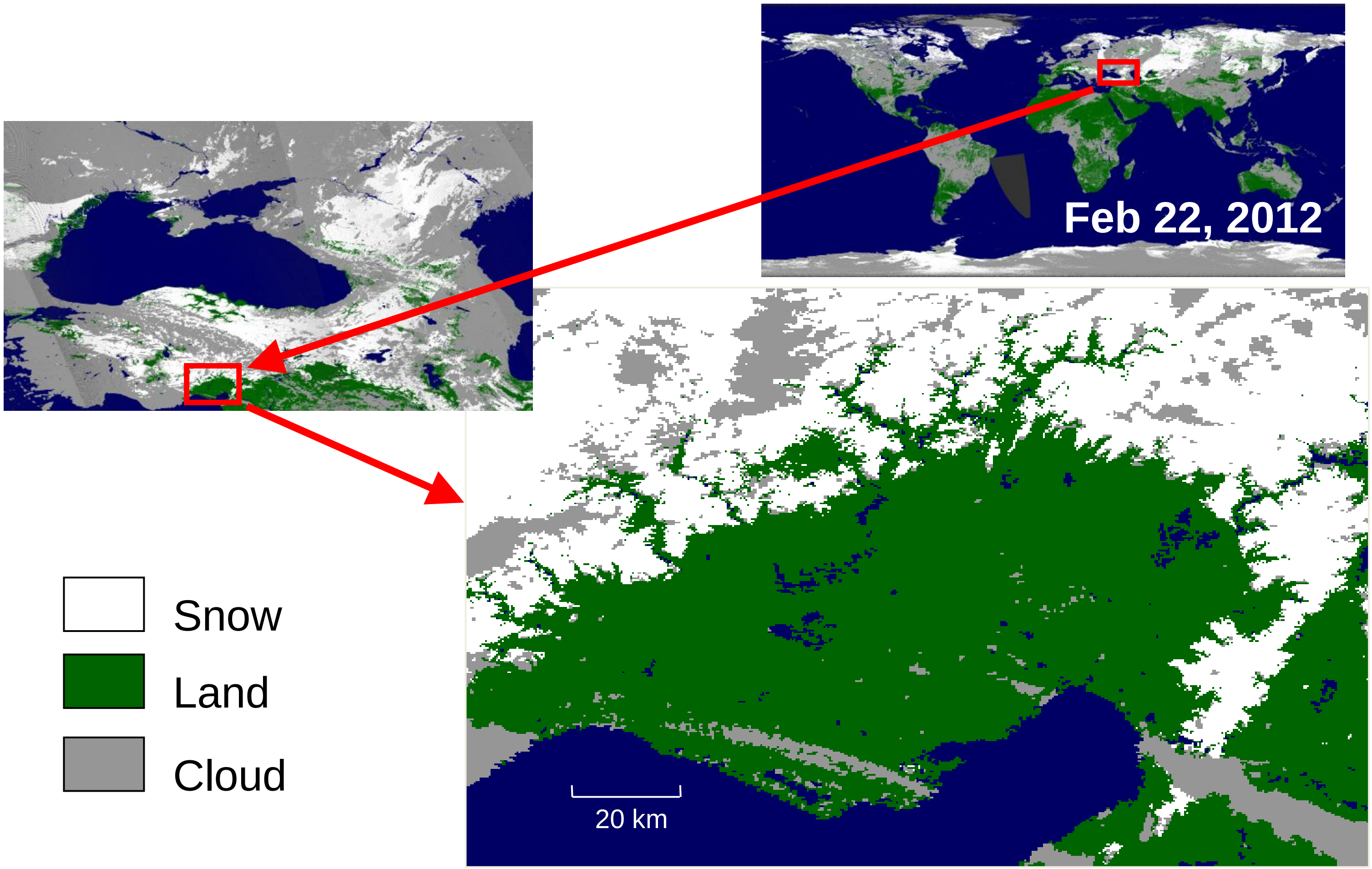


VIIRS ice age using NG (left) and OTIM (right) algorithms, March 4, 2012. OTIM ice thickness/age is based only on VIIRS IST.

