VIIRS CRYOSPHERE SESSION

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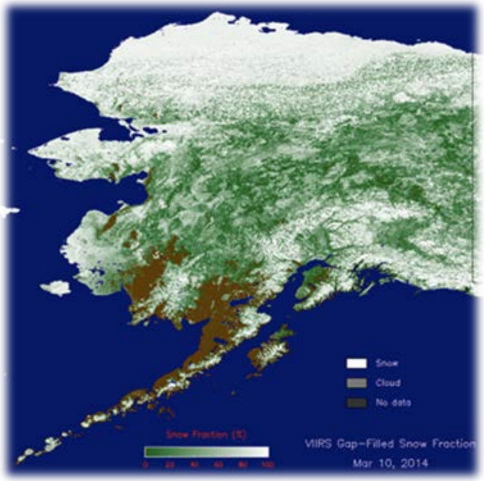
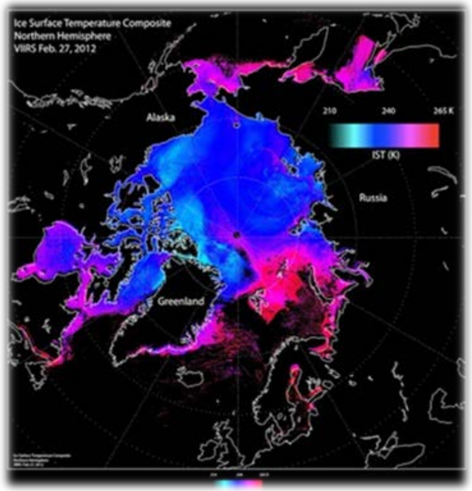
VIIRS Operational Products

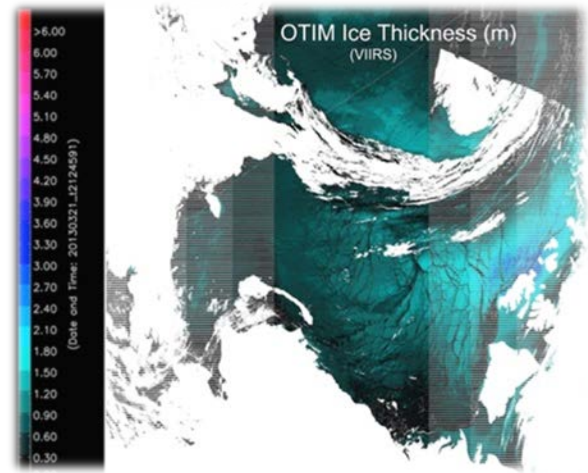
Snow Fraction



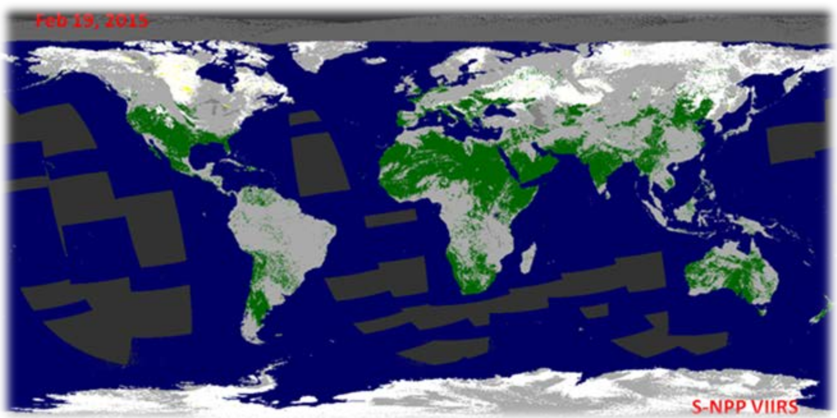
Ice Surface Temperature



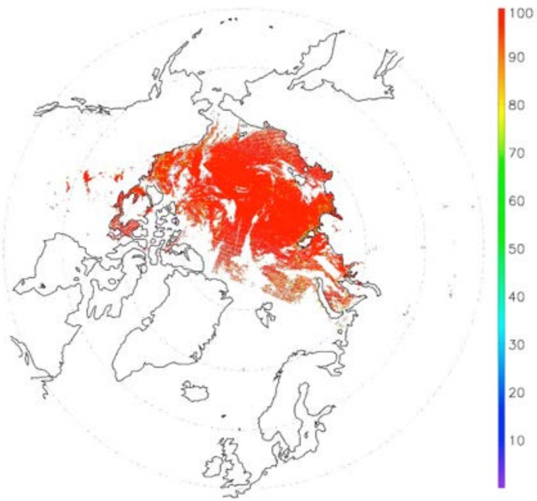
Ice Thickness/Age



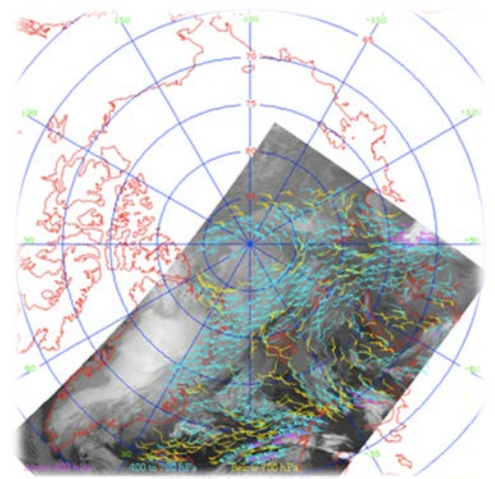
Snow Cover (binary)



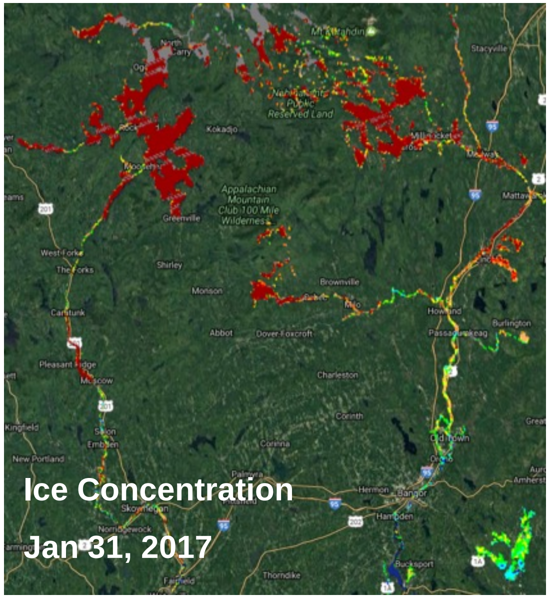
Ice Concentration



Polar Winds

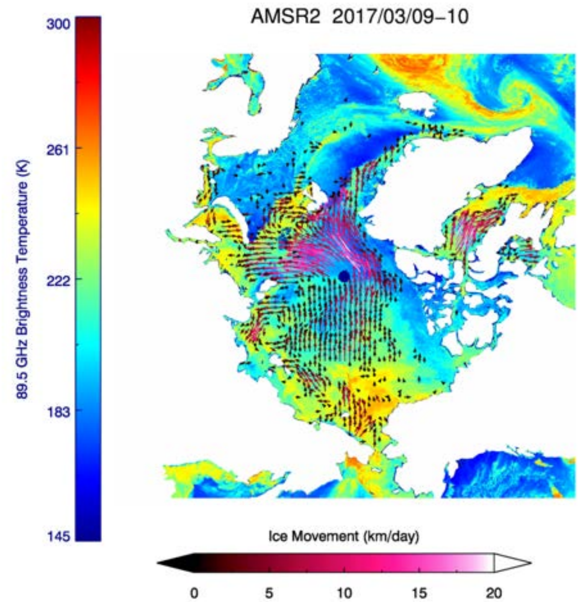


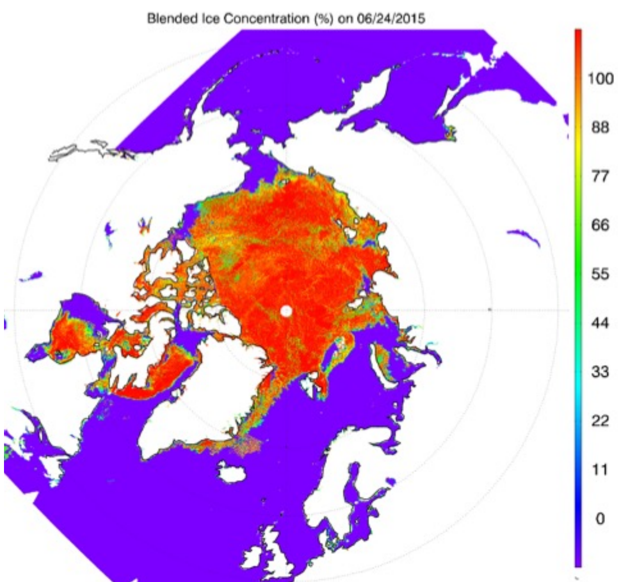
Experimental Products



River Ice

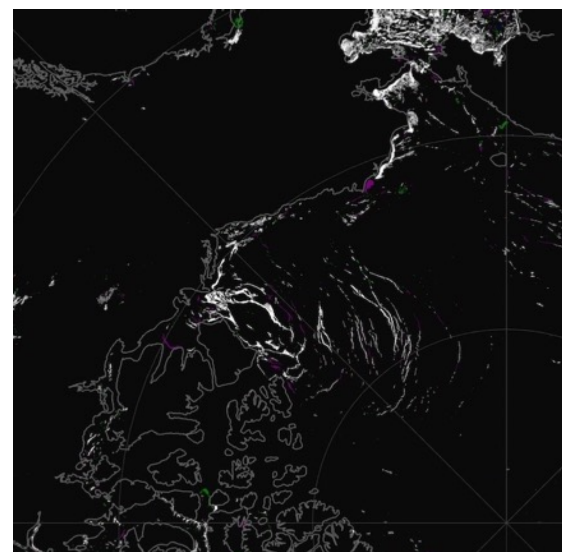
Ice Motion





Blended Ice Concentration

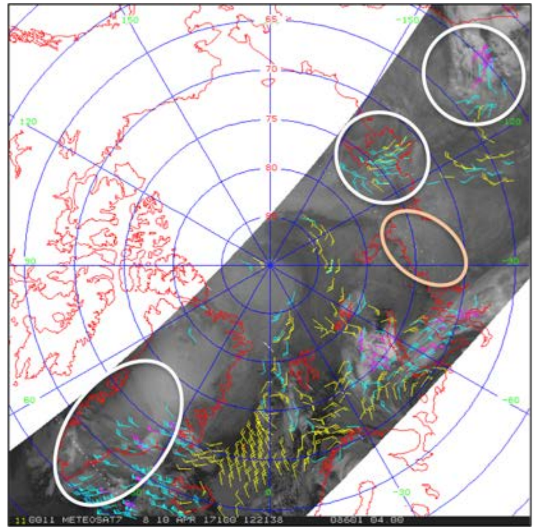
Sea Ice Leads

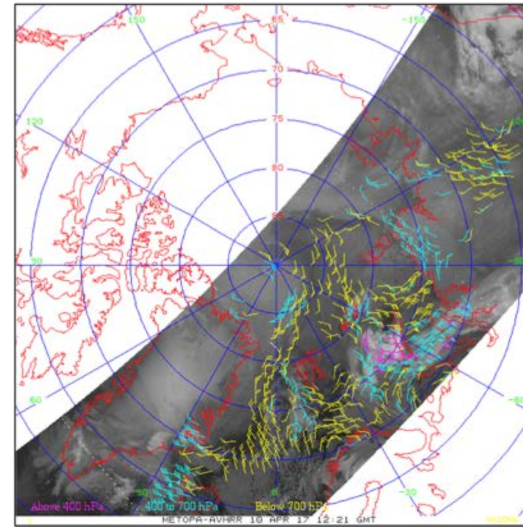


Experimental Products, cont.

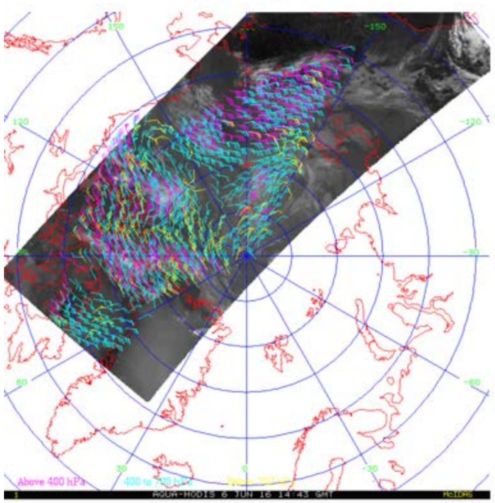
Winds from combined S-NPP and JPSS-1

Far right: Single-satellite AVHRR winds. Right: Winds from Metop-A and –B.

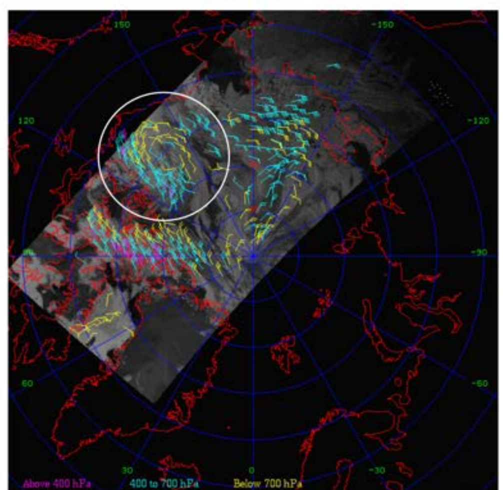




WV + IR



SWIR



Polar winds with the SWIR band

Agenda

13:15 Introduction and welcome –Jeff Key (NOAA/STAR)

1. Enterprise and Operational Products

13:20 Binary snow cover and snow fraction – Peter Romanov (CREST)

13:45 Sea ice surface temperature - Mark Tschudi (CU/CCAR/CIRES)

14:00 Sea ice concentration – Yinghui Liu (CIMSS)

14:15 Sea ice thickness and age – Xuanji Wang (CIMSS)

14:30 Polar winds – Jeff Key

14:35 Discussion: IDPS to NDE transition issues - All

Agenda, cont.

2. New and Experimental Products

14:45 River ice – Peter Romanov

15:00 **Break (15 min)**

15:15 Sea ice motion – Aaron Letterly (CIMSS)

15:30 Blended sea ice concentration – Yinghui Liu, Sean Helfrich (STAR)

15:45 Sea ice leads – Jay Hoffman (remote) (CIMSS)

3. Applications of JPSS cryosphere products

16:00 NCEP – Mike Ek

16:15 NAVO – Bruce McKenzie

16:30 National Ice Center – Sean Helfrich

16:45 Open discussion and wrap-up – All

17:00 **End of session**

River and lake ice

Ice sheets,
ice caps,
ice shelves

Sea ice

Permafrost and
seasonally-frozen
ground

Snow

Glaciers

GCW Global Cryosphere Watch

VIIRS SNOW COVER PRODUCTS: CURRENT STATUS AND PLANS

Peter Romanov
CREST/CUNY at NOAA/STAR
peter.romanov@noaa.gov

Outline

- VIIRS Binary Snow Cover and Fractional Snow Cover
  - Definition, requirements
  - IDPS product performance
  - Enterprise products and performance
  - Further algorithm enhancements

Cal/Val Team Members

Name	Organization	Roles and Responsibilities
Jeff Key	NOAA/NESDIS	Cryosphere Team Lead
Peter Romanov	CUNY/CREST	Snow Products Lead
Sean Helfrich	NOAA/NIC	User/Applications
Michael Ek	NOAA/NWS	User/Applications

JPSS ESPC (JERD) Requirements

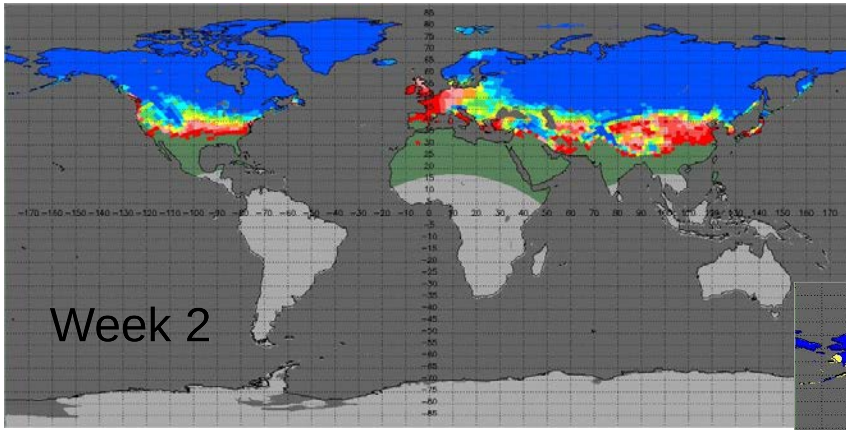
- Binary snow map:
  - Snow/no snow discrimination
  - 90% probability of correct typing
    - Over climatologically snow-affected areas

- Snow fraction:
  - “Viewable” snow fraction
  - 20% accuracy

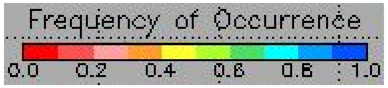
- Both products are
  - Clear-sky daytime-only land products
  - Derived at 375 m resolution

- Both products depend on the accuracy of VIIRS cloud mask.

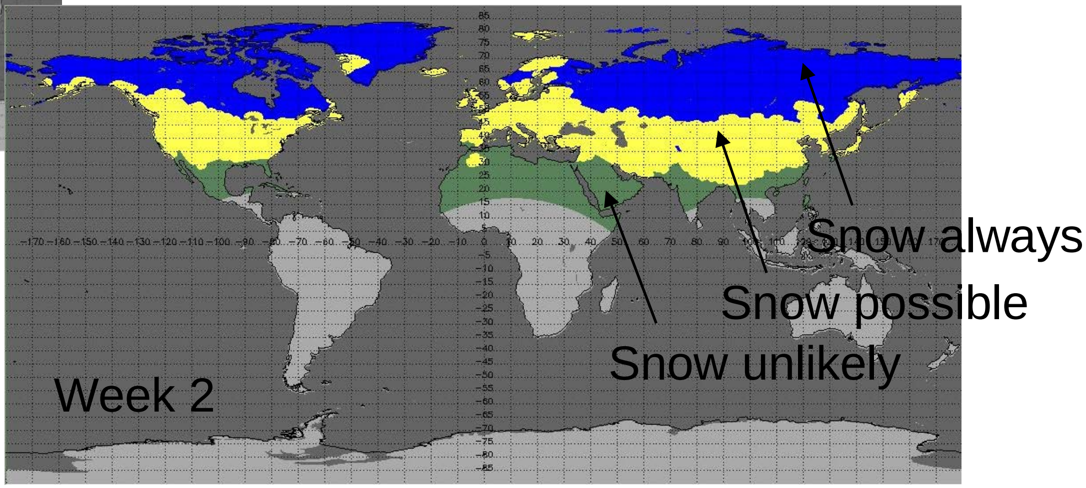
Climatologically snow-affected areas



Weekly climatic snow cover occurrence



Snow cover occurrence categories

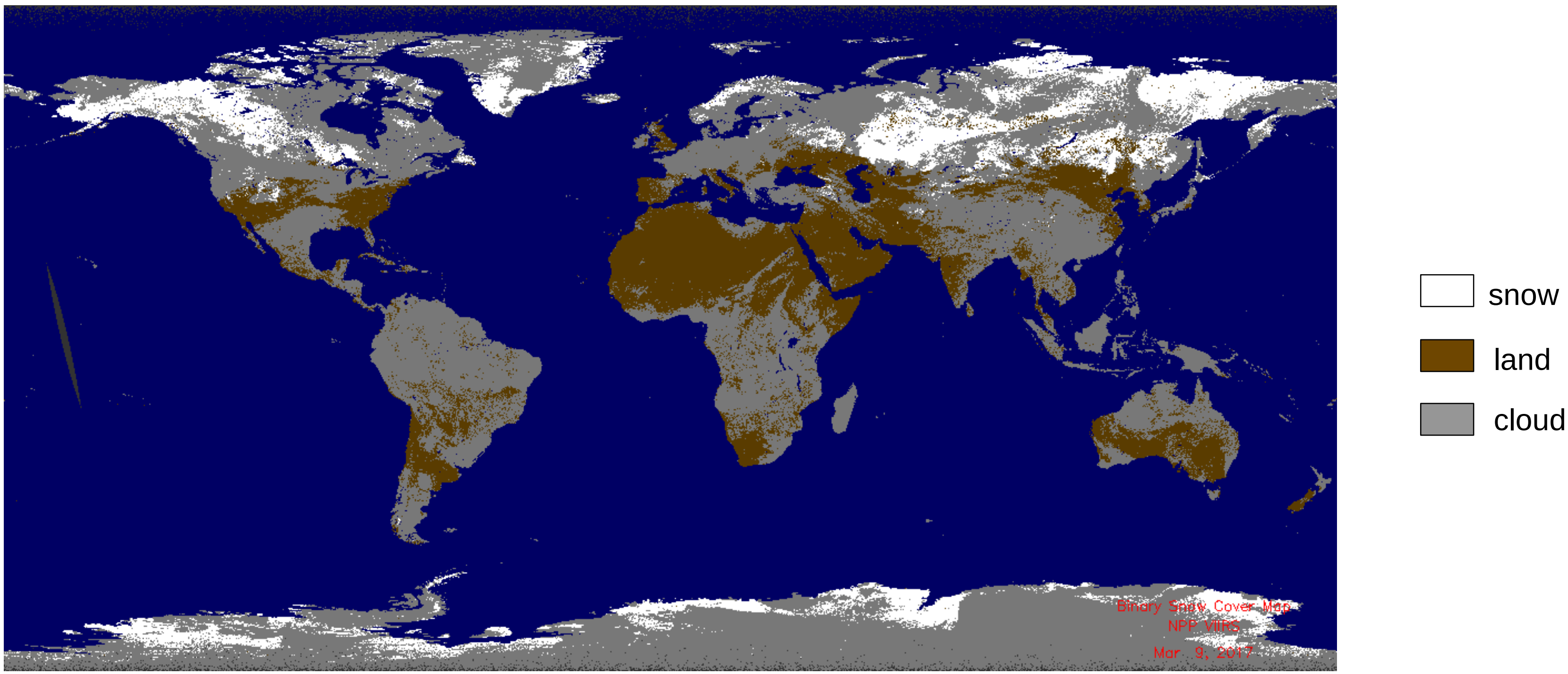


- Accuracy estimates are focused on the “snow possible” region (shown in yellow)