Pixels	NG ice age	OTIM ice age	Difference (NG - OTIM)
Ice free	8%	0%	8%
New/Young ice	60%	0%	60%
All other ice	32%	100%	-68%

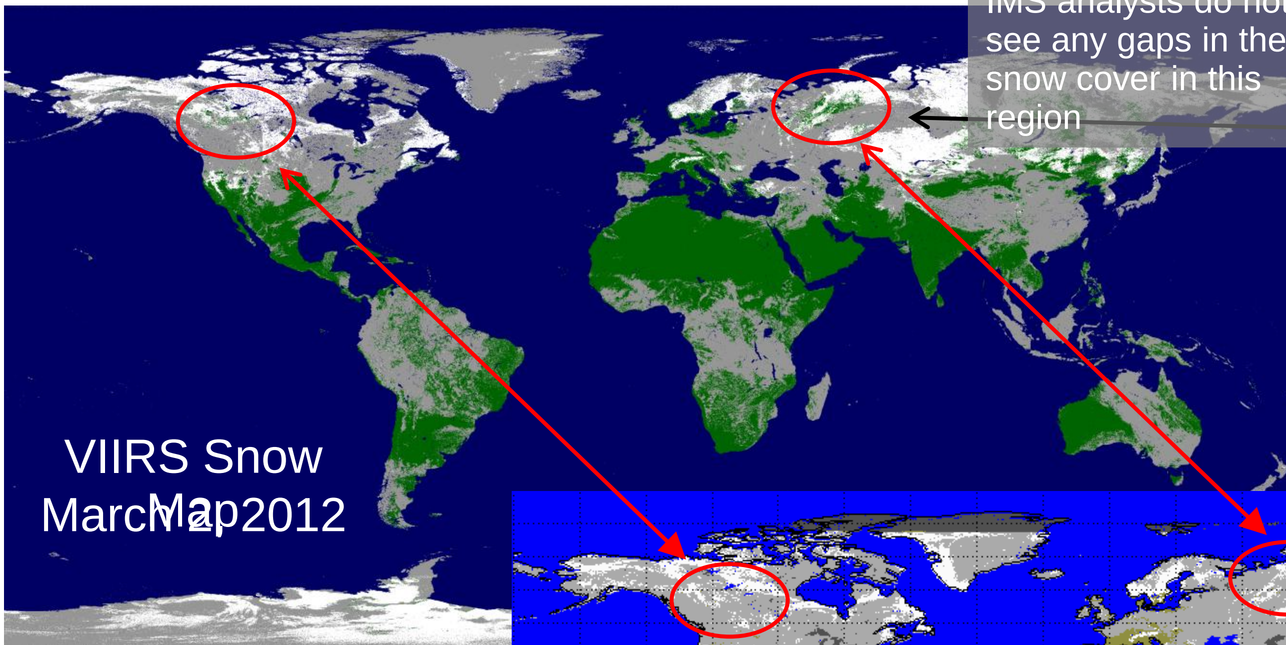
Validation of Snow Properties

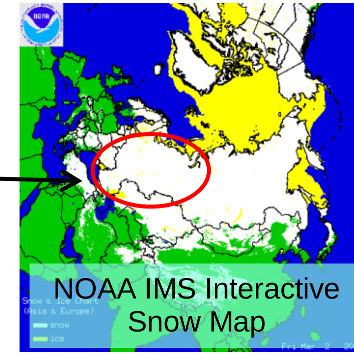
Global gridded VIIRS snow map: **Realistic, detailed** characterization of regional snow cover at high spatial resolution

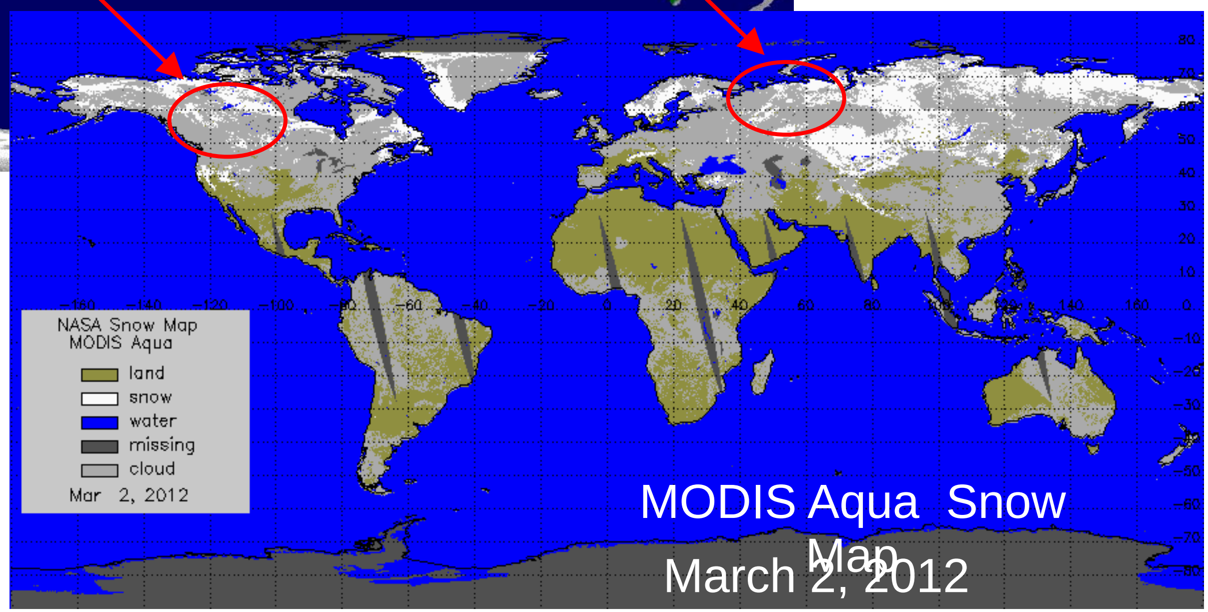


0.5 km spatial resolution

VIIRS misses more snow than MODIS



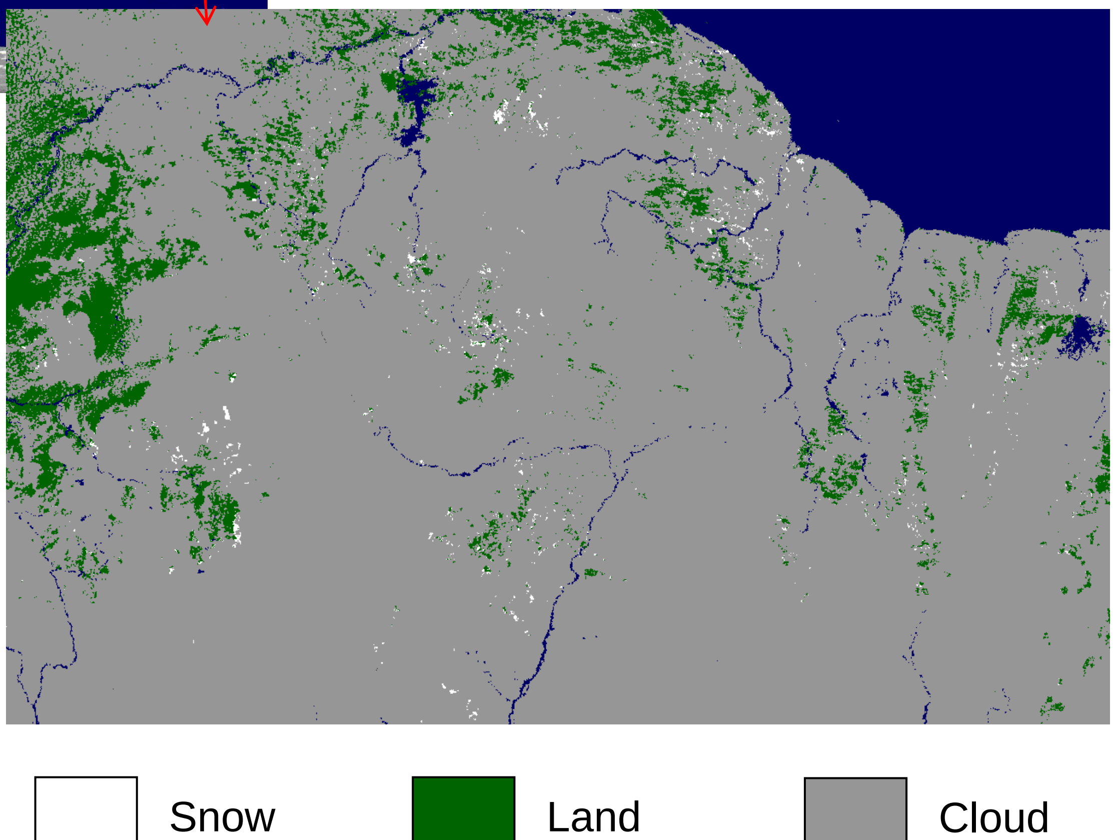




Example of substantial snow misses in the VIIRS map (above). Snow misses are much smaller in the MODIS product (right). However MODIS labels more pixels as “cloudy”