Binary Snow Cover

IDPS Daily Product Monitoring

- Algorithm analogous to MODIS SnowMap
- Product locally gridded to 0.01 deg geographical projection
- Evaluation through : Visual examination, comparison with IMS and in situ data

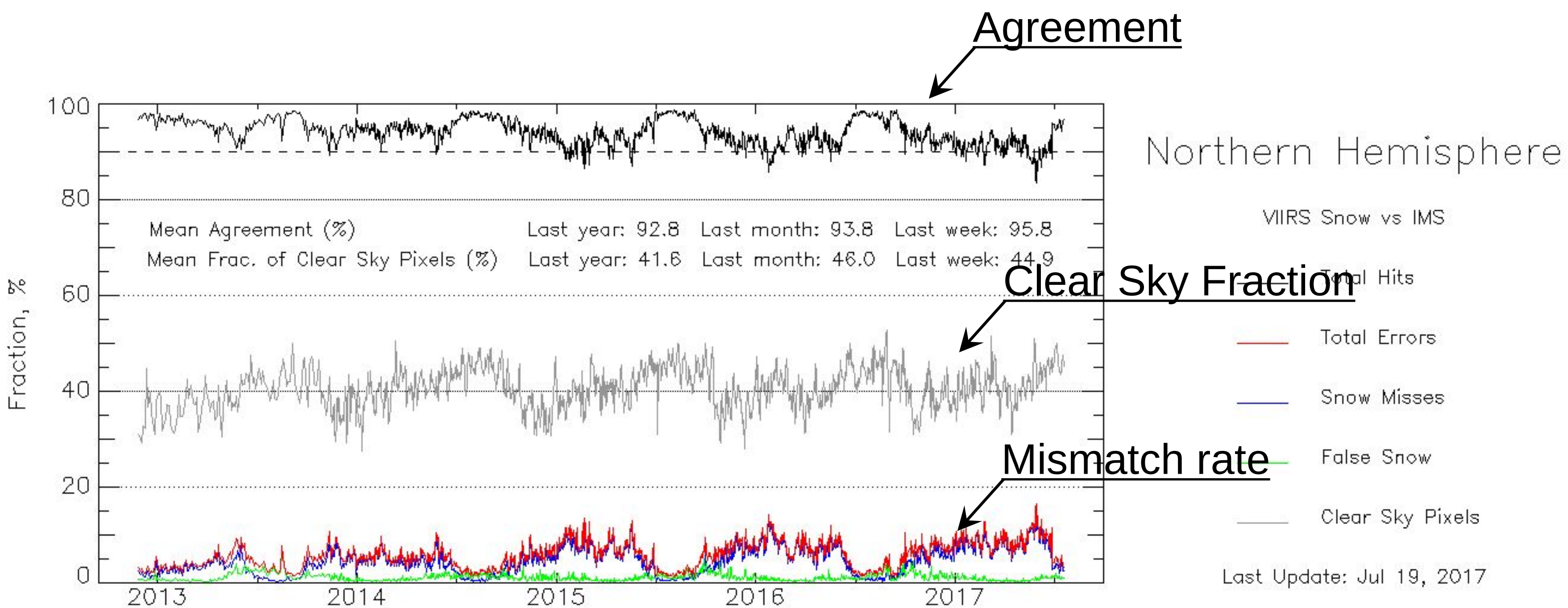


- On the Web (map updated daily)

  http://www.star.nesdis.noaa.gov/smcd/emb/snow/viirs/viirs-snow-fraction.html
  http://www.star.nesdis.noaa.gov/jpss/EDRs/products_snow.php

VIIRS IDPS Snow vs IMS

VIIRS binary snow map : Daily agreement to IMS

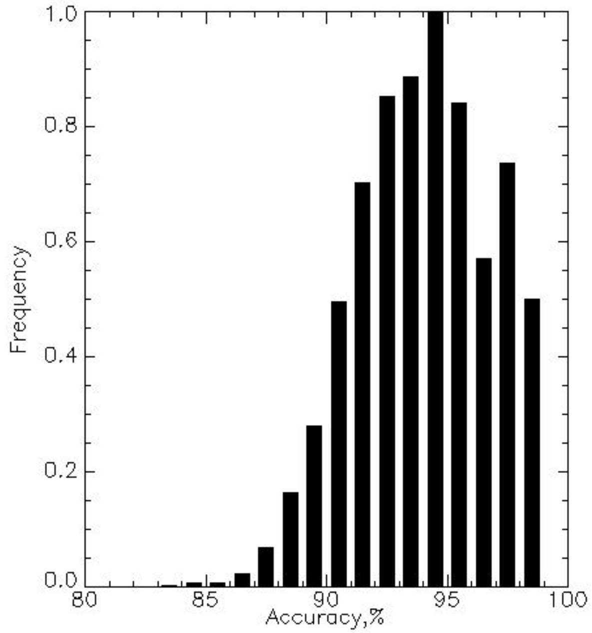


- Agreement rate: mostly over 90%
- IMS maps more snow than VIIRS
- VIIRS cloud fraction over land: ~ 60%

IDPS Binary Snow: Accuracy

Daily rate of agreement of VIIRS IDPS snow maps

- To IMS (NH, over “snow possible” areas)
  - Mean: 93%,
  - Range: 85-99%
- To in situ reports (CONUS, November-April)
  - Mean: 92%
  - Range: 83-96%



VIIRS vs IMS daily rate of agreement statistics

Product	Requirement	Performance
Binary Snow	90% Correct Typing	Mean: 92-93% Range: 83-98%

Product generally satisfies current requirements

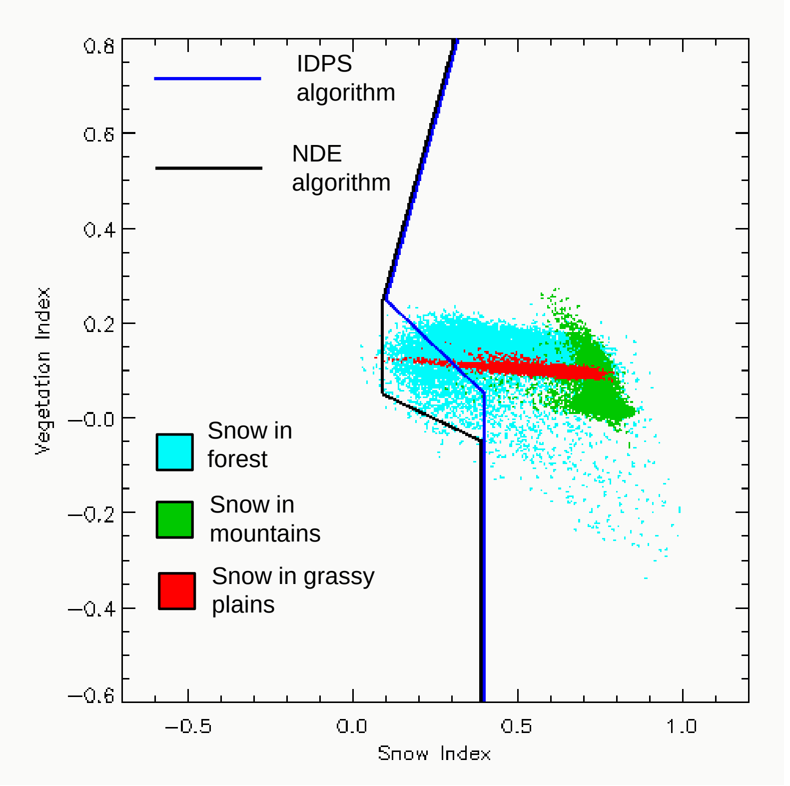
Enterprise Binary Snow Algorithm

Intent: More efficient snow detection in forests
Reduce spurious (false) snow retrievals

Two-stage algorithm:

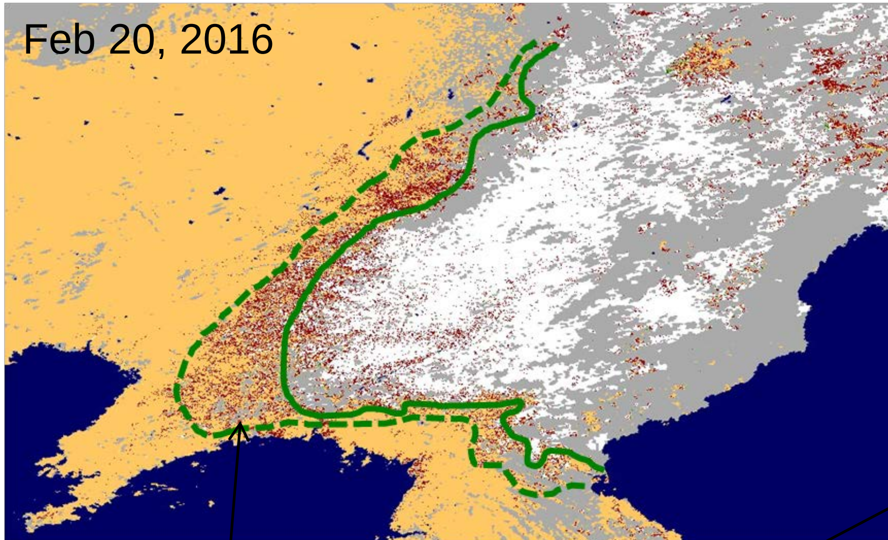
1. Spectral tests (bands I1, I2, I3, I5)
- Improved snow identification in forest

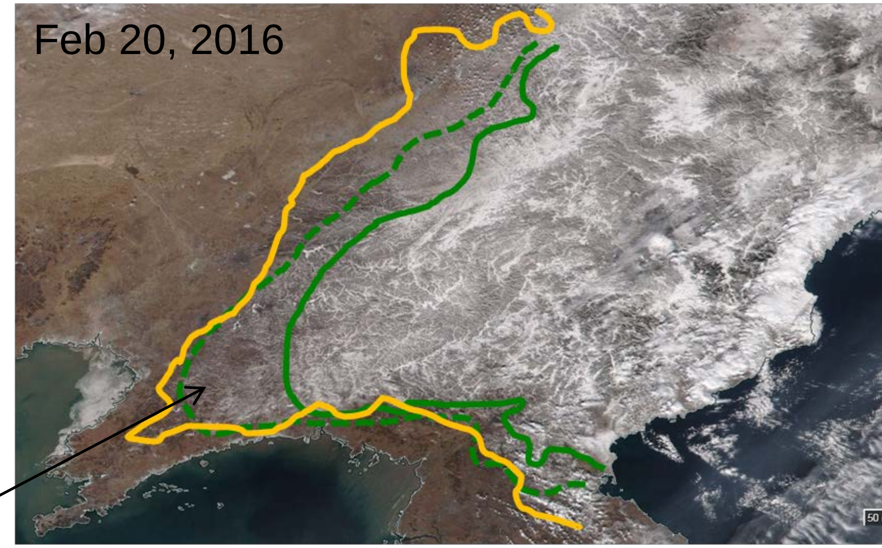
2. Consistency tests
- Eliminate spurious snow



Consistency tests (applied to "snow" pixels) :
- Snow climatology
- Surface temperature climatology
- Spatial consistency
- Temperature spatial uniformity

NDE vs IDPS Binary Snow Product





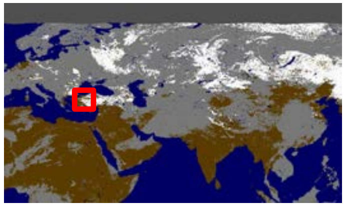
- IMS snow
- IDPS snow
- NDE snow
- Snow mapped by NDE but not IDPS
- Snow mapped by both NDE and IDPS
- Clouds

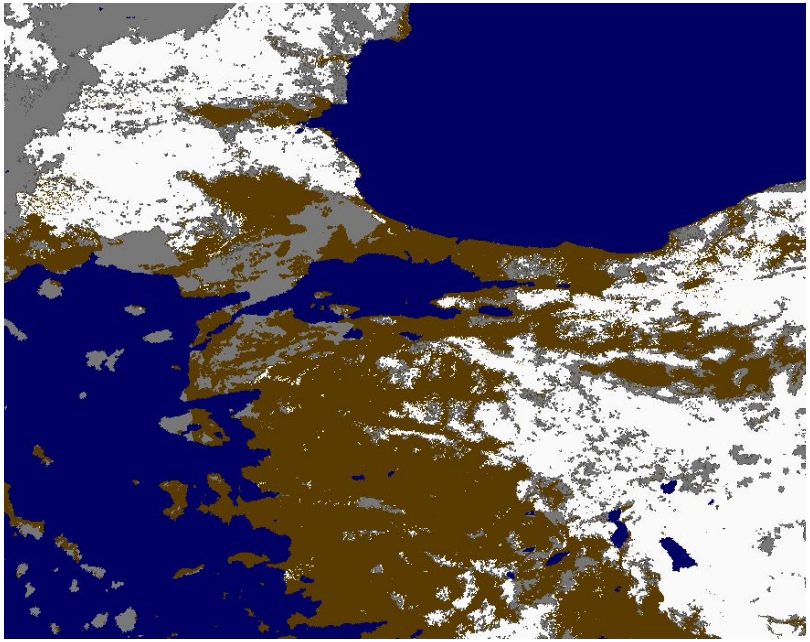
IMS snow

NDE algorithm maps more snow in the transition zone, better fits IMS

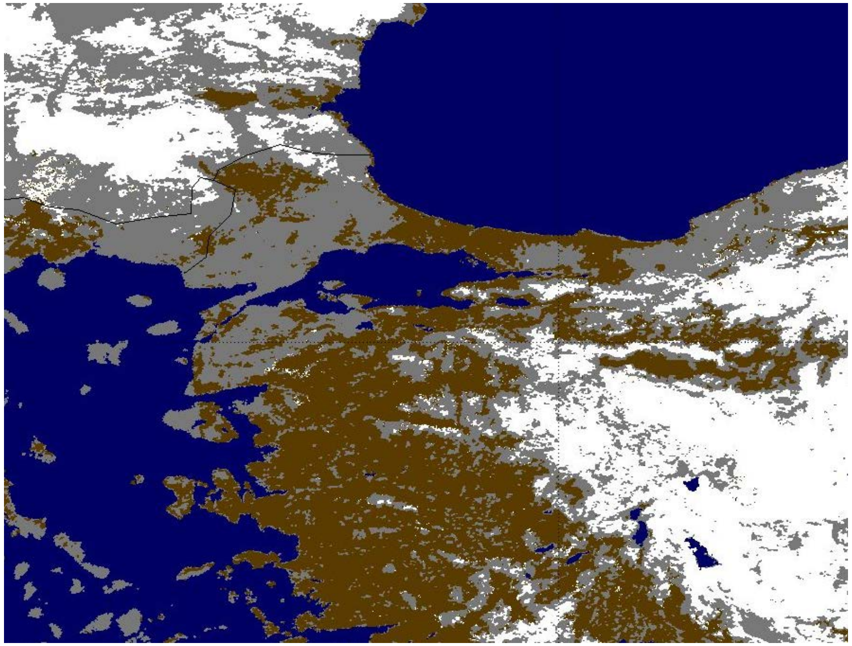
NDE vs IDPS Binary Snow Product

NDE: Better delineation of the snow cover boundary due to less conservative cloud masking in the snow/no-snow transition zone





NDE, Feb 2 2017

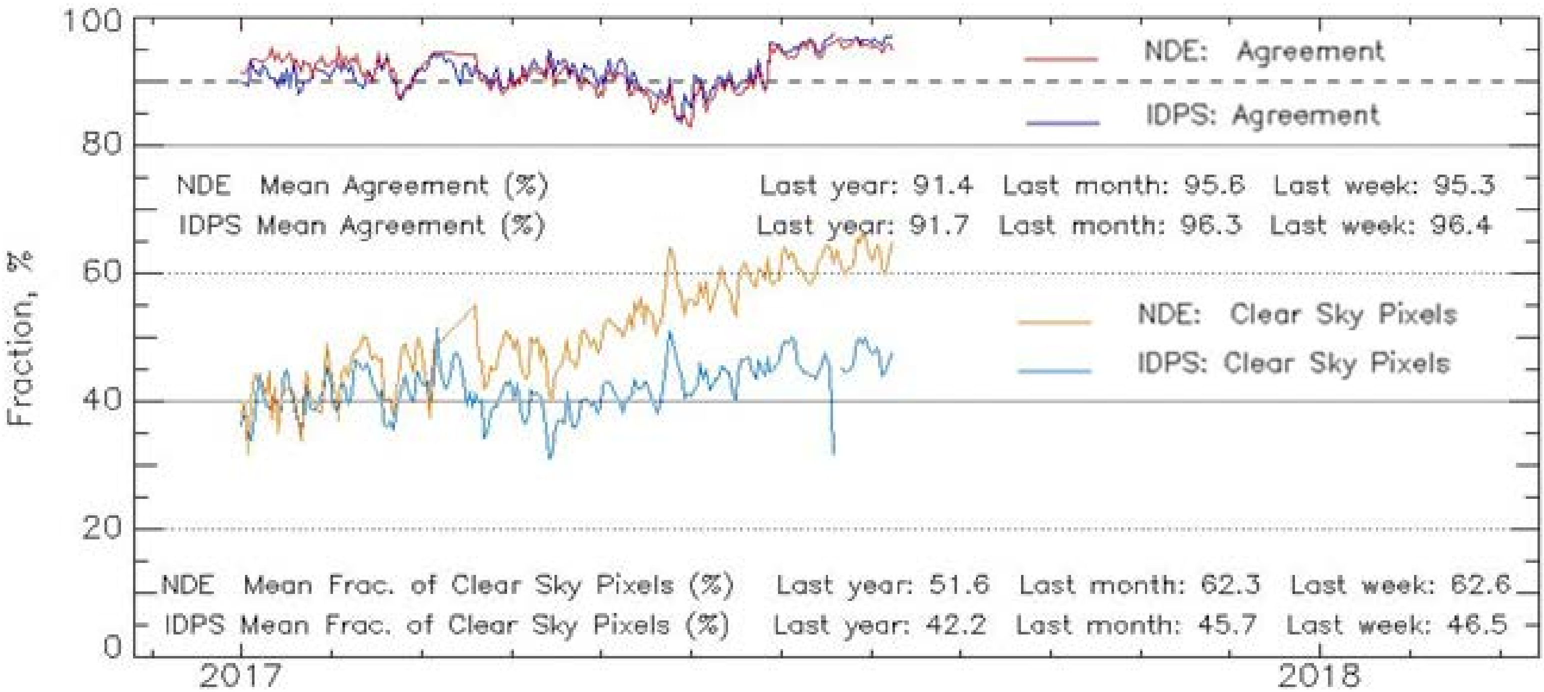


IDPS, Feb 2 2017

snow land cloud No data

NDE & IDPS: Binary Snow Accuracy

IDPS and NDE products vs IMS over N.Hemisphere



NDE vs IDPS

- Somewhat better (1-2%) accuracy in winter, similar accuracy in spring
- More clear sky views (less clouds), hence, better area coverage

NDE snow product satisfies requirements

Snow Fraction

Enterprise (NDE) Snow Fraction

NDE: Two algorithms implemented, replaced 2x2 aggregation approach in IDPS.

1. NDSI-based

$$\textbf{SnowFraction} = -0.01 + 1.45 * \textbf{NDSI}$$

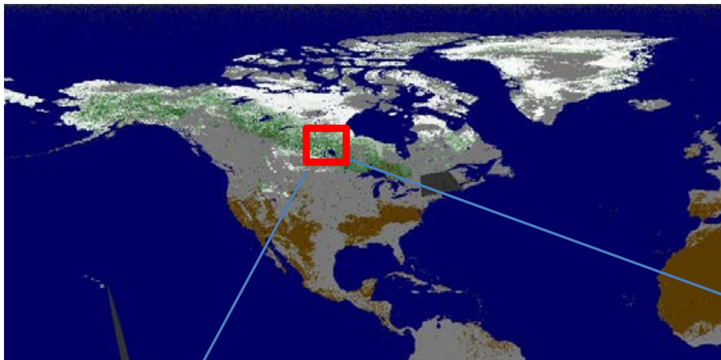
- **NDSI =** $(R_{0.6} - R_{1.6}) / (R_{0.6} + R_{1.6})$
- MODIS heritage algorithm, used up to Collection 5 (not in Collection 6)

2. Visible reflectance-based

$$\textbf{SnowFraction} = (R - R_{land}) / (R_{snow} - R_{land})$$

- Uses VIIRS band I1 (0.6 µm) reflectance (**R**)
- Algorithm used with GOES Imager and AVHRR; Approach similar to GOES-R

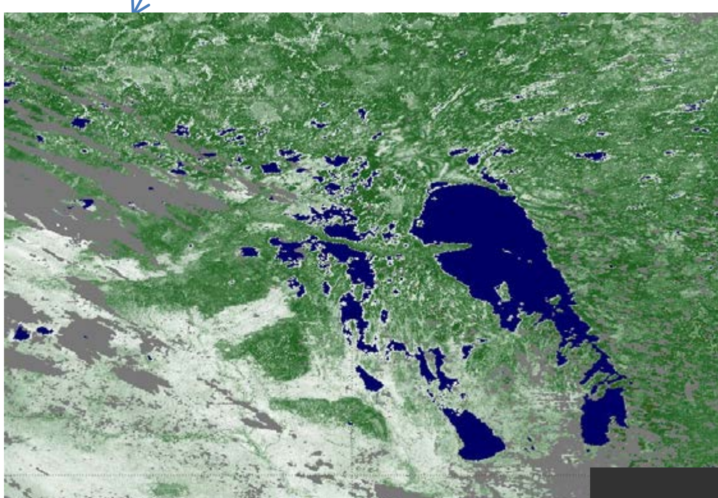
Snow Fraction: Two Algorithms



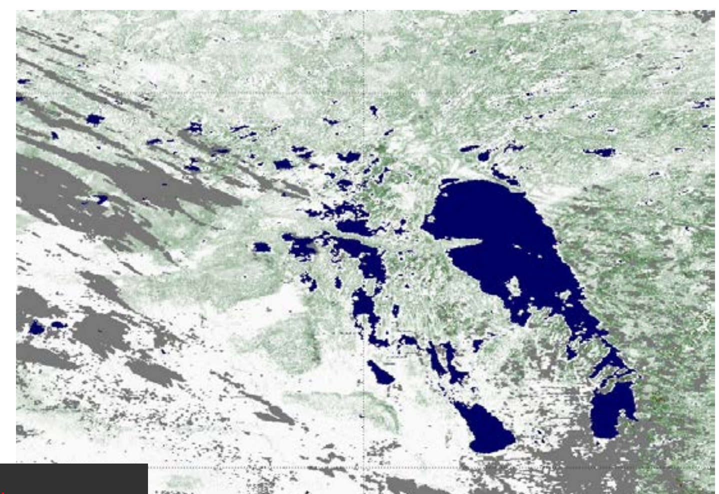
Reflectance-based Snow Fraction vs NDSI-based snow fraction

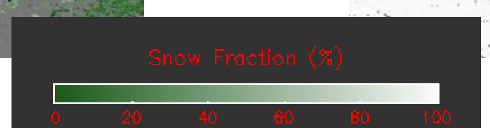
- Generally similar snow fraction patterns
- NDSI snow fraction is much larger in the forest

Reflectance-based snow fraction



NDSI-based snow fraction





Clouds are shown in gray

Snow Fraction Evaluation

Theoretically estimated accuracy: 10-20%

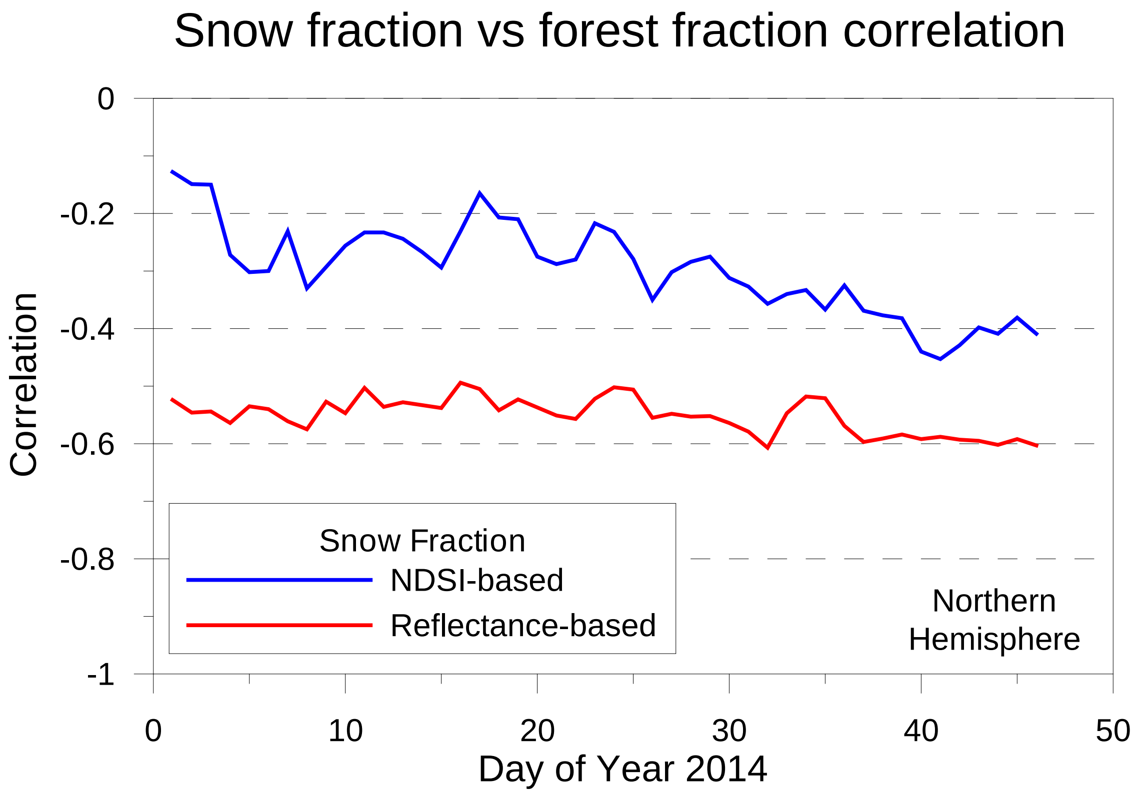
vs Landsat: mean agreement ~ 17%, range: 5-25%

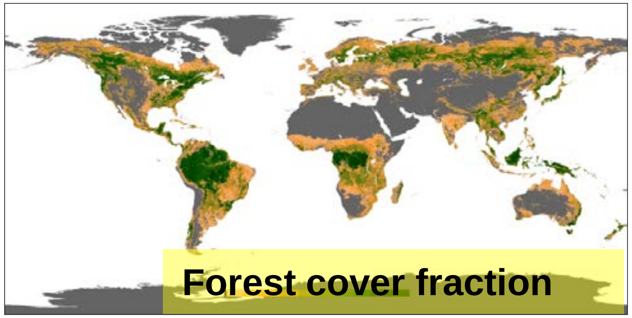
- Comparison over open areas
- Estimates are not independent, limited validity

Verification through consistency testing

- Day-to-day repeatability of spatial patterns
- Consistency with the forest cover distribution
- Consistency with in situ snow depth data over open flat areas.

Consistency with Forest Fraction

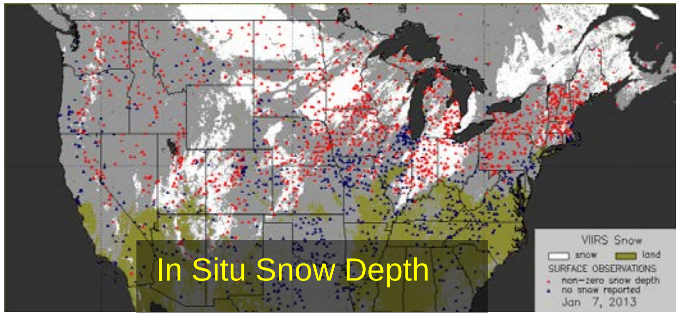




- Stronger correlation (-0.5 ÷-0.6), indicates better consistency of Reflectance-based snow fraction with the forest cover distribution

Consistency with Snow Depth

- VIIRS Snow Fraction vs matched In situ Snow Depth
- Correlation calculated over Great Plains
- Correlation is positive meaning that estimated snow fraction is consistent with the snow depth data



Snow Fraction vs Snow Depth Statistics

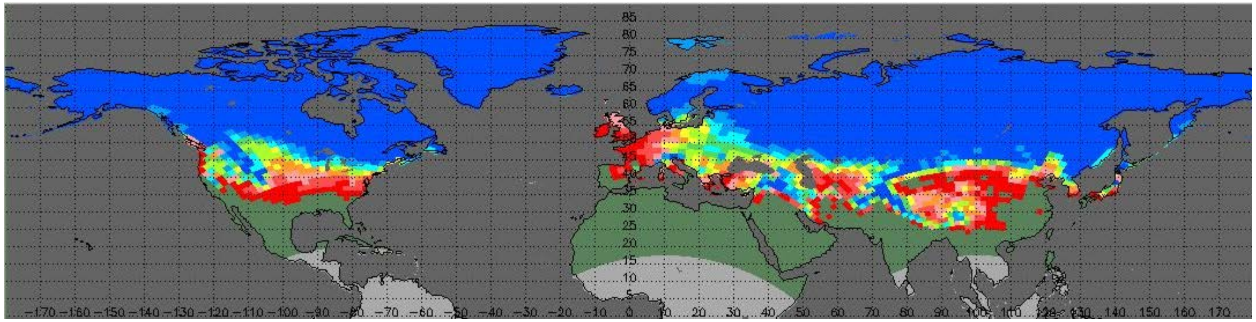
Date	Snow Depth Range, cm	Number of match-ups	Reflectance-based		NDSI-based	
			Mean SnFrac	Correlation	Mean SnFrac	Correlation
01/05/17	2 - 76	175	0.76	0.38	0.76	0.22
01/15/17	2 – 129	134	0.76	0.42	0.96	0.33
01/25/17	2 - 101	21	0.79	0.45	0.93	0.23
02/05/17	2 - 53	51	0.7	0.53	0.83	0.42
02/15/17	2 - 91	93	0.54	0.66	0.80	0.51
Mean (Jan-Mar 2017)			0.60	**0.51**	0.81	**0.44**

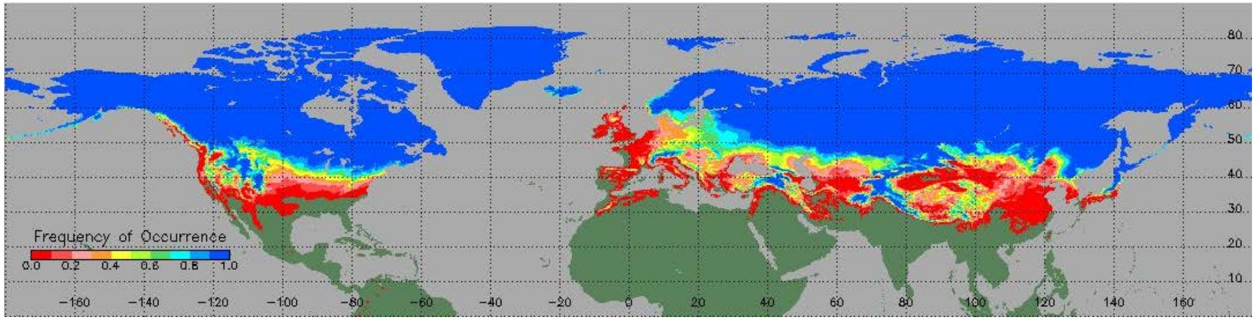
Planned Enhancements

Further Enhancements

Updated snow cover climatology

- Old: based on 200 km resolution IMS 1972-1998
- New: based on 4 km IMS 2014-2017





Further Enhancements, Cont'd

Canopy-corrected ("not viewable) snow fraction

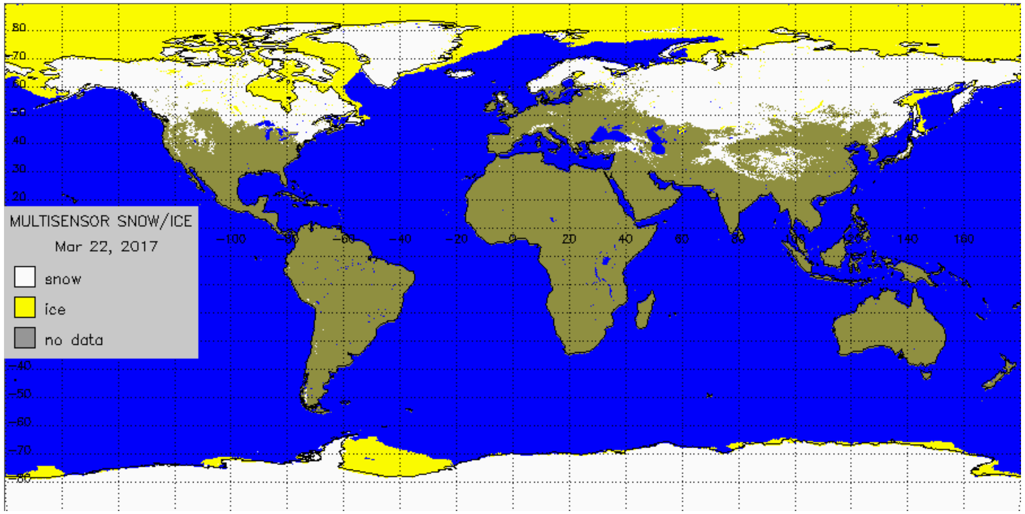
- Represents snow cover fraction on the ground
- Needed in hydrological applications
- Algorithm needs forest masking factor and derived "viewable snow fraction":

$$F_{adj} = F_{viewable} / (1 - F_{masking})$$

Further Enhancements, Cont'd

Gap-free blended snow cover map (VIIRS + microwave)

- Involves GCOM AMSR2 or DMSP/SSMIS snow retrievals
- May use GMASI approach to merging vis/IR and MW data
- Effective spatial resolution:
  - 1 km clear sky
  - 5-10 km cloudy/polar night
- May add ice cover to the gridded product



Summary

IDPS Snow algorithms and products

- Demonstrate robust performance.
- Satisfy current accuracy requirements

Enterprise Snow algorithms and products

- Have been implemented in the NDE system.
- Evaluation and monitoring is conducted since Jan 2017
- Provide improved characterization of snow pack properties
- Ready for JPSS-1. Meet requirements.

Further improvements of both algorithms/products are planned

SUOMI- NPP VIIRS ICE SURFACE TEMPERATURE STATUS

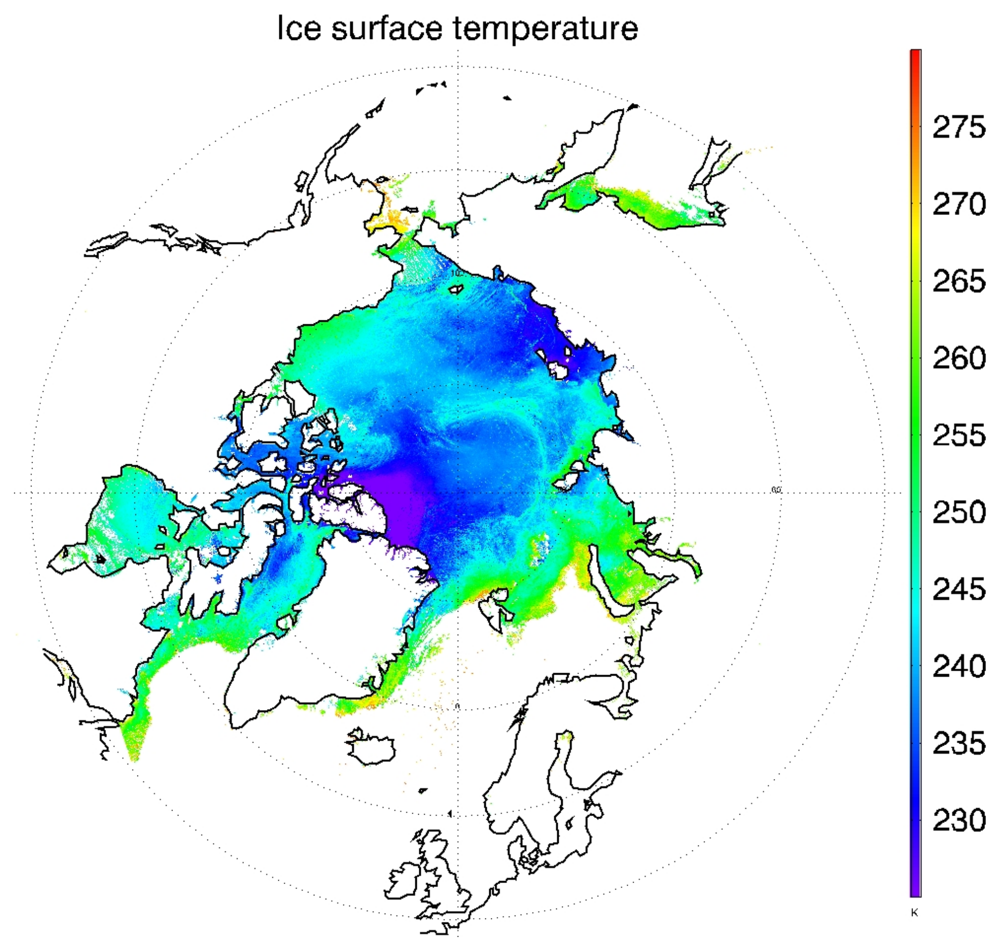
Mark Tschudi, CCAR, University of Colorado, Boulder
303-492-8274; mark.tschudi@Colorado.edu
Cryosphere: with J. Key, Y. Liu, R. Dvorak, X. Wang, A. Letterly

Cal/Val Team Members

PI	Organization	Team Members	Roles and Responsibilities
J. Key	NOAA NESDIS	M. Tschudi Y. Liu R. Dworak X. Wang A. Letterly	Ice conc & thickness cal/val IST development, cal/val IST cal/val Ice thickness development, cal/val NDE cryo products assessment

VIIRS Ice Surface Temperature

IST is the radiating, or "skin", temperature at the ice surface. It includes the aggregate temperature of objects comprising the ice surface, including snow and melt water on the ice.



Ice surface temperature (IST) composite from all overpasses over the Arctic on March 1, 2015. From *Liu et al*., 2015.

Summary of the VIIRS IST EDR

- The VIIRS Ice Surface Temperature (IST) EDR provides surface temperatures retrieved at VIIRS moderate resolution (750m), for Arctic and Antarctic sea ice for both day and night.
- The baseline split window algorithm statistical regression method is based on the IST algorithm of *Key and Haefliger.,* 1992:

$$IST = a + bT_{11} + c(T_{11}-T_{12}) + d(T_{11}-T_{12})(\sec(z)-1)$$

T_{11} and T_{12} : TOA TB's for ~11 and 12 µm bands
z: satellite zenith angle
a, b, c, d: regression coefficients.

- Threshold Measurement Uncertainty = **1K** over a measurement range of 213–275 K.

Key, J., and M. Haefliger (1992), Arctic ice surface temperature retrieval from AVHRR thermal channels, J. Geophys. Res., 97(D5), 5885–5893.

VIIRS IST Validation Approach

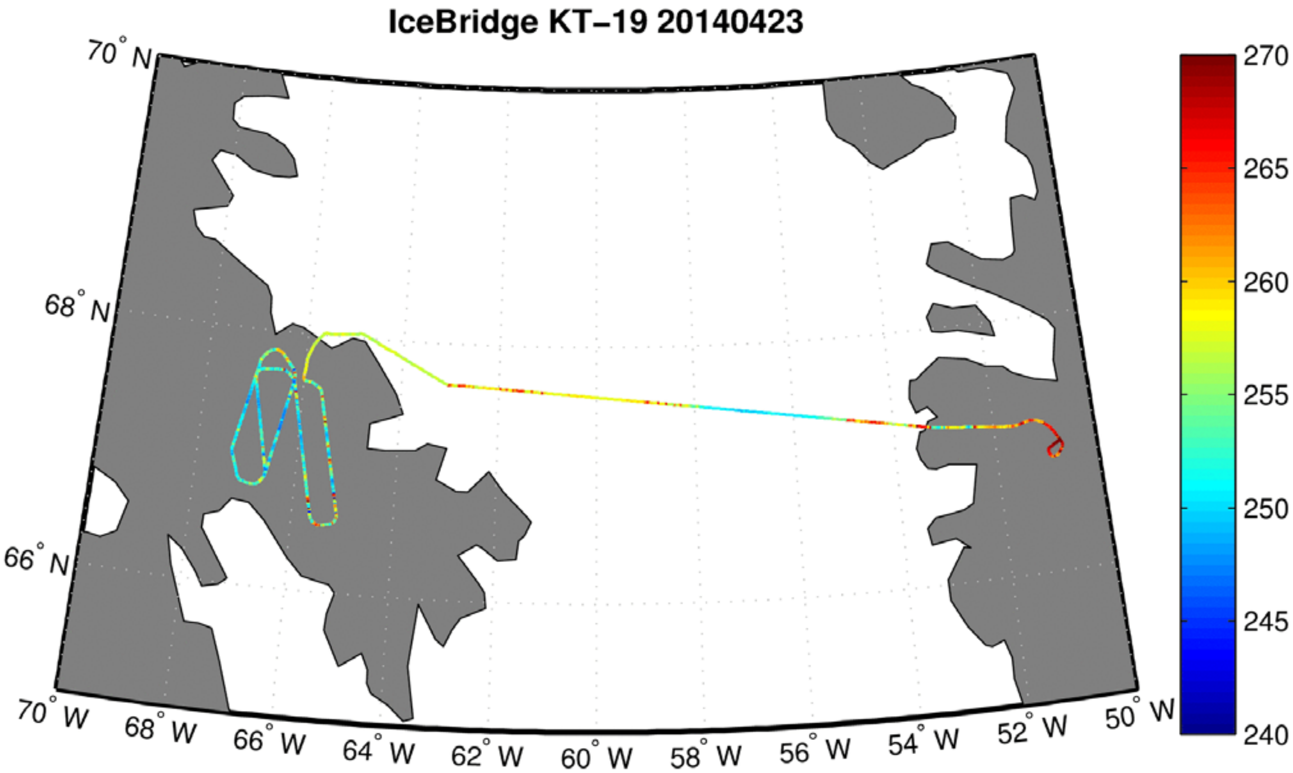
Validation Dataset	Parameter	Spatial Resolution	Spatial Coverage
NASA IceBridge KT-19 IR Surface Temperature	Snow/ice temperature	15 x 15 m	Arctic and Antarctic
MODIS Ice Surface Temperature	Snow/ice temperature	1 km	Arctic and Antarctic
MODIS simultaneous nadir overpass	Snow/ice temperature	0.05 degree longitude by 0.05 degree latitude	Arctic
Arctic drifting buoy	2 m air temperature	Point observations	Arctic
NCEP/NCAR reanalysis	Air temperature at 0.995 sigma level	2.5 x 2.5 degree latitude/longitude	Arctic and Antarctic

VIIRS IST EDR Validation with IceBridge IST

- IceBridge NASA P-3 aircraft carries a KT-19: a downward-pointing, IR pyrometer that measures IST
- No atmospheric corrections applied
- Spot size = 15m
- Resolution = 0.1° C
- Sampling = 10Hz

Krabill, W. B. and E. Buzay. 2012, updated 2014. IceBridge KT19 IR Surface Temperature. Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Center.