Snow commission errors are frequent and easily seen in tropical areas

Commission errors occur due to the confusion of clouds with snow cover



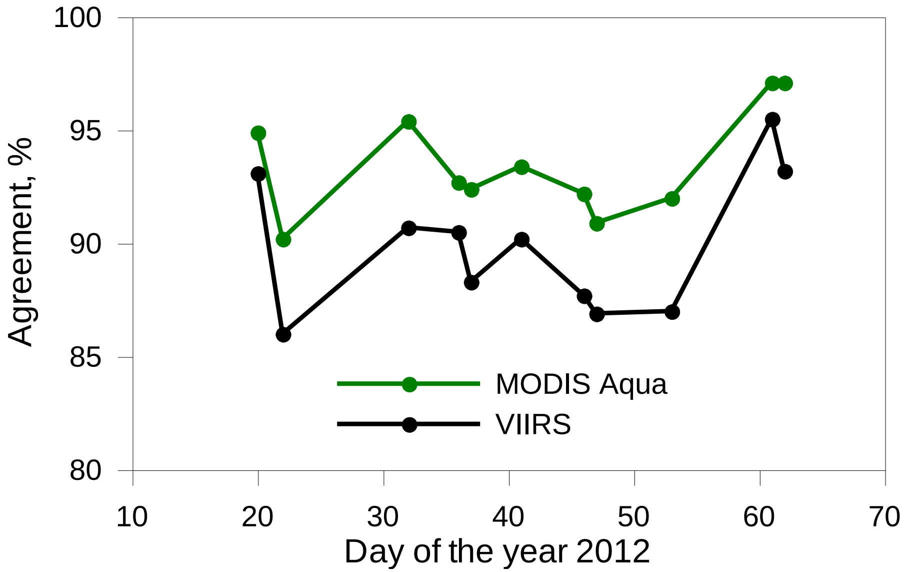
Area size: ~ 800 x 1200 km

<u>Classification results:</u>
Water: 10.2%
Cloud: 82.8%
Land: 6.6%
Snow: 0.4% (errors)

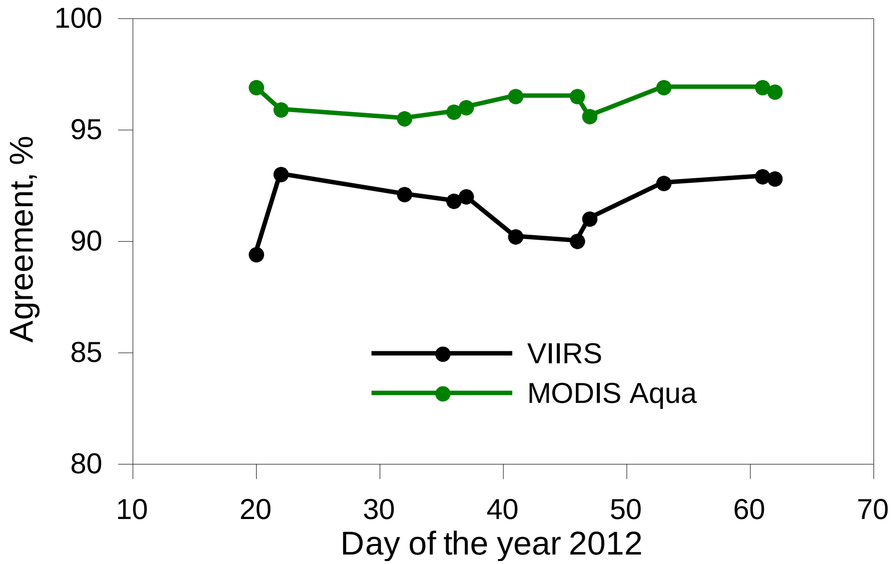
However, the area is completely snow-free.