IceBridge IST flickers with NDE IST, April 23, 2014

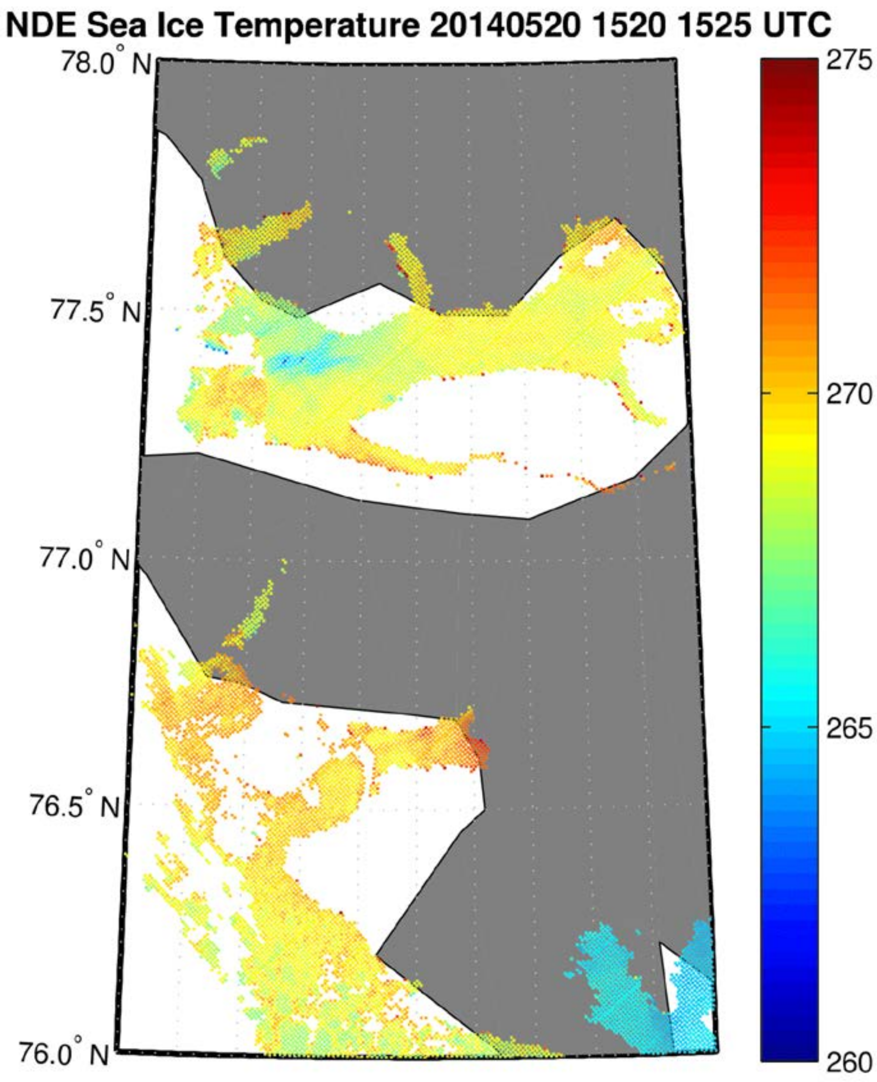


Ice Bridge flight over Western Greenland, Baffin Bay and Baffin Island

NDE was 2.3 K warmer than KT-19

IDPS was 1.9 K warmer

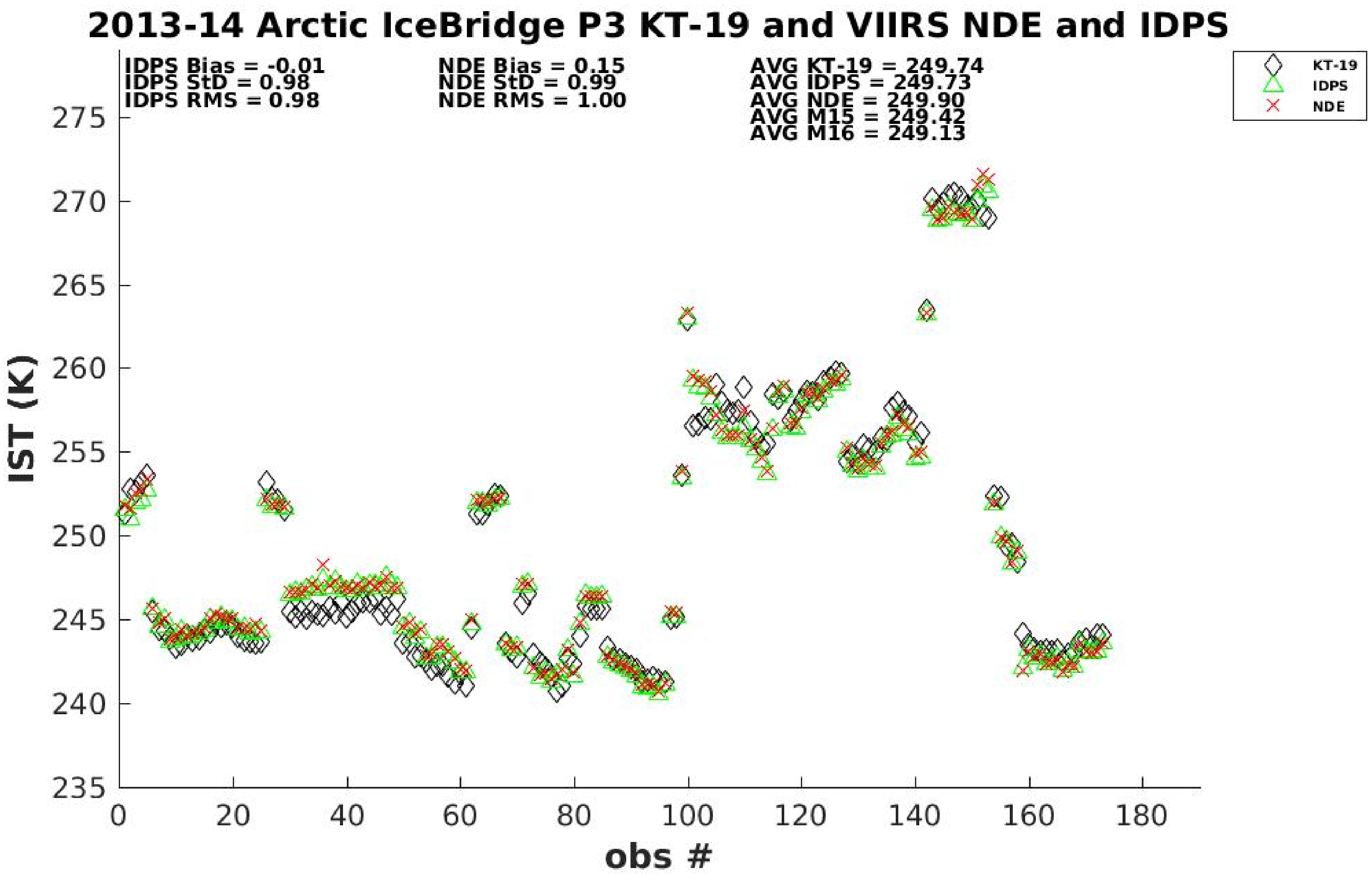
Another NDE / IceBridge IST flicker



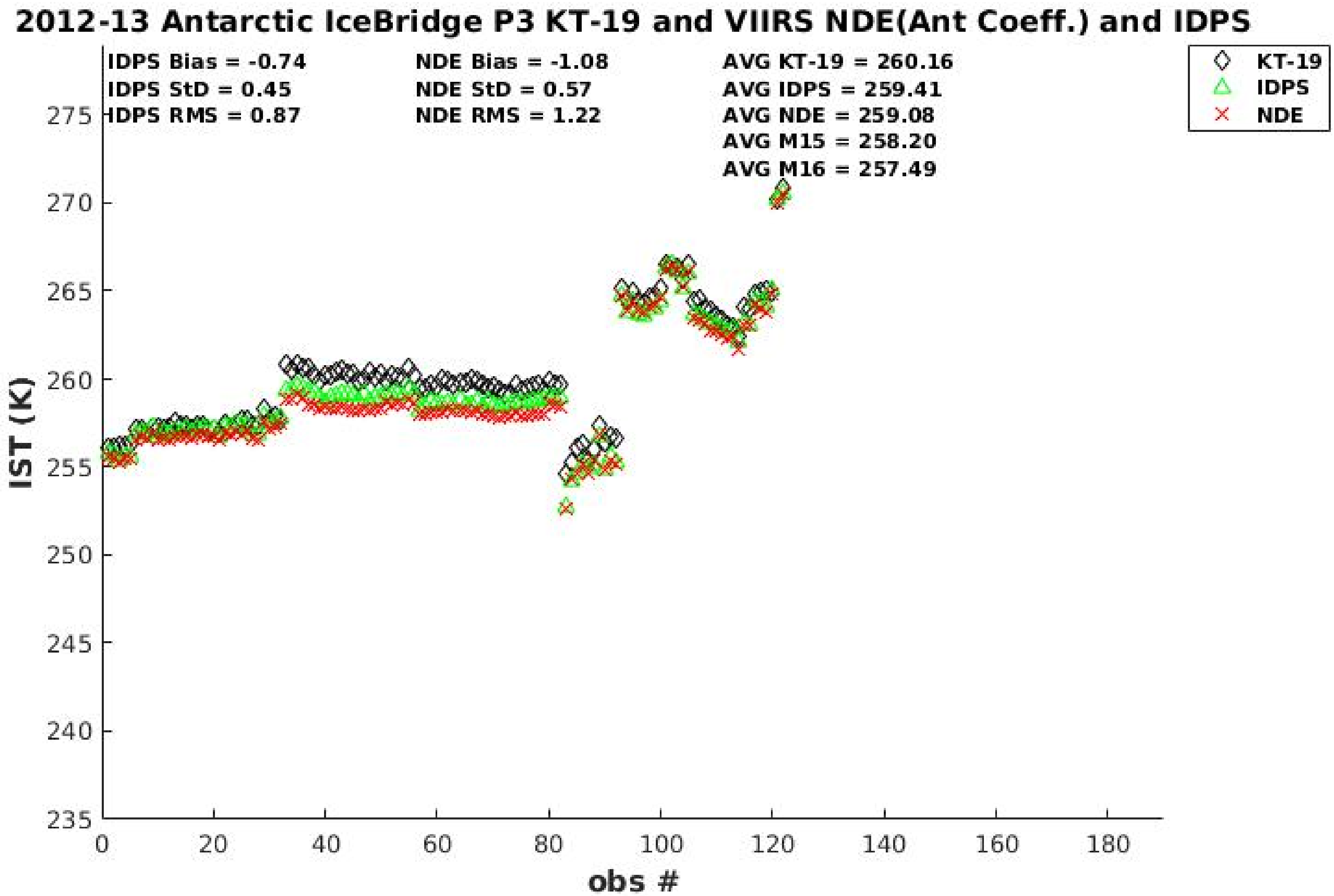
Over this scene along NW Greenland coastline NDE was on average 0.7 K colder than KT-19 Ice Surface Temp.

not shown: IDPS was 0.8 K colder

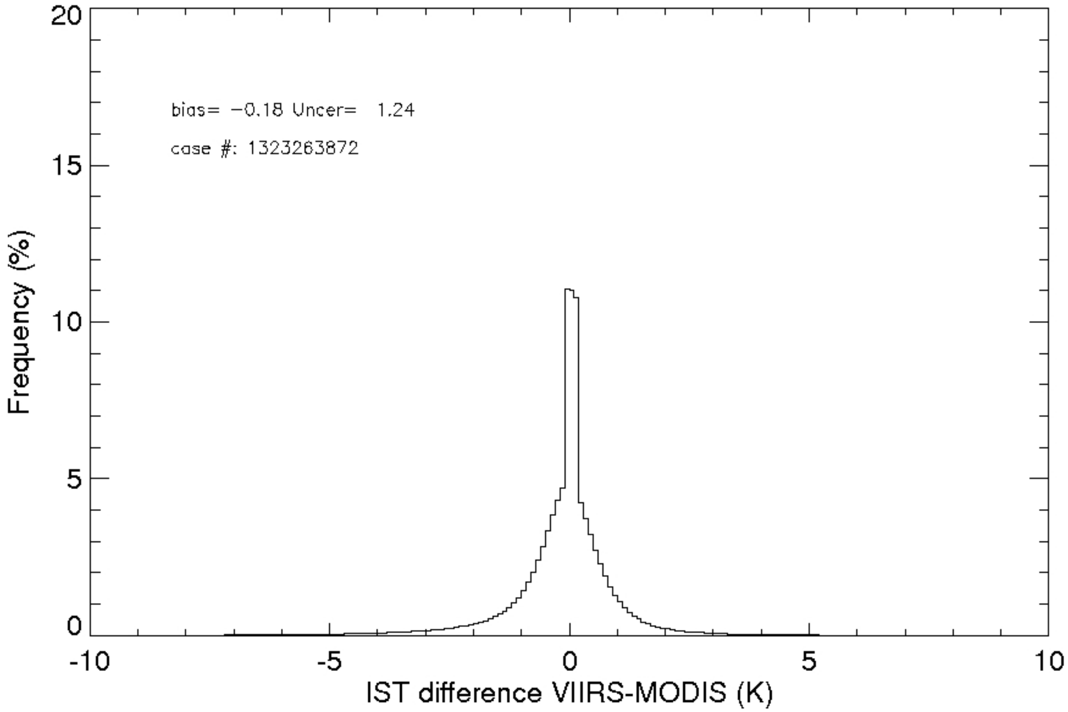
VIIRS IST IceBridge Validation



Antarctic KT-19, VIIRS NDE & IDPS IST



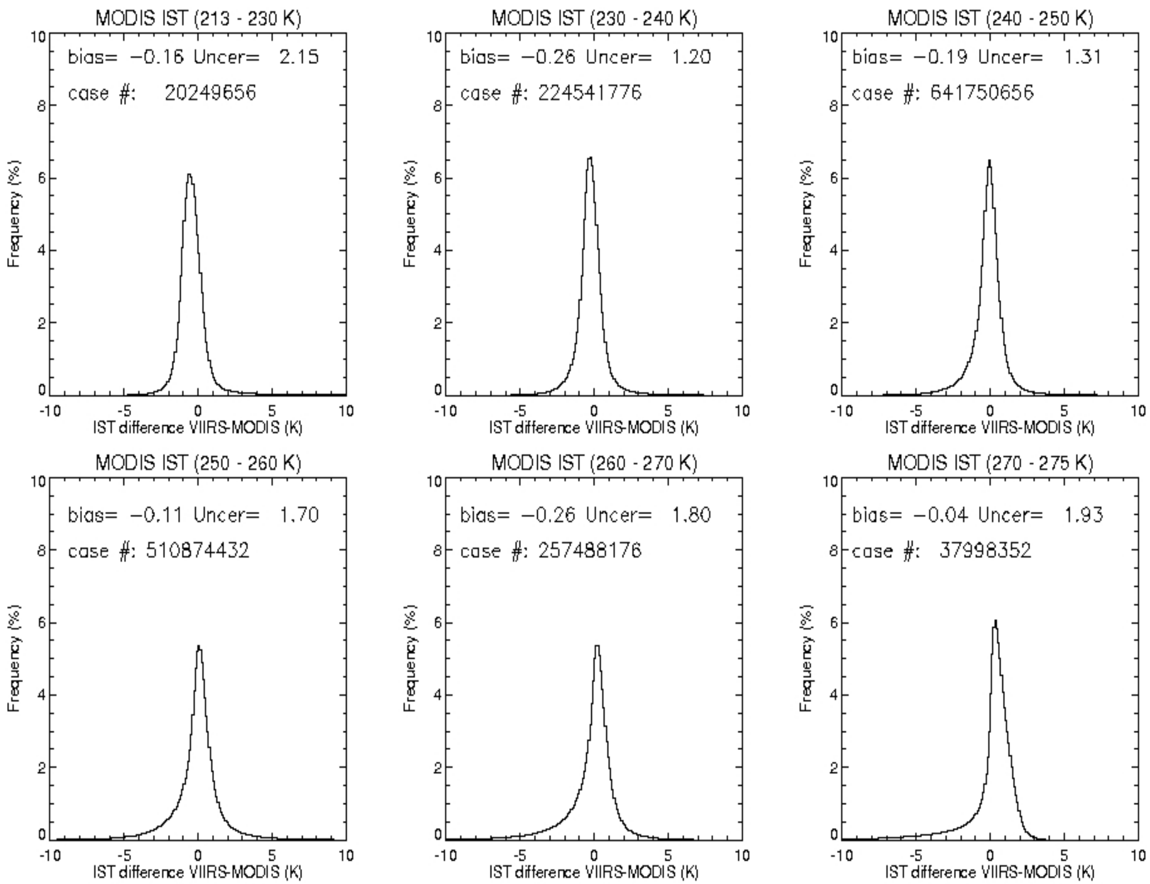
VIIRS / MODIS IST Inter-comparison



Differences between NPP VIIRS and MODIS (Aqua and Terra) IST in the Arctic from August 2012 to July 2015.

From: *Yinghui Liu, Jeffrey Key, Mark Tschudi, Richard Dworak, Robert Mahoney, and Daniel Baldwin*, 2015: Validation of the Suomi NPP VIIRS Ice Surface Temperature Environmental Data Record, *Remote Sens.* **2015**, *7*, 13507-13527; doi:10.3390/rs71013507

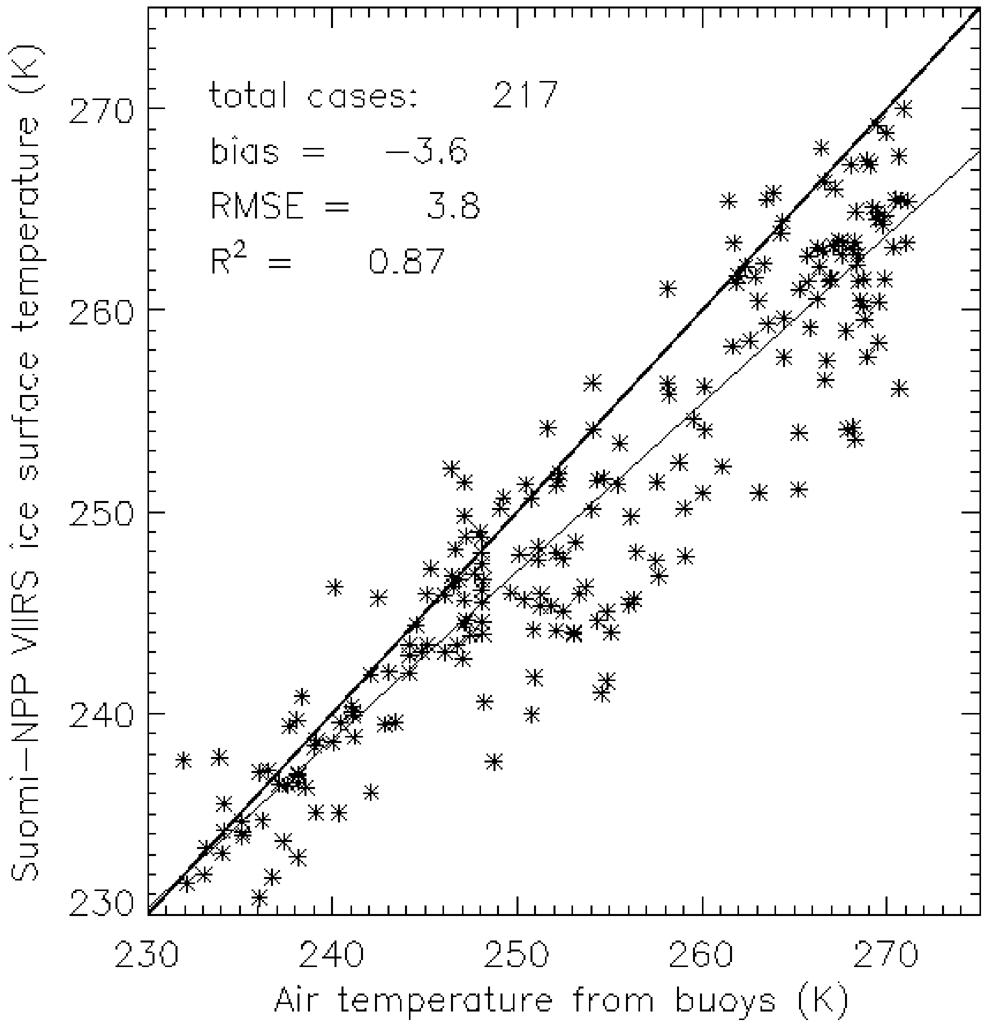
VIIRS IST vs. MODIS IST



NPP VIIRS and MODIS (Aqua and Terra) IST differences in the Arctic and Antarctica from August 2012 to July 2015. VIIRS-MODIS bias and uncertainty (RMS) are indicated for each bin.

From *Liu et al.*, 2015

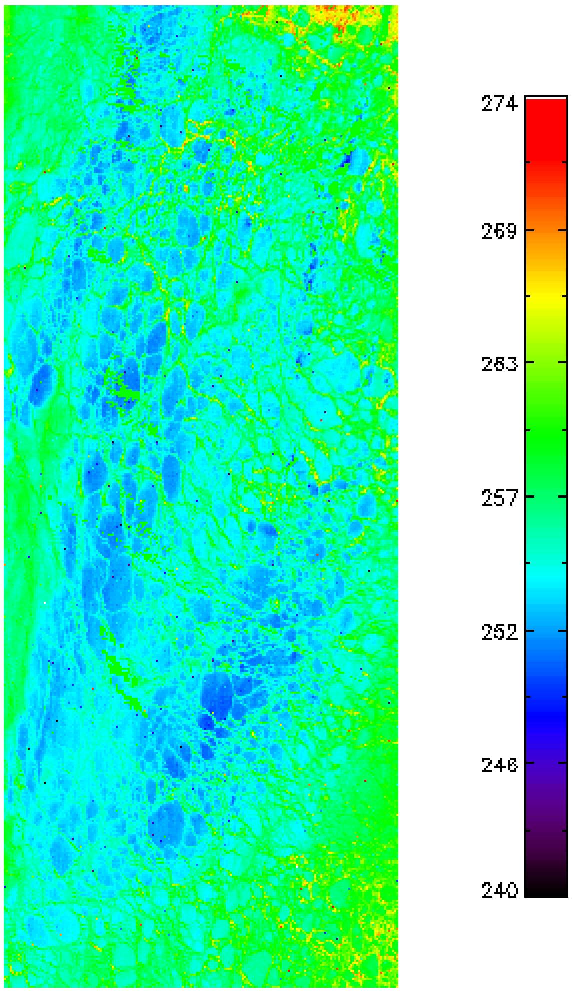
VIIRS IST vs. buoys



Scatter plot of surface air temperature from Arctic buoys and NPP VIIRS IST from August 2012 to June 2014, with the thick line as the 1 to 1 ratio line, and thin line as the linear regression.

From *Liu et al*., 2015

NASA's Suomi-NPP VIIRS IST



- Utilizes similar split window to NOAA product:

$$IST = a_o + a_1 T_{M15} + a_2(T_{M15} - T_{M16}) + a_3(T_{M15} - T_{M16})(\sec(z) - 1)$$

- Has been delivered to NASA's NSIDC DAAC
- Upgrades have been proposed in response to NASA AO

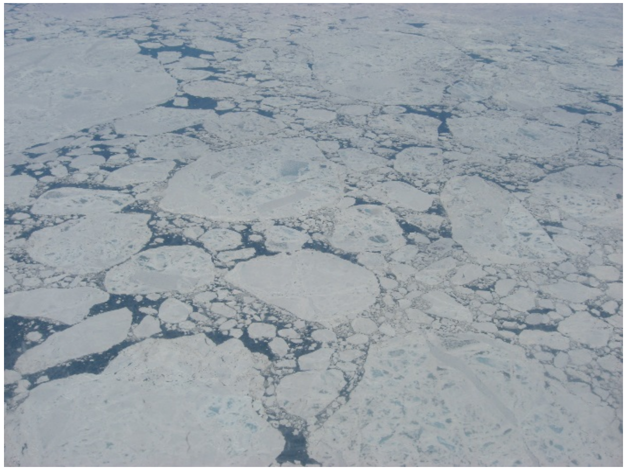
Left: VIIRS IST (K) from the NASA VIIRS IST product
Sept 12, 2014, 21:10 UTC
Beaufort Sea, AK

Product Status Summary

- The NOAA Enterprise IST product is stable and is accurate to within 1K
- No VIIRS IST code changes currently planned, except for an update to regression coefficients based on our cal/val work
- More cal/val planned after determination and update of new coefficients
- NASA VIIRS IST has been delivered to NASA's NSIDC DAAC
  - IST ATBD delivered to NASA GSFC
  - User Guide delivered to NSIDC

Conclusions

- NDE VIIRS IST in most cases meets the requirement of 1K measurement uncertainty
- *Liu et al*., 2015 describes the IST product and cal/val work in detail
- NDE VIIRS IST calibration coefficients will be adjusted and cal/val'd, based on previous cal/val results
- Improvements in the VIIRS IST performance have been realized as the VIIRS Cloud Mask matures
- NASA's IST product has been developed & delivered to provide continuity with the NASA MODIS product
- THANK YOU!



Overflow slides

Flow for the VIIRS Operational (IDPS) IST

NPPxDRs & IPs

VIIRS 750m SDR
VIIRS 750m TC GEO
VIIRS Cloud Mask IP
VIIRS Ice Concentration IP
VIIRS Aerosol Optical Thickness IP

Auxiliary Data

VIIRS IST Tunable parameters
VIIRS IST Regression Coefficient LUT

VIIRS_ST_04

Ice Surface Temperature

Output EDRs & IPs

VIIRS Ice Surface Temp. EDR

S-NPP ICE CONCENTRATION STATUS

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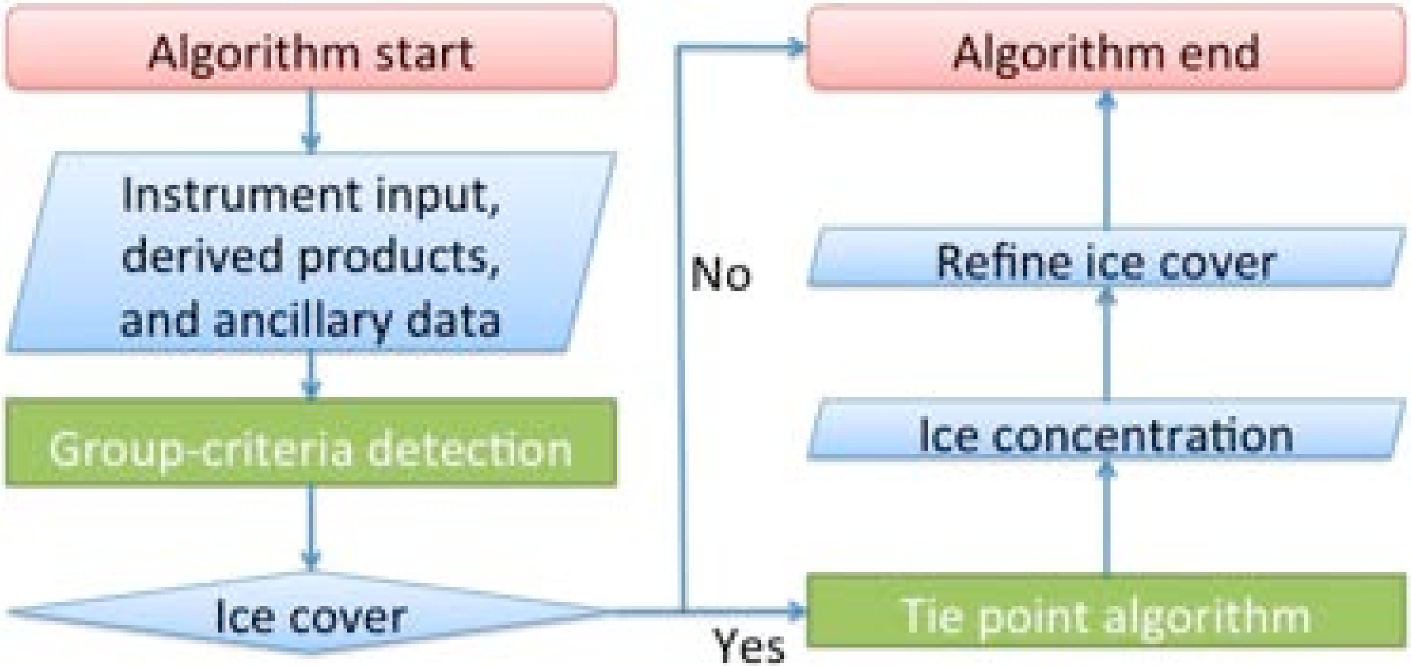
Collaborators: Jeff Key, Rich Dworak, Mark Tschudi, Dan Baldwin

Ice Concentration Team

PI	Organization	Team Members	Roles and Responsibilities
J. Key	NESDIS	Y. Liu (UW/CIMSS) M. Tschudi (CU/CCAR) D. Baldwin (CCAR) R. Dworak (CIMSS) X. Wang (CIMSS)	Ice conc. Development and cal/val Ice concentration cal/val Ice concentration cal/val Ice concentration data cal/val Ice concentration application

Enterprise Algorithm Overview



Difference with IDPS algorithm:

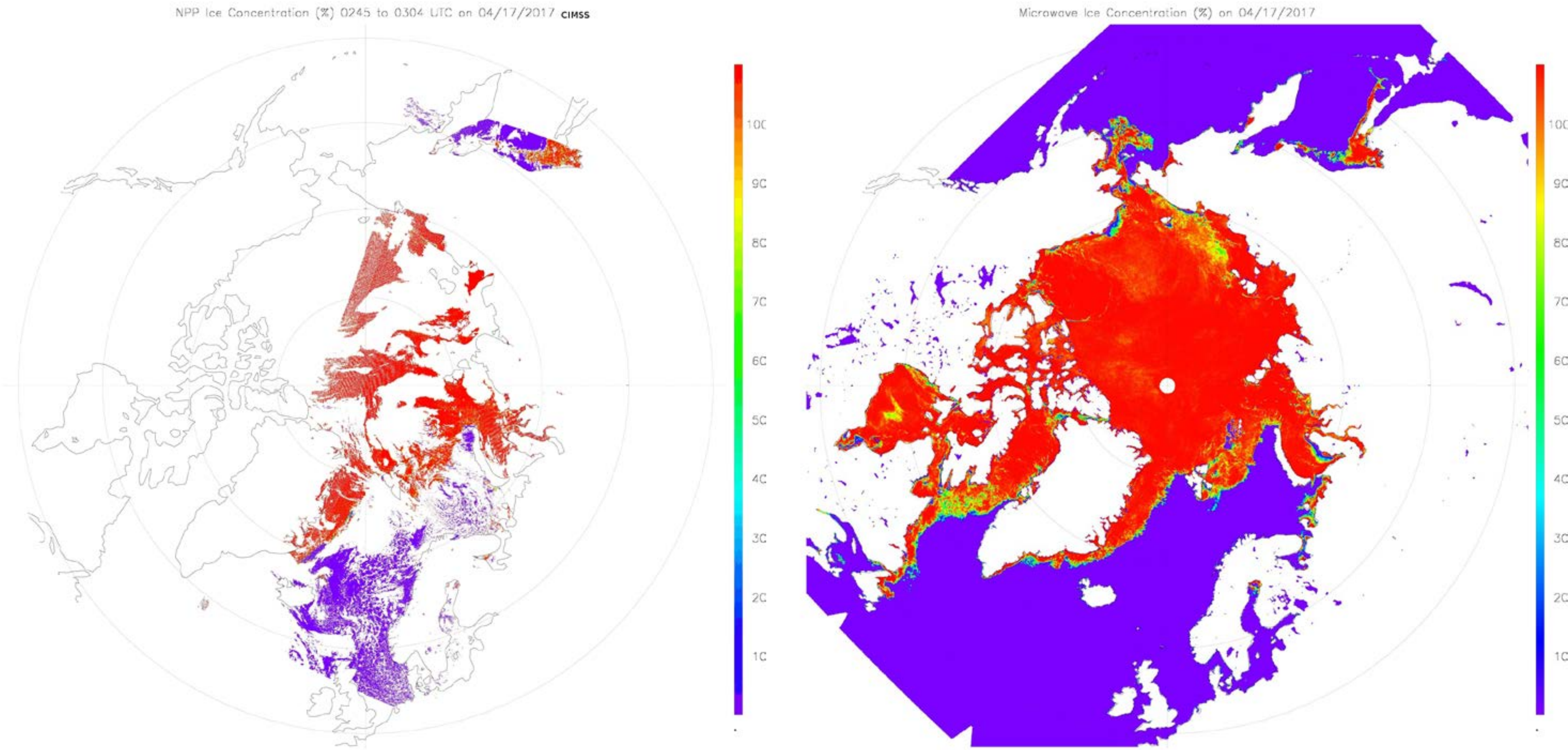
- Enterprise algorithm applies threshold method to identify ice covered pixels first with Normalized Difference Snow Index (NDSI) explicitly used;
- Retrieves Ice Concentration (IC) using tie-point algorithm on single band information of 0.64 µm reflectance at daytime and surface temperature at nighttime,
- Final ice identification is refined by the retrieved SIC;
- IDPS SIC algorithm applies band weighted ICs from tie point algorithm on multiple bands, with identification of ice covered pixels implicitly included.
- Enterprise IC is in M-band resolution, and IDPS product is in I-band resolution

Requirements

Attribute	Threshold	Performance
a. Vertical Coverage	Ice Surface	Ice Surface
b. Horizontal Cell Size		
1. Clear	1.0 km	1.0 km
2. All Weather	No capability	No capability
c. Mapping Uncertainty, 3 Sigma		
1. Clear	1 km at Nadir	1.0 km
2. Cloudy	No capability	No capability
d. Measurement Range		
2. Ice Concentration	0.0 – 1.0	0.0 – 1.0
e. Measurement Uncertainty		
2. Ice Concentration	10%	10%
f. Refresh	At least 90% coverage of the globe every 24 hours (monthly average)	At least 90% coverage of the globe every 24 hours (monthly average)
g. Geographic coverage	All ice-covered regions of the global ocean	All ice-covered regions of the global ocean

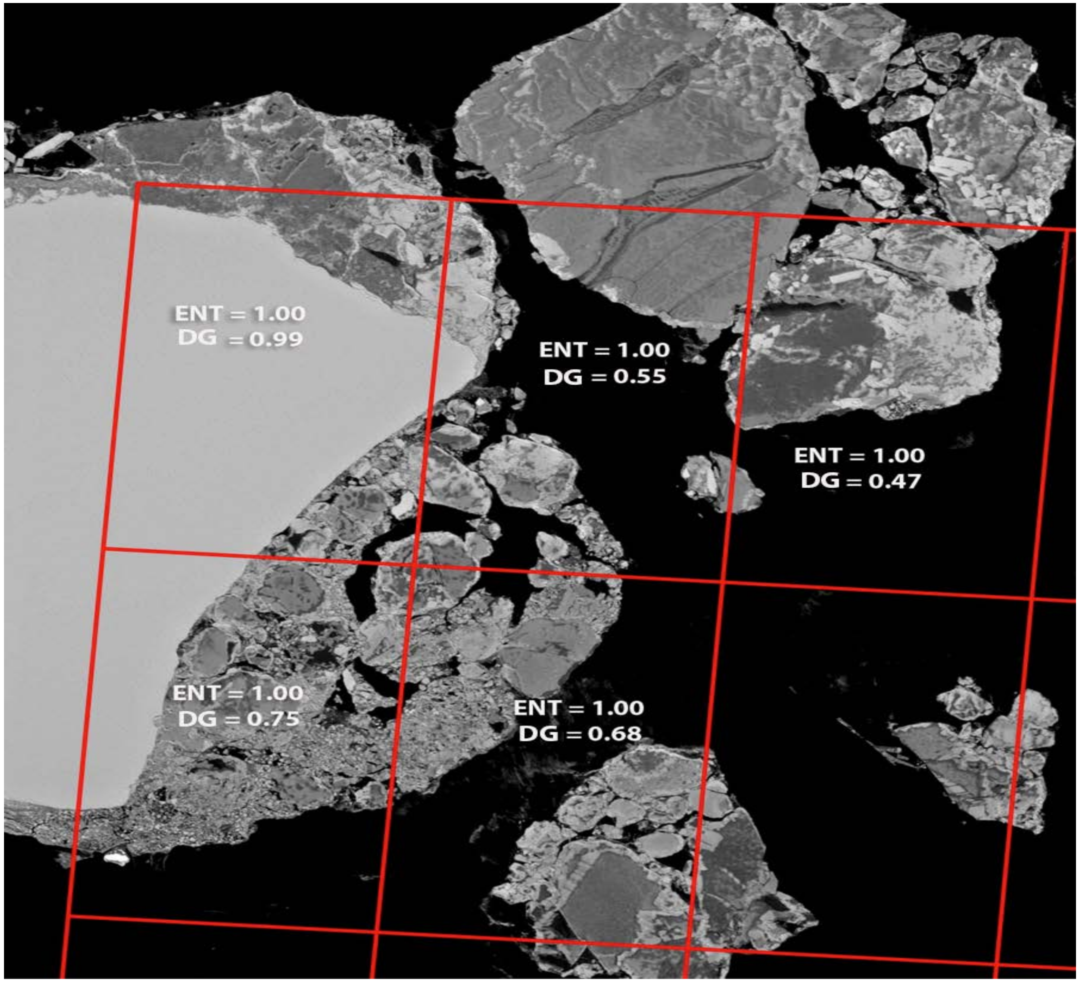
Operational Product

NDE CM appears to identify more cloud than IDPS, with some possible cloud leakage



Operational NDE VIIRS ice concentration from PDA, and from local run (left), and SSMIS ice concentration (right) on April 17, 2017.

Validation



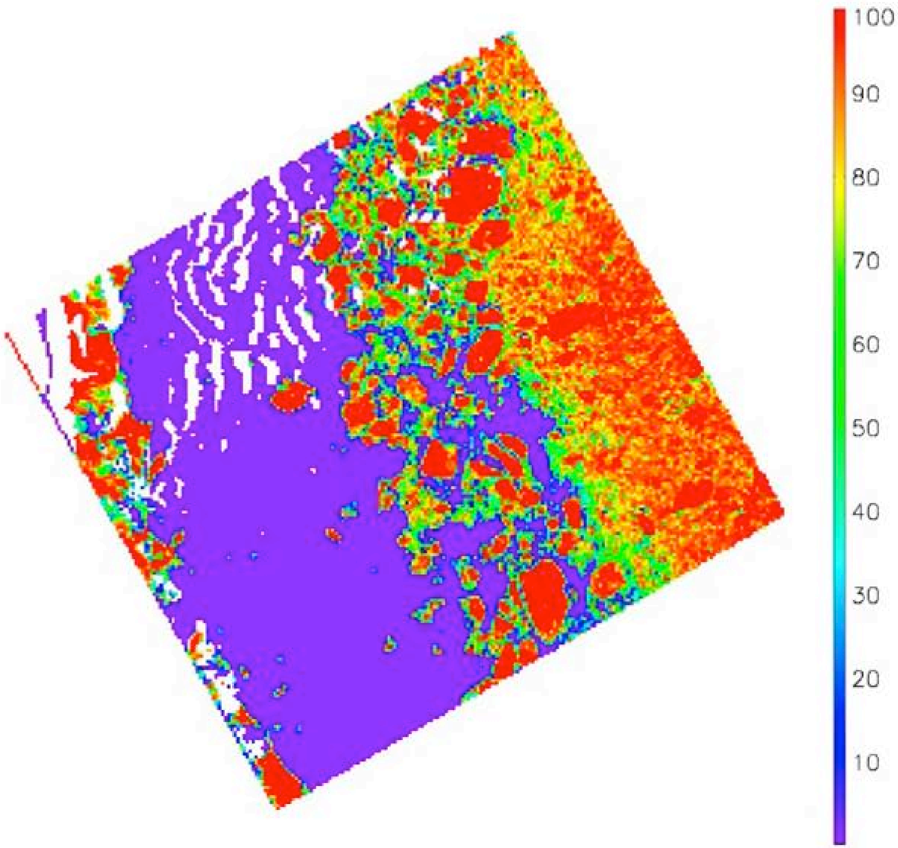
VIIRS M-Band FOVs from the Enterprise SIC during May 10, 2014, overlaid upon corresponding DigitalGlobe data. Numbers in boxes are Enterprise SIC and SIC estimate computed from DG image.

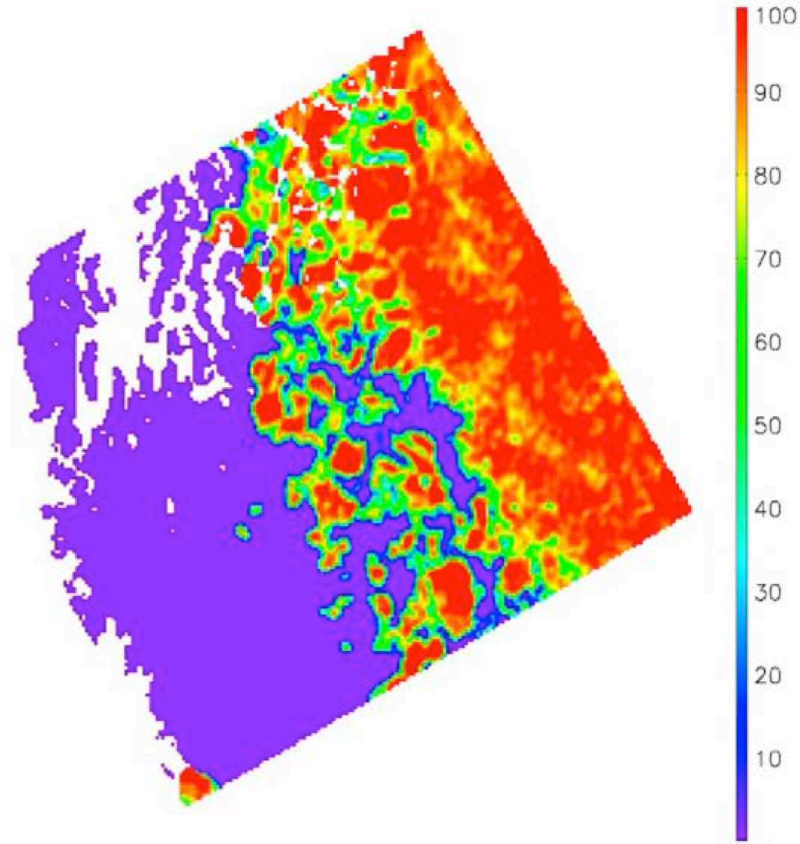
Validation

IDPS and Enterprise SIC values vs. DG SIC estimate for March 21, 2014, for three normalized difference threshold values. * Aggregate bins over a broader range; ** All IDPS and Enterprise SIC values of 0.0 were eliminated from the statistics for this bin.