<u>The rate of snow commission errors in clear sky land pixels is 5.7%</u>

VIIRS vs MODIS snow: MODIS looks better so far

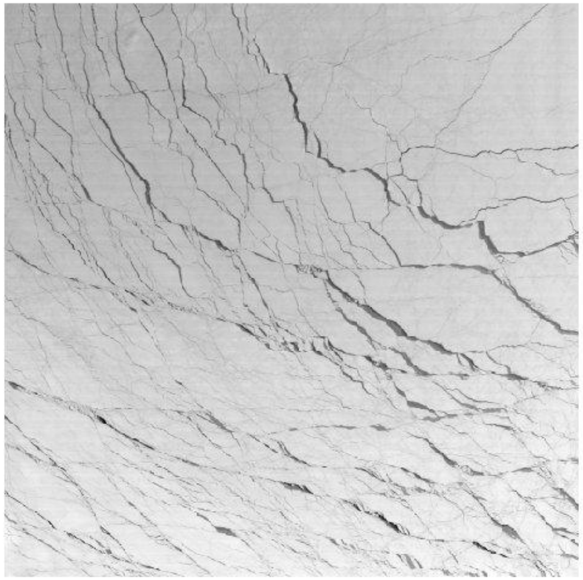


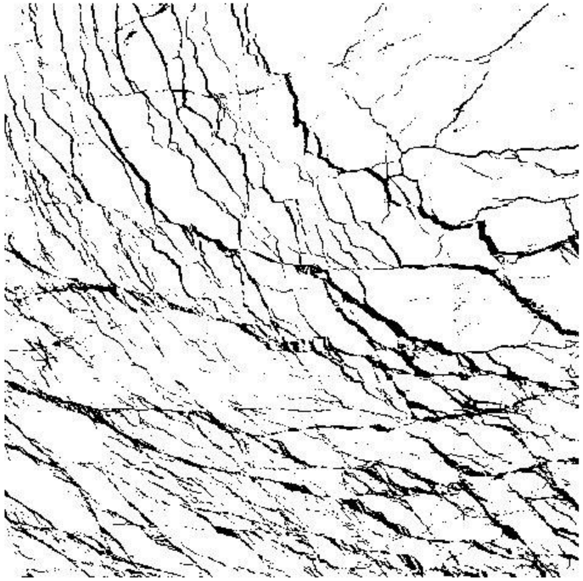
- MODIS and VIIRS gridded snow vs **in situ** observations
- 400 to 900 comparisons daily
- CONUS area

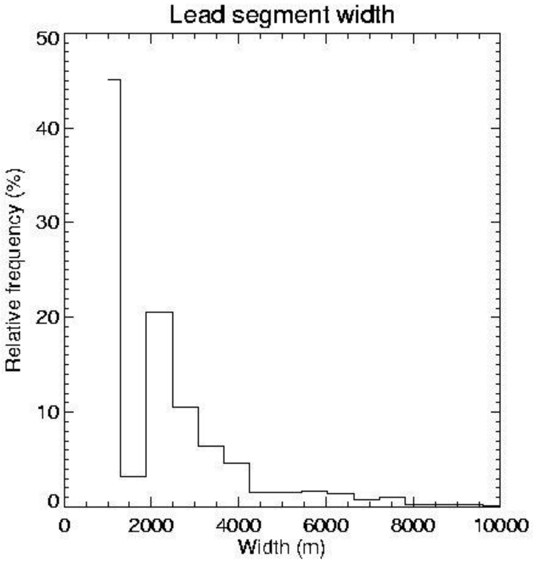


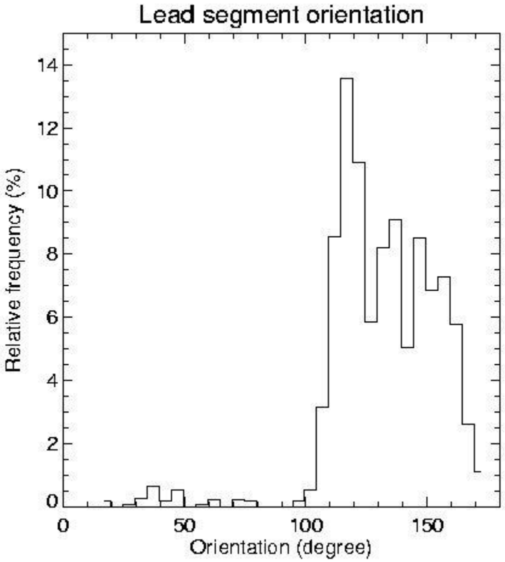
- MODIS and VIIRS vs **IMS maps**
- Northern Hemisphere
- 30N-70N area

New VIIRS Proving Ground Effort: Sea Ice Leads









The reflectance at 0.64 μm from MODIS (upper left), mask of leads derived using group thresholds method (upper right), distributions of lead segment width (lower left), and lead segment orientation (lower right) based on the mask of leads. The scene is over the Beaufort and Chukchi Seas on March 11, 2009.

Uses and Users (again)

- Numerical Weather Prediction (NWP centers)
  - Snow and ice cover are commonly used.
  - Ice thickness is used in some applications; should be used universally!
- Navigation and Transportation (National Ice Center, Alaska Ice Desk, local services)
  - Shipping, national security
  - Highway, railroad, municipal, and commercial snow removal services
- Hydrologic Modeling (NOHRSC, local services)

  Satellite-derived snow information is assimilated into spatially distributed snow models that forecast snow depth, snowpack water content, and snow melt
    - River flood forecasters – the protection of life, property, and commerce
    - Emergency managers and responders
    - Water supply forecasters – spring snow melt water is valued at ~$350 billion annually
    - Soil moisture forecasters and agriculture, forestry, and wildfire managers
    - Recreation industry
    - Business managers responsible for winter-product placement and market evaluation
- Climate Modeling, Monitoring, and Analysis (Reanalysis projects, science community)