Ice Concentration Range (based on DG SIC Estimate	Normalized Difference Threshold Value	Number FOVs IDPS/Enterprise	Bias (DG-IDPS) /(DG.-Ent)	RMS IDPS/Enterprise
0.0 – 1.0	0.3	1386/196	-0.06/-0.11	0.24/0.22
	0.5	**1386/196**	**0.04/-0.05**	**0.24/0.14**
	0.7	1386/196	0.13/-0.01	0.30/0.10
0.0– 0.4 *	0.3	1130/152	-0.06/-0.08	0.23/0.23
	0.5	**946/140**	**0.01/-0.02**	**0.16/0.12**
	0.7	812/133	0.03/0.02	0.09/0.10
0.4 – 1.0 *	0.3	256/44	-0.08/-0.18	0.29/0.22
	0.5	**440/56**	**0.12/-0.12**	**0.36/0.19**
	0.7	574/63	0.27/-0.07	0.47/0.12
0.4 – 1.0 (0.0 eliminated) **	0.3	234/44	-0.15/-0.18	0.21/0.22
	0.5	**327/56**	**-0.05/-0.12**	**0.21/0.19**
	0.7	375/63	0.02/-0.07	0.19/0.12

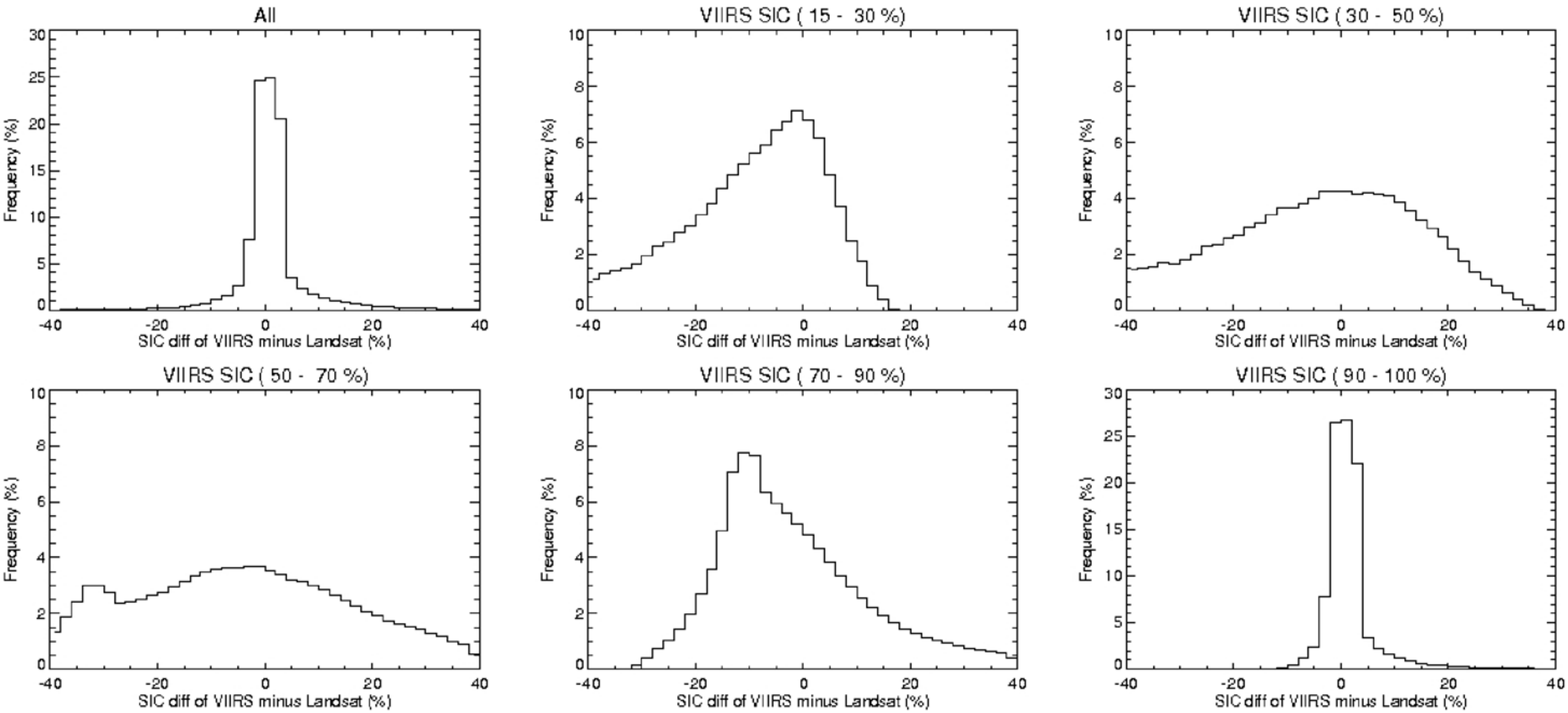
Validation





(**left**) Ice concentration (IC) derived from the Landsat image (30 m resolution); and (**right**) the calculated IC using the Suomi NPP VIIRS. White areas denote pixels flagged out as either land or cloud.

Validation



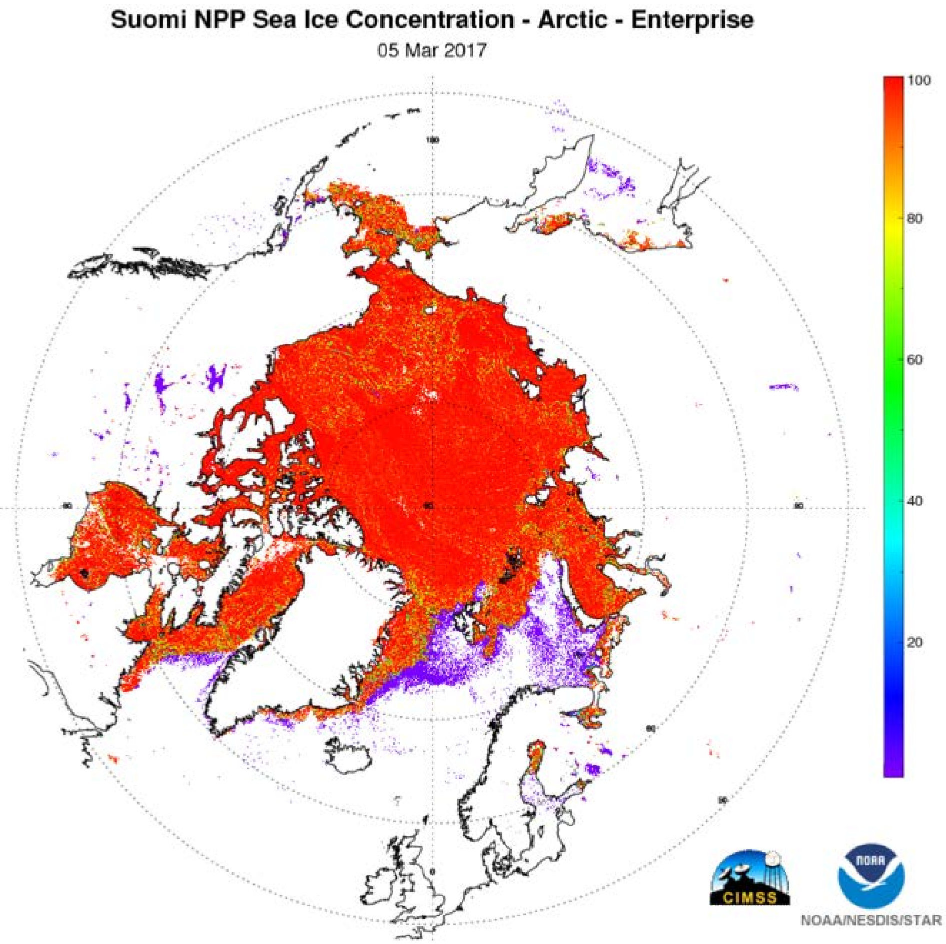
Comparison of VIIRS and Landsat ice concentrations for different concentration ranges/bins when a tie point adjustment scheme is employed.

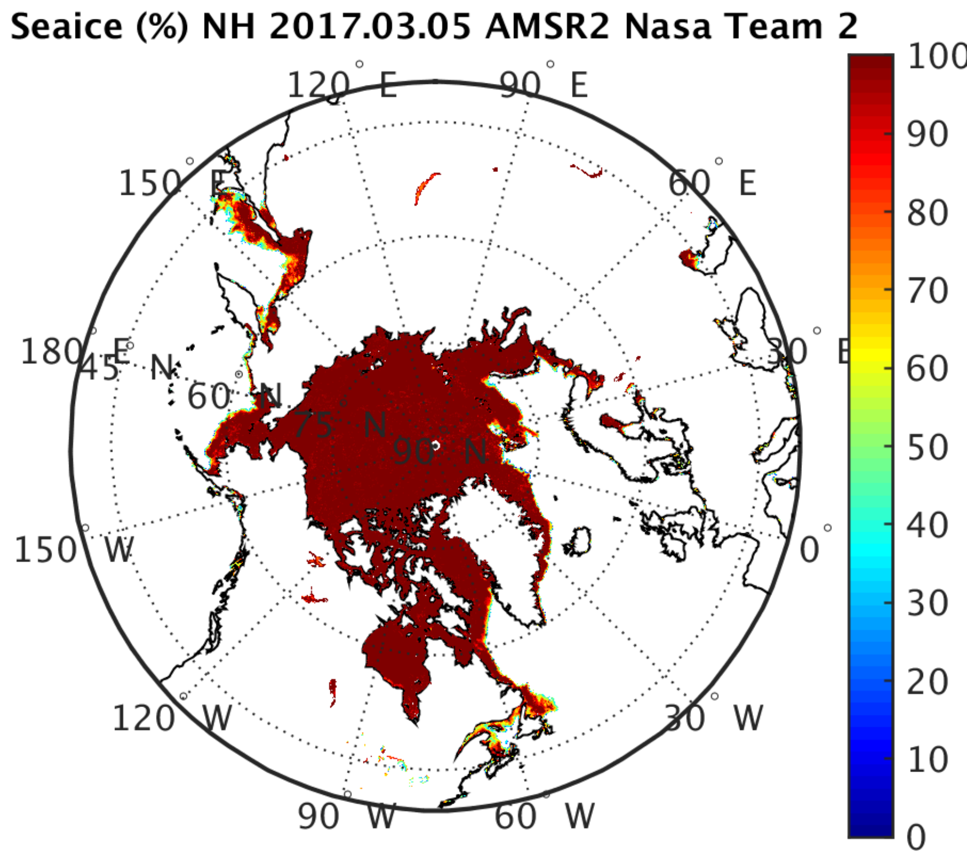
Validation

Table 8. Bias and RMSE with bias removed (precision) for comparisons of VIIRS minus Landsat ice concentrations for different concentration ranges/bins after tie point adjustment.

	Overall	VIIRS SIC 15%–30%	VIIRS SIC 30%–50%	VIIRS SIC 50%–70%	VIIRS SIC 70%–90%	VIIRS SIC 90%–100%
Case number	2,480,093	6055	16,559	34,428	168,009	2,255,042
Bias (%)	1.4	−12.6	−9.1	−4.5	0.3	1.6
RMSE (%)	8.9	17.4	22.4	21.7	17.2	7.2

Validation and Monitoring

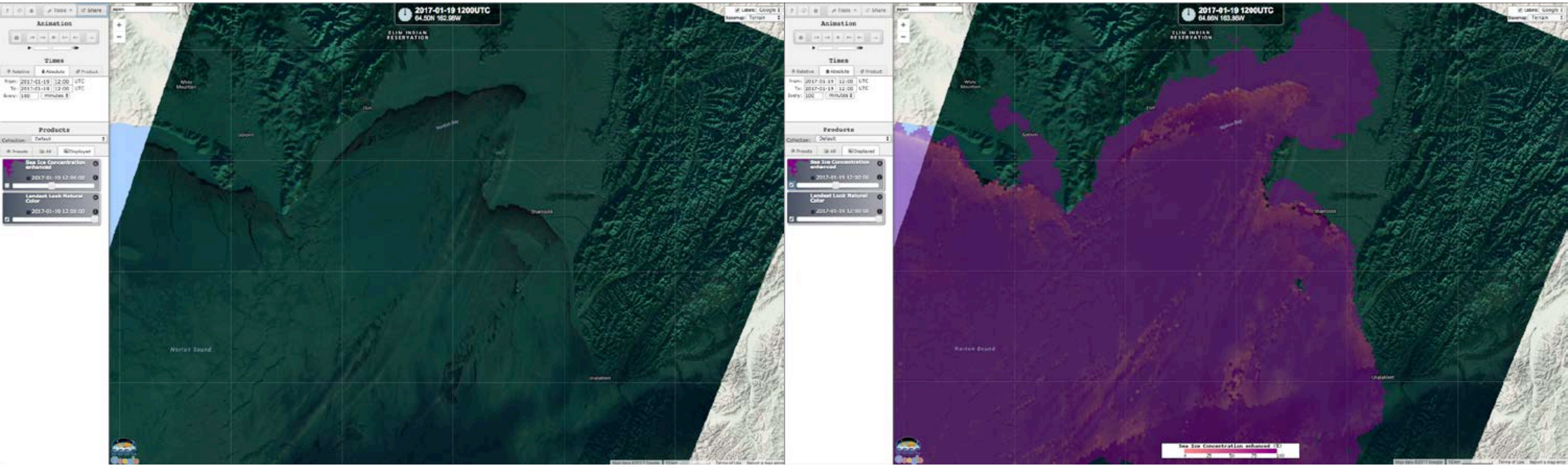




Daily Ice concentration (IC) composite from VIIRS (**left**); and IC AMSR2 (**right**) over the Arctic on March 5th 2017. White areas in the AMSR2 image denote pixels flagged as either land or the area with IC less than 15%. White areas in the VIIRS data denote pixels flagged as land, ice-free ocean, or cloud.

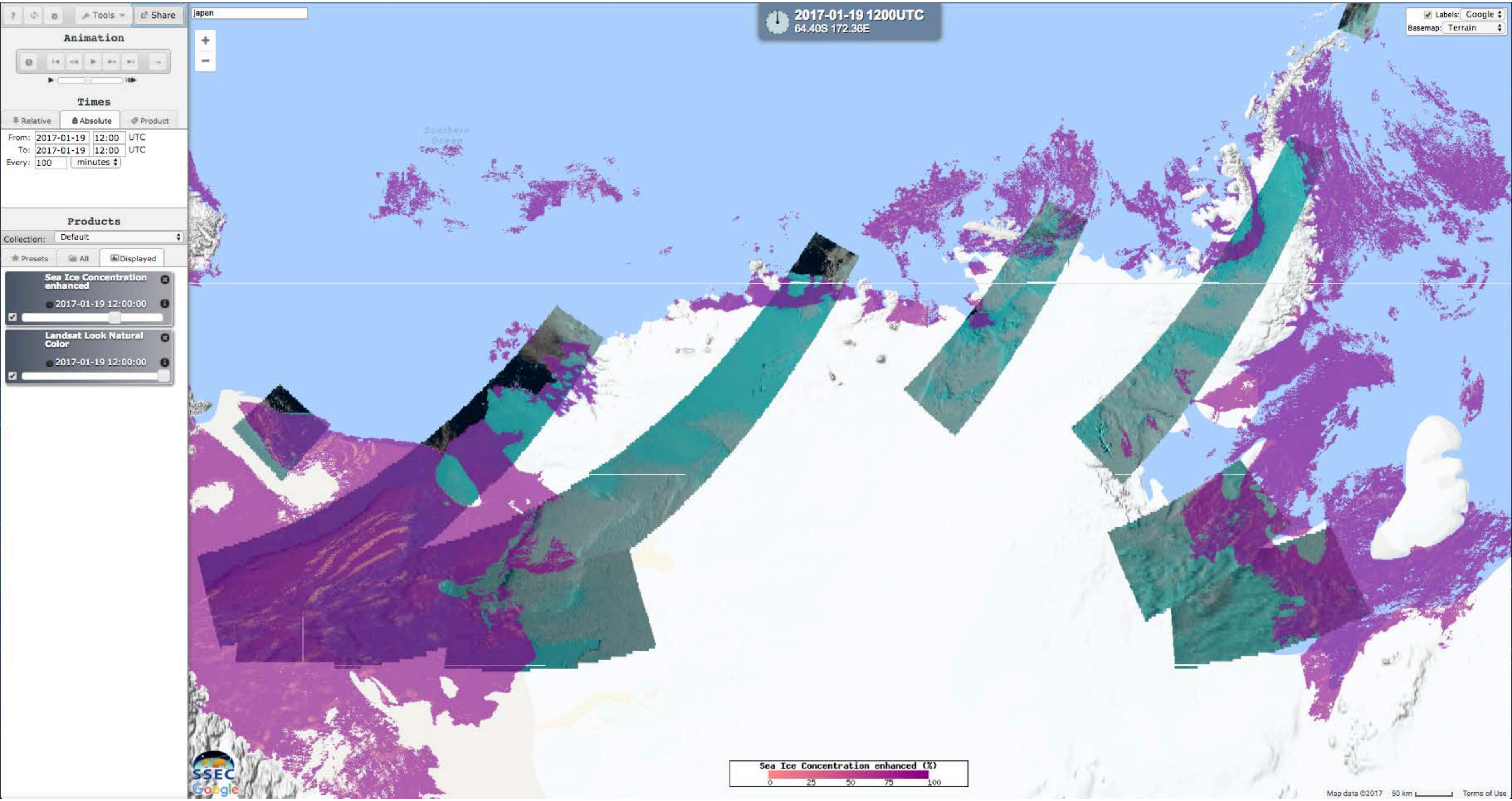
Validation and Monitoring

VIIRS ice concentration daily composite has been installed in the RealEarth Info sections. This provides a tool to monitor and validate VIIRS IC with Landsat data.



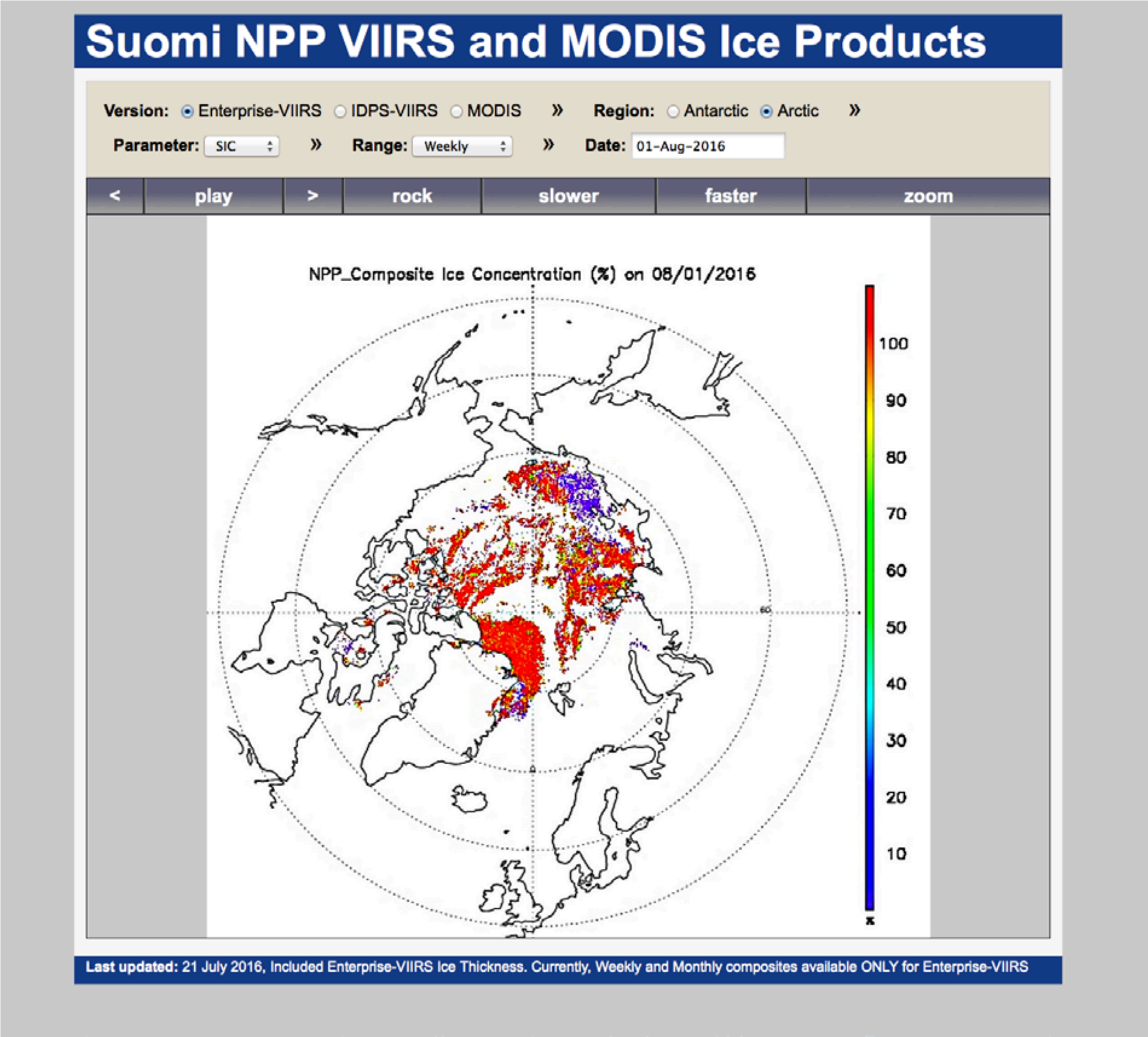
Landsat NatureColor (left), and VIIRS ice concentration (right) centered over the west coast of Alaska on January 9th 2017.

Validation and Monitoring



Landsat NatureColor (left), and VIIRS ice concentration (right) over Antarctica on January 9th 2017.

Long term Monitoring and Website Links

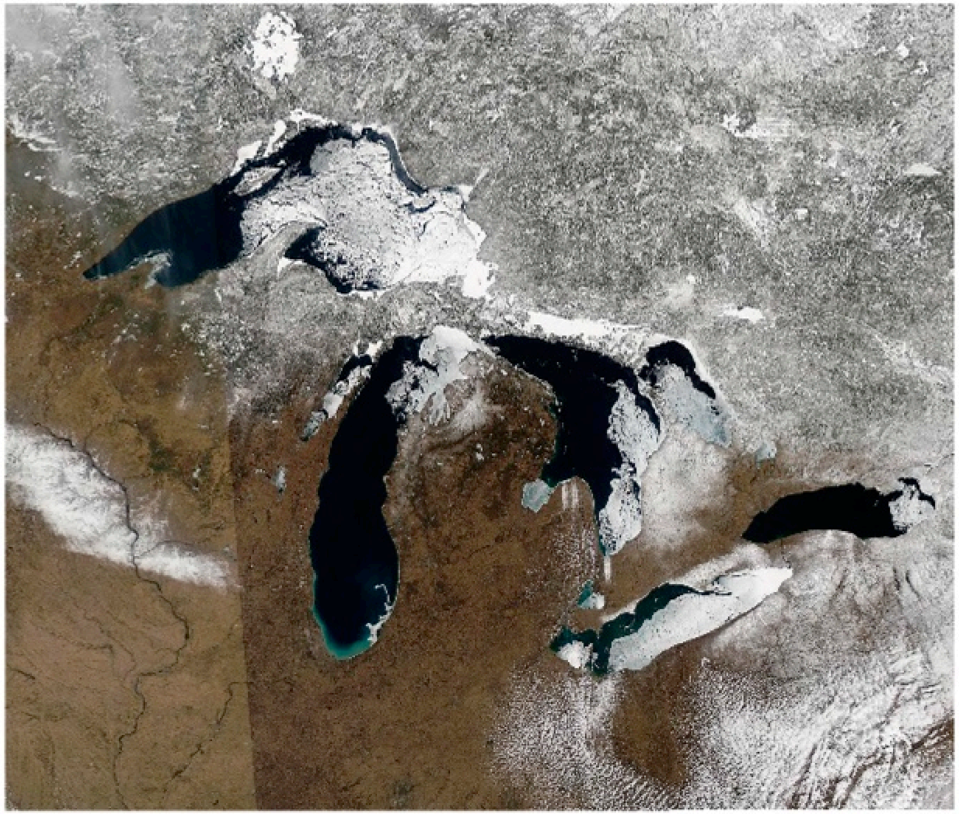


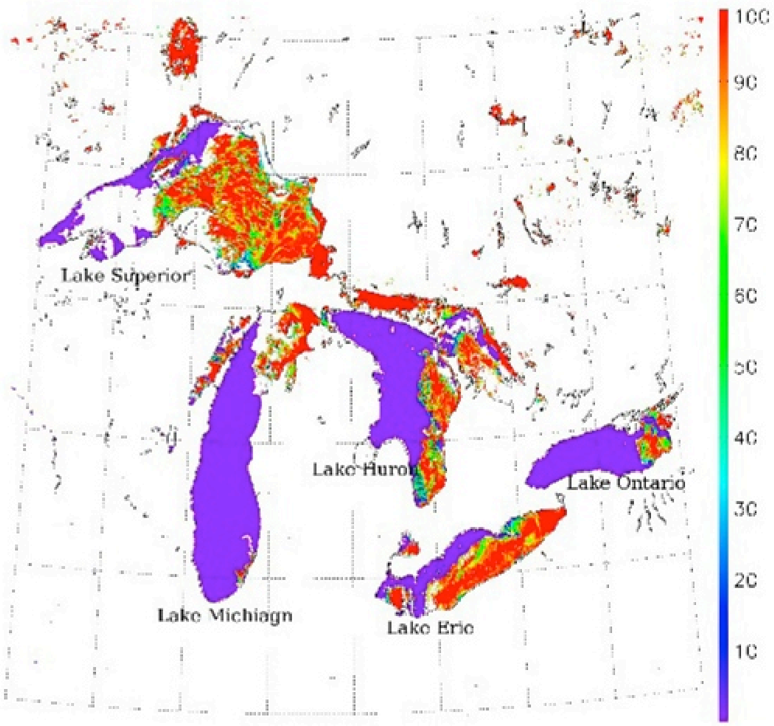
Ice concentration near real-time Enterprise product has been generated and monitored routinely, and figures have been archived and shown on CIMSS website at http://stratus.ssec.wisc.edu/ice-products/anibrowser/index.php, and at JPSS EDRs LTM site, http://www.star.nesdis.noaa.gov/jpss/EDRs/products_cryosphere.php

User Interaction

- Ice concentration is being archived by Naval Research Laboratory for applications in model simulation
- Ice concentration is used by National Ice Center
- Ice concentration has been archived for Walt Meier of GSFC for comparison with microwave products
- Have been in contact with researchers on the possibility in using JPSS ice concentration product in the operational weather forecasting model

Product Example





Aqua MODIS true-color image at 6:20 p.m. UTC on 28 March 2015 (**left**); and the corresponding ice concentration (**right**).

Future Improvement

Future plan:

- Algorithm can be improved with further evaluation to include the tie point adjustment approach;
- Algorithm can be improved to produce higher spatial resolution products of I-band spatial resolution, with ice surface temperature with I-band spatial resolution available;
- VIIRS ice concentration due to cloud leakage can be reduced with historical maximum ice coverage using ice coverage data from NOAA's Interactive Multisensor Snow and Ice Mapping System (IMS);
- Validation will be expanded with more Landsat data, historical SAR data, C-band SAR onboard Sentinel-1, and high optical imagery onboard Sentinel-2.

Summary and Path Forward

- The Suomi NPP and JPSS VIIRS Enterprise Ice Concentration product has high potential to become an extremely useful JPSS product.

- Performance evaluation based on comparisons with microwave and Landsat indicate that the VIIRS Ice Concentration meets the performance requirements; evaluation with DigitalGlobe indicates further improvement might be needed. Both evaluations show VIIRS ice concentration is an useful product for identifying ice extent for both day and night for clear sky conditions.

- Further improvement and evaluation is needed with new ice concentration products from sensors with very high spatial resolution onboard the newly launched European satellites.

SEA ICE THICKNESS AND AGE

Xuanji Wang[1], **Jeff Key**[2], **and Mark Tschudi**[3]

[1]Cooperative Institute for Meteorological Satellite Studies, U. Wisconsin-Madison, xuanjiw@ssec.wisc.edu

[2]NOAA Satellite and Information Services, Madison, Wisconsin

[3]Colorado Center for Astrodynamics Research, CU-Boulder

Ice Thickness and age Team

PI	Organization	Team Members	Roles and Responsibilities
J. Key	NESDIS	X. Wang (CIMSS) M. Tschudi (CU/CCAR) D. Baldwin (CCAR)	Ice thickness development and cal/val Ice thickness cal/val Ice thicknesscal/val

Requirements

EDR Attribute	Threshold	Objective
a. Vertical Coverage	Ice Surface	Ice Surface
b. Horizontal Cell Size **1. Clear** **2. All weather**	 1.0 km No capability	 0.5 km 1 km
c. Mapping Uncertainty, 3 sigma **1. Clear** **2. Cloudy**	 5 km No capability	 0.5 km 1 km
d. Measure Range **1. Ice Age**	**Ice Free, New Young, All other ice**	**Ice free, New/Nilas, Grey, Grey-white, First Year Thin, First Year Medium, First Year Thick, Second Year, Multiyear, Smooth and Deformed Ice**
2. Ice Concentration	0/10 to 10/10	0/10 to 10/10
e. Measurement Uncertainty **1. Probability of Correct Typing (Ice Age)** **2. Ice Concentration**	 70% Note 1	 90% 5%
f. Refresh	At least 90% coverage of the global every 24 hours (monthly average)	6 hrs
g. Geographic coverage	All Ice-covered regions of the global ocean	All Ice-covered regions of the global ocean

Notes:
1. VIIRS produces a sea ice concentration IP in clear sky conditions, which is provided as an input to the ice surface temperature calculation

Enterprise Ice Thickness Algorithm: The One-dimensional Thermodynamic Ice Model (OTIM)

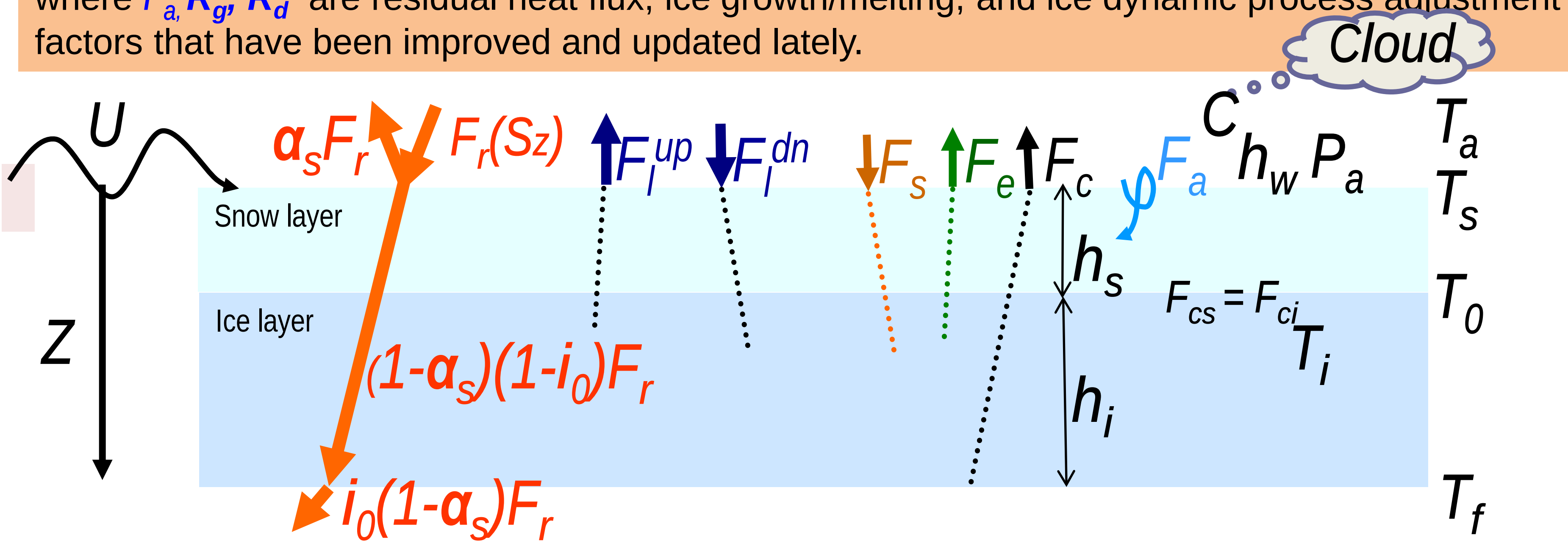
Based on the surface energy budget at thermo-equilibrium state, the fundamental equation is

$$(1-\alpha_s)(1-i_0)F_r - F_l^{up} + F_l^{dn} + F_s + F_e + F_c = F_a(\alpha_s, T_s, U, h_i, C, h_s, \ldots)$$

After parameterizations of thermal radiation (F_r, F_l^{up}, F_l^{dn}) and turbulent (sensible & latent) heat (F_s, F_e), ice thickness h_i becomes a function of 11 model controlling variables plus two factors:

$$h_i = f(\boldsymbol{\alpha}_s, i_0, Sz, T_s, T_i, T_a, P_a, h_w, U, C, h_s, F_a, R_g, R_d),$$

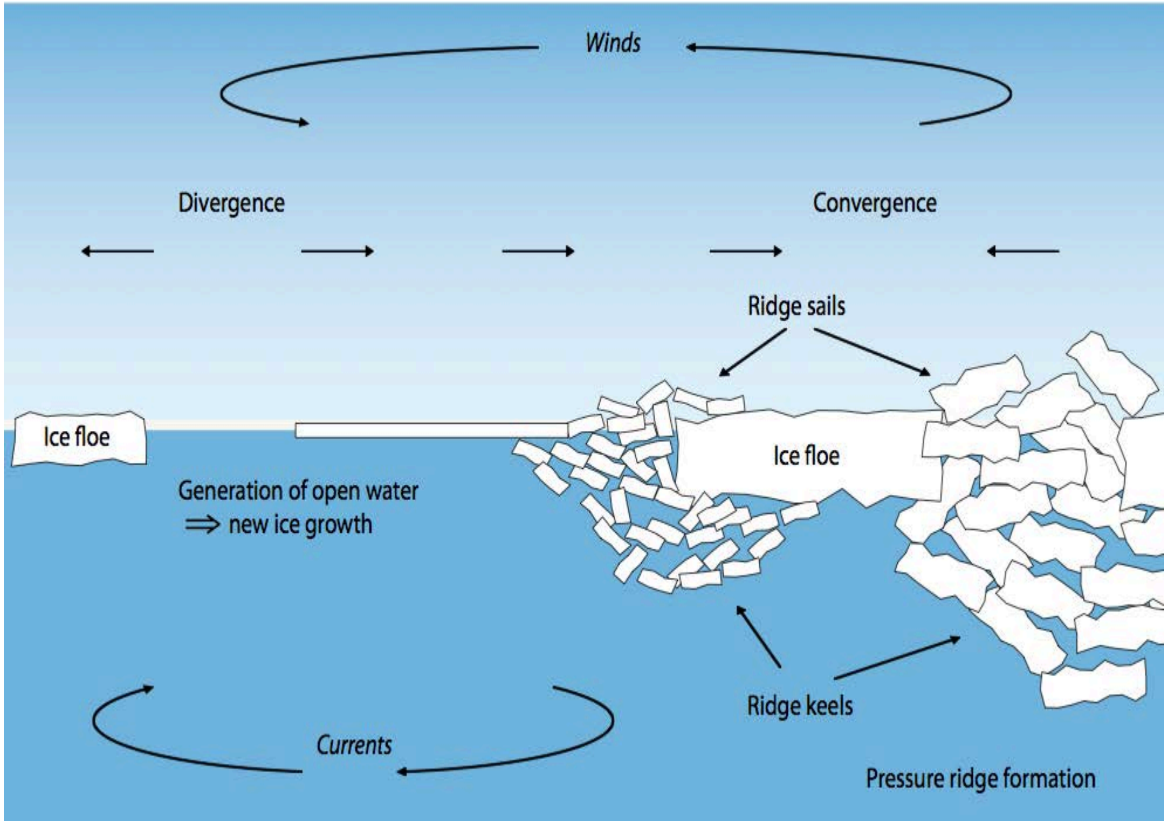
where F_a, $\boldsymbol{R_g}$, $\boldsymbol{R_d}$ are residual heat flux, ice growth/melting, and ice dynamic process adjustment factors that have been improved and updated lately.



Algorithm Improvement and Consistency

Recent OTIM improvements include: 1) Residual flux F_a from regression equation, not the lookup table that is currently used in the enterprise ; 2) Ice motion physical dynamic factor; and 3) Ice growth/melt thermal dynamic factor, for the purpose of explicit ice physical/thermal dynamic processes consideration and broad applications.

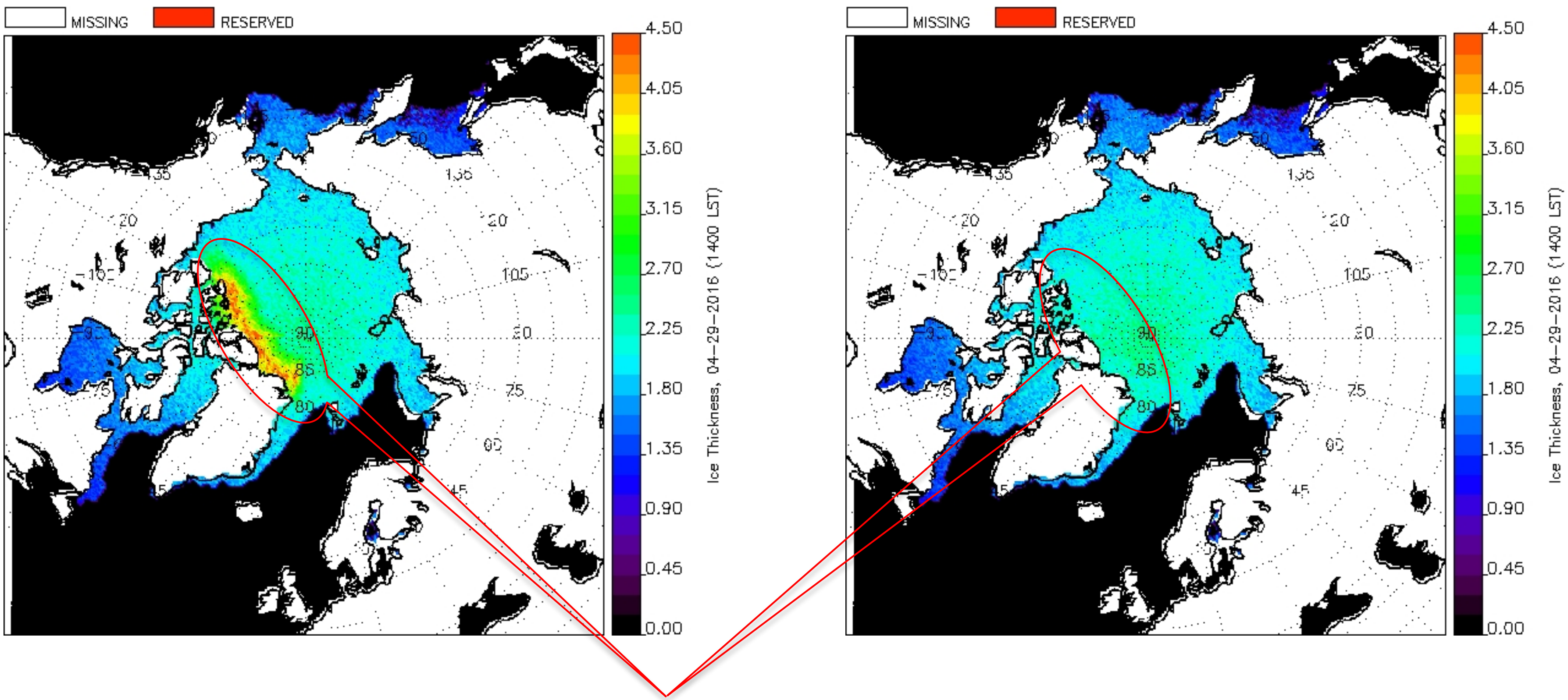
Processes that affect ice thickness. *(from SWIPA, 2011)*



Algorithm Improvement and Consistency

OTIM : Ice motion physical dynamic factor

ON **April 29, 2016** **OFF**

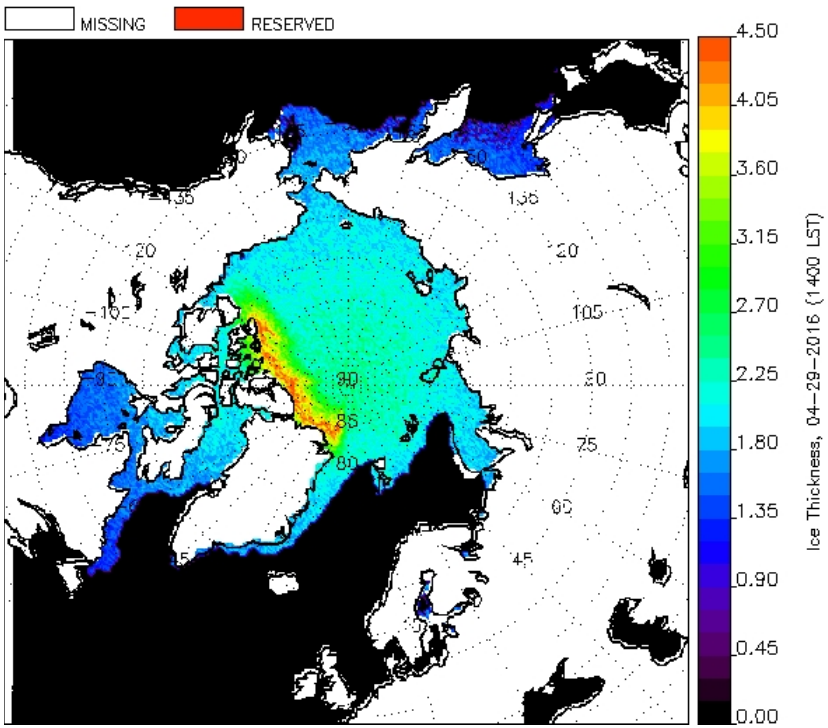


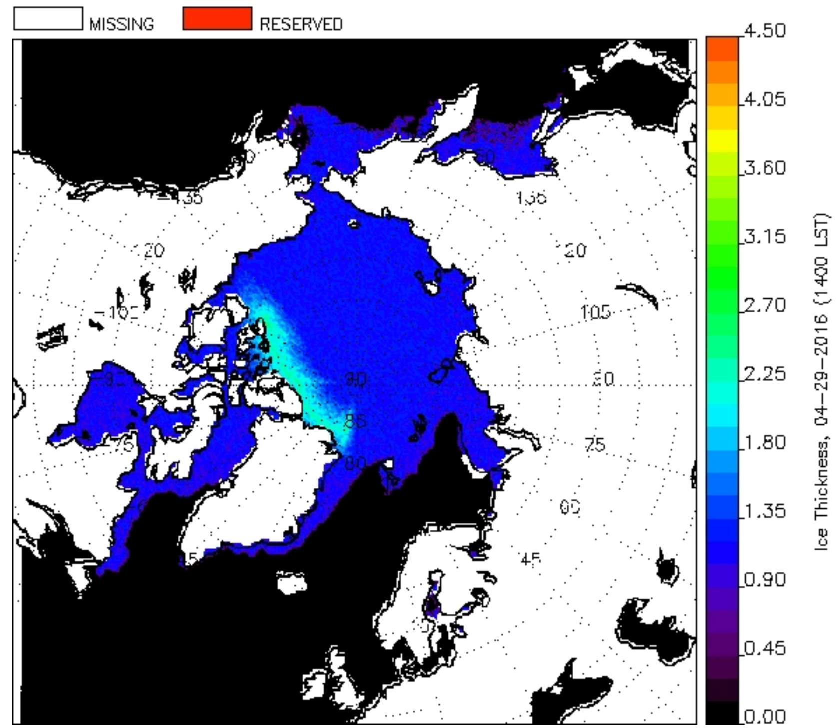
See the difference along the Canadian Archipelagos when Ice motion physical dynamic factor is turned on and off (left and right).

Algorithm Improvement and Consistency

OTIM : Ice growth/melt thermal dynamic factor

ON **April 29, 2016** **OFF**





See the difference in the two images when Ice growth/melt thermal dynamic factor is turned on and off (left and right).

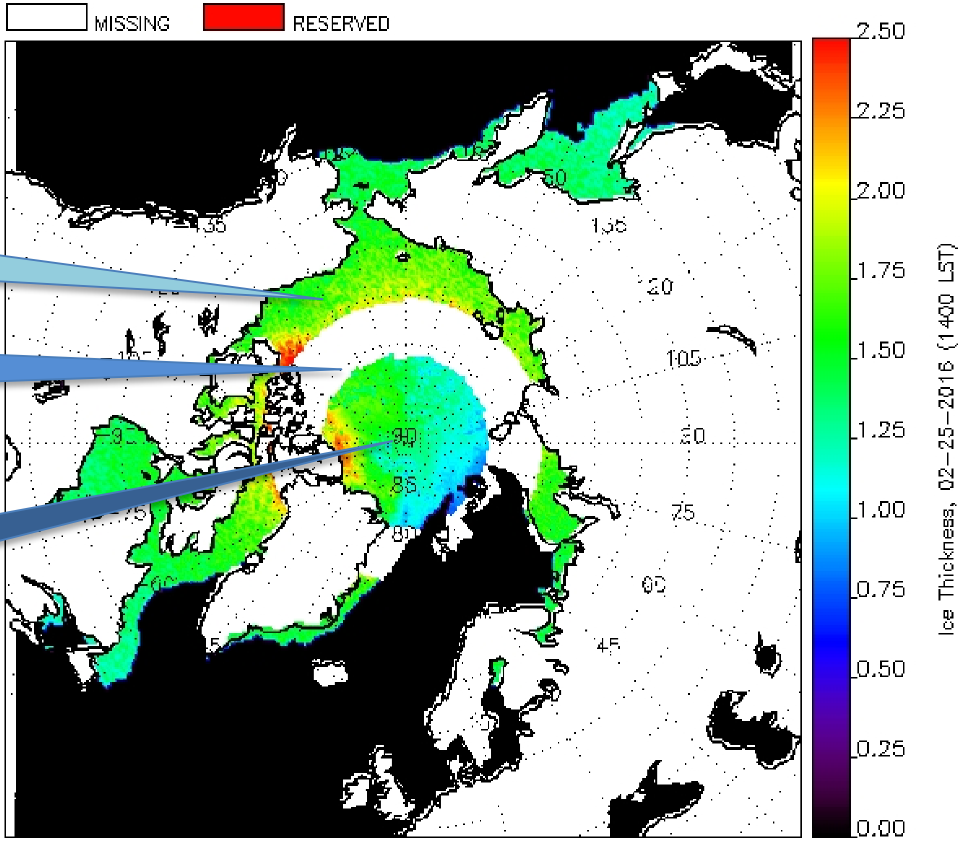
Algorithm Improvement and Consistency

OTIM : Algorithm Day-Night Consistency

Bright area – Day (Solar zenith angle: < 86.5º)

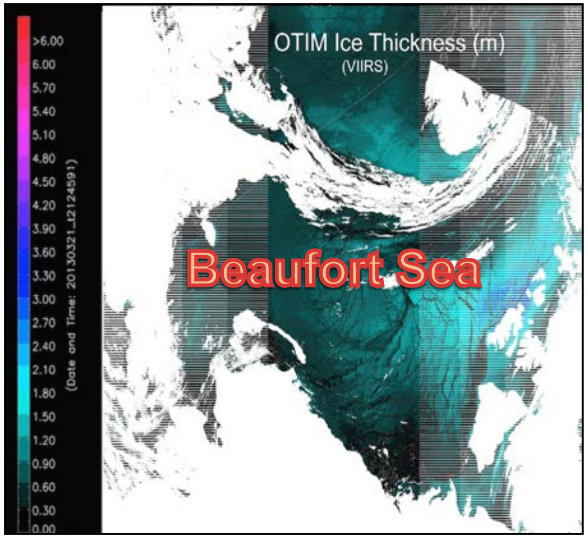
Dim area (Solar zenith angle: 86.5º ~ 90.5º)

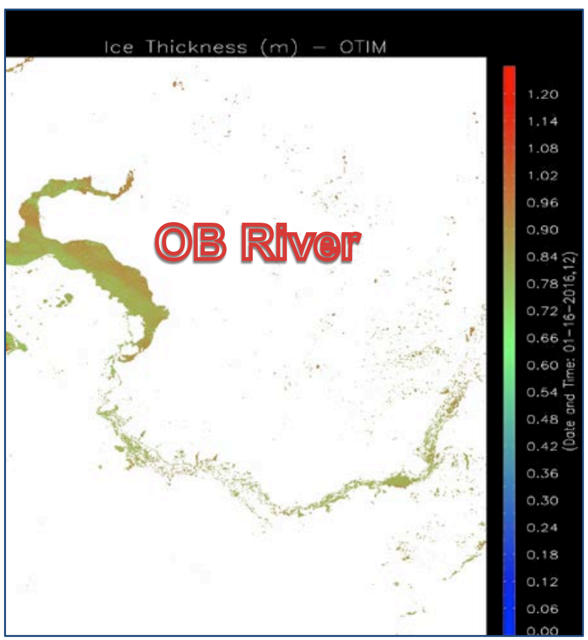
Dark area – Night (Solar zenith angle: > 90.5º)



February 25, 2016

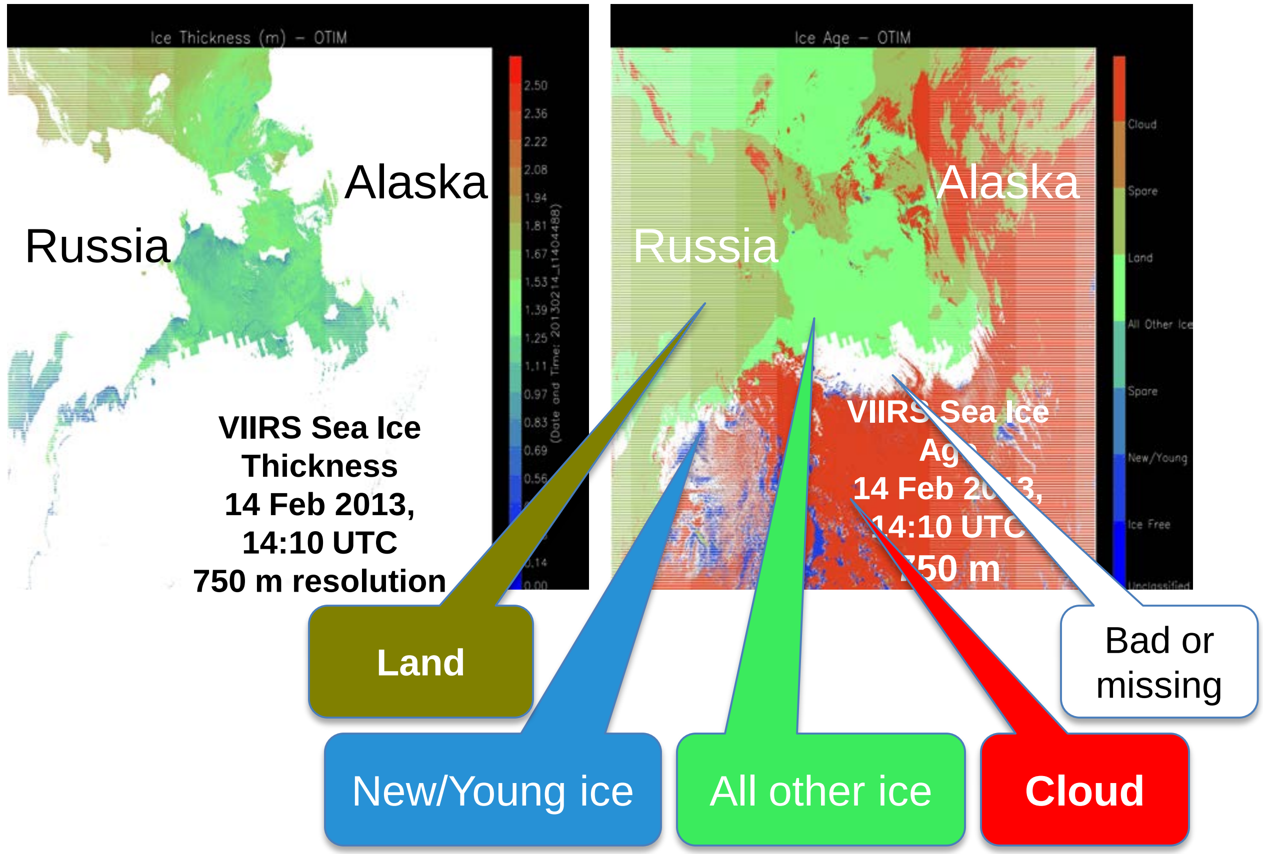
Examples of OTIM Ice Thickness and Age from VIIRS





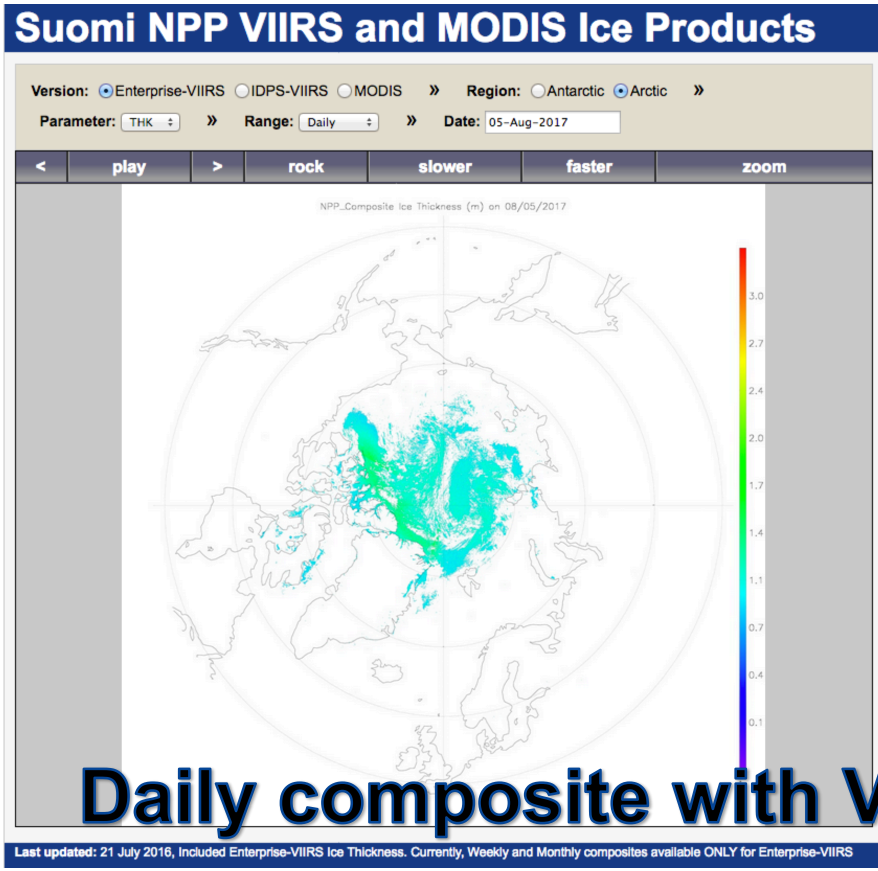
Ice Thickness and Age

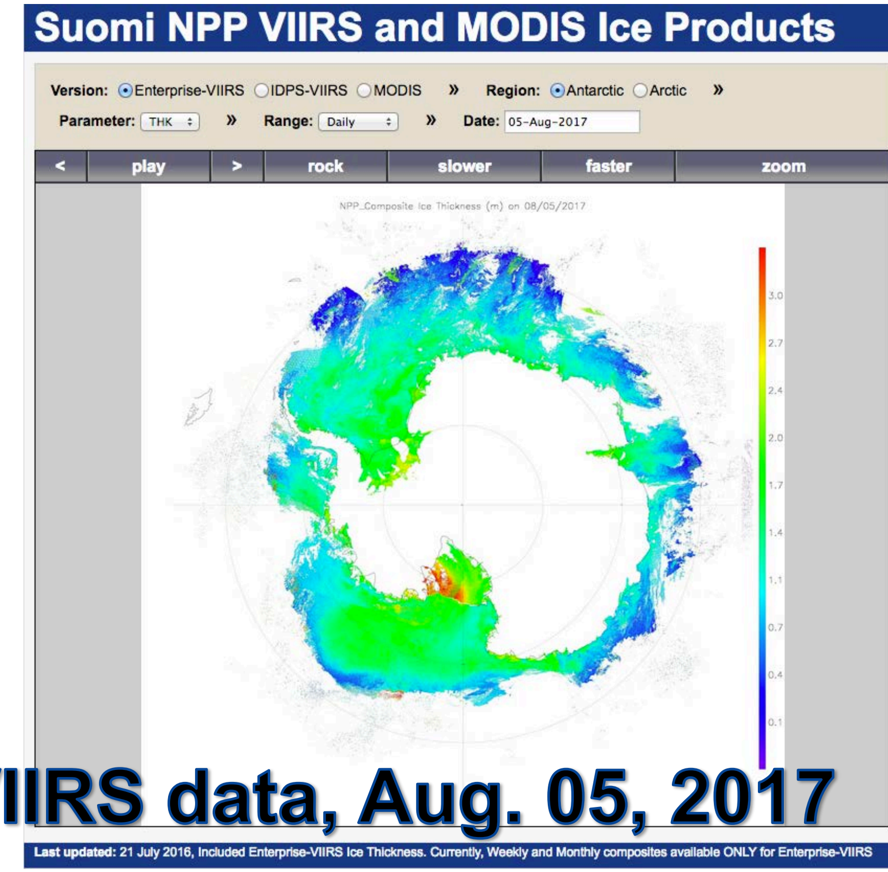
OTIM - Energy Budget Approach



Near real-time VIIRS Sea Ice Thickness

The OTIM retrieved near real-time Arctic and Antarctic sea ice thickness with Suomi NPP VIIRS data under clear sky condition is now available at CIMSS. They will be added to the STAR LTM website in the near future.





Daily composite with VIIRS data, Aug. 05, 2017

https://stratus.ssec.wisc.edu/ice-products/anibrowser/

Validation

Statistical results of the comparison in sea ice thickness between **APP-x (OTIM), PIOMAS, CryoSat-2, and IceBridge** for matched locations.

Period	Statistics	APP-x	PIOMAS	CryoSat-2	IceBridge
MAR (4819)	Mean	2.45	2.44	2.49	2.27
	STD	0.56	0.55	0.60	1.03
	Median	2.39	2.49	2.39	2.16
	Mode	2.33	2.89	2.32	1.89
	Skewness	0.44	0.04	0.92	0.70
APR (292)	Mean	2.94	2.80	3.23	3.38
	STD	0.54	0.58	1.01	1.25
	Median	2.92	2.94	3.52	3.05
	Mode	2.42	2.33	3.63	3.70
	Skewness	0.06	-0.05	-0.42	0.62
MARAPR (5111)	Mean	2.47	2.46	2.53	2.33
	STD	0.57	0.56	0.65	1.08
	Median	2.41	2.51	2.41	2.22
	Mode	2.33	2.04	2.32	3.17
	Skewness	0.41	0.05	0.95	0.76
	Bias statistics and dataset correlation with IceBridge				
MAR	mean	0.18	0.18	0.23	-
	STD	0.76	0.77	0.94	-
	Correlation	0.70 (<0.001)	0.68 (<0.001)	0.44 (<0.001)	-
	Median	0.28	0.25	0.30	-
	Mode	0.70	none	none	-
	Skewness	-0.88	-0.81	-0.65	-
APR	mean	-0.44	-0.58	-0.13	-
	STD	1.00	1.02	1.85	-
	Correlation	0.64 (<0.001)	0.60 (<0.001)	0.33 (<0.001)	-
	Median	-0.23	-0.35	0.02	-
	Mode	0.27	-0.31	0.40	-
	Skewness	-0.32	-0.30	-0.48	-
MARAPR	mean	0.18	0.18	0.29	-
	STD	0.68	0.69	0.84	-
	Correlation	0.70 (<0.001)	0.68 (<0.001)	0.40 (<0.001)	
	Median	0.25	0.23	0.29	-
	Mode	none	none	none	-
	Skewness	-0.88	-0.85	-0.79	-

Descriptive statistics of the ice thickness (top half) in four datasets and their differences and correlation with IceBridge thickness (bottom half) in the two IceBridge periods (meters). MAR is March; APR is April; MARAPR is March and April, over 2011-2013. The number in parentheses beneath the period name is the total number of pixels used for the comparison in that period. P-values are given in parentheses beneath the correlation coefficients.

Overall, the APP-x ice thickness from OTIM is the closest to the IceBridge measurements in terms of mean bias (0.18 m), STD (0.68m), and correlation (0.70).

Validation

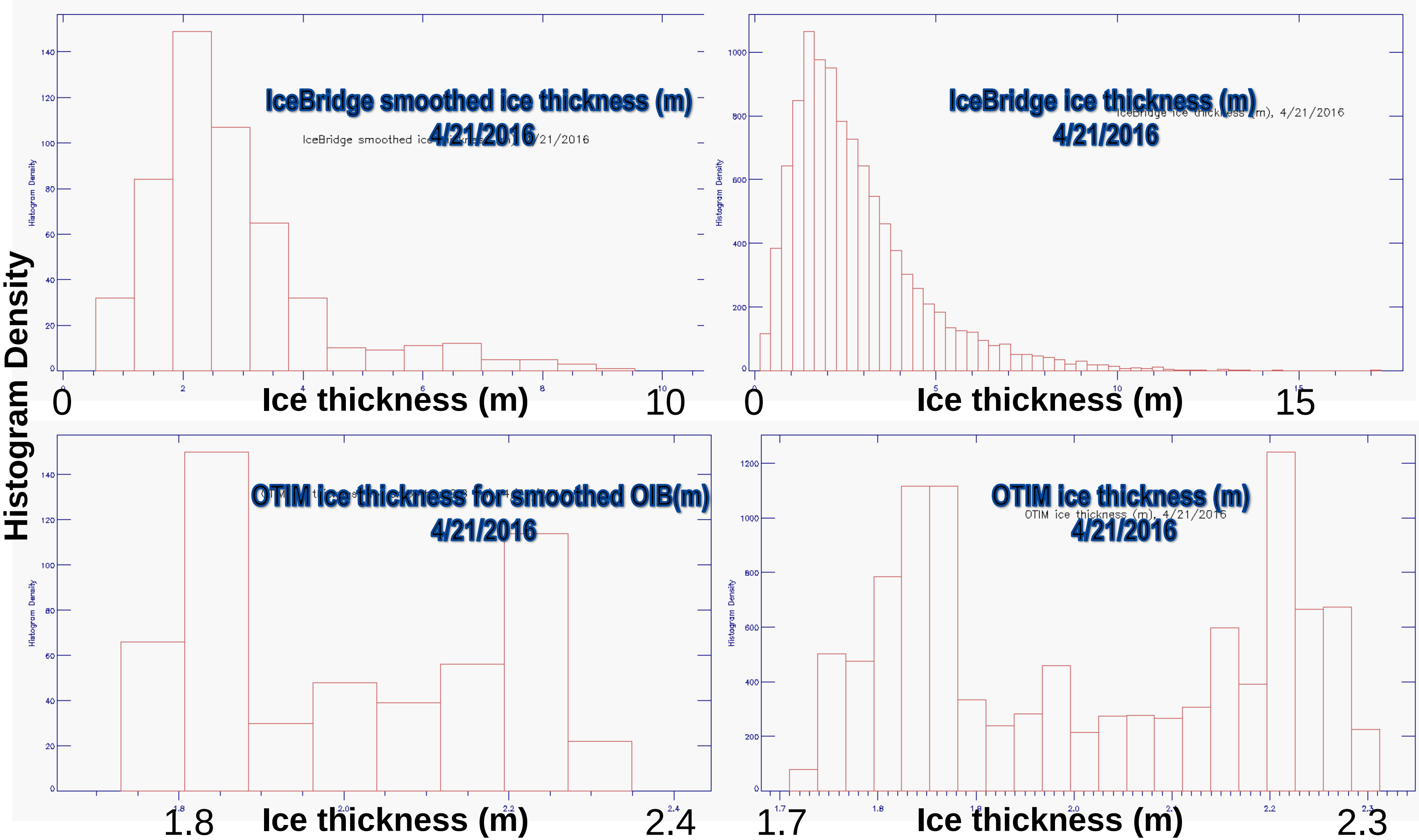
Statistical results of the comparison in sea ice thickness between **S-NPP (OTIM) and NASA IceBridge** (aircraft lidar + snow radar) for matched locations.

Case no	Date	S-NPP		IceBridge		S-NPP minus IceBridge			
		mean	STD	mean	STD	mean	STD	percent (%)	matched pixels
1	2014.03.12	1.18	0.52	1.45	0.69	-0.27	0.55	-5.34	495
2	2014.03.13	2.48	0.55	2.24	0.52	0.24	0.55	16.49	438
3	2014.03.24	1.88	0.78	2.33	0.48	-0.45	0.78	-6.31	803
4	2014.03.31	2.28	0.21	2.56	0.35	-0.28	0.43	-8.97	37
5	2015.03.24	2.06	0.59	2.45	0.43	-0.39	0.75	-11.63	1050
6	2015.03.29	1.72	0.43	1.88	0.54	-0.16	0.74	-1.69	5153
Average		1.93	0.50	2.15	0.50	**-0.22**	**0.63**	-2.91	7976 (total)

From 24 cases of S-NPP granule data when IceBridge has measurements, 6 cases out of the total 24 cases from S-NPP have good overlapped locations with IceBridge where they both have ice thickness values for comparison.

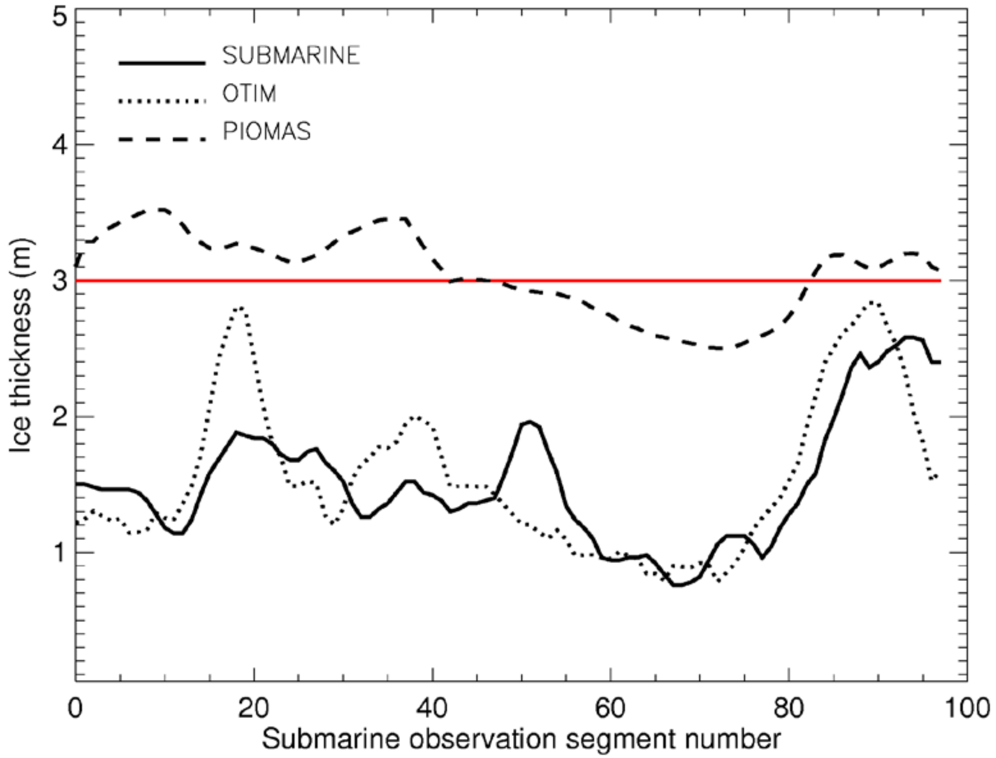
Validation

Statistical results of the comparison in sea ice thickness between S-NPP (OTIM) and NASA IceBridge (aircraft lidar + snow radar) for matched locations.



Validation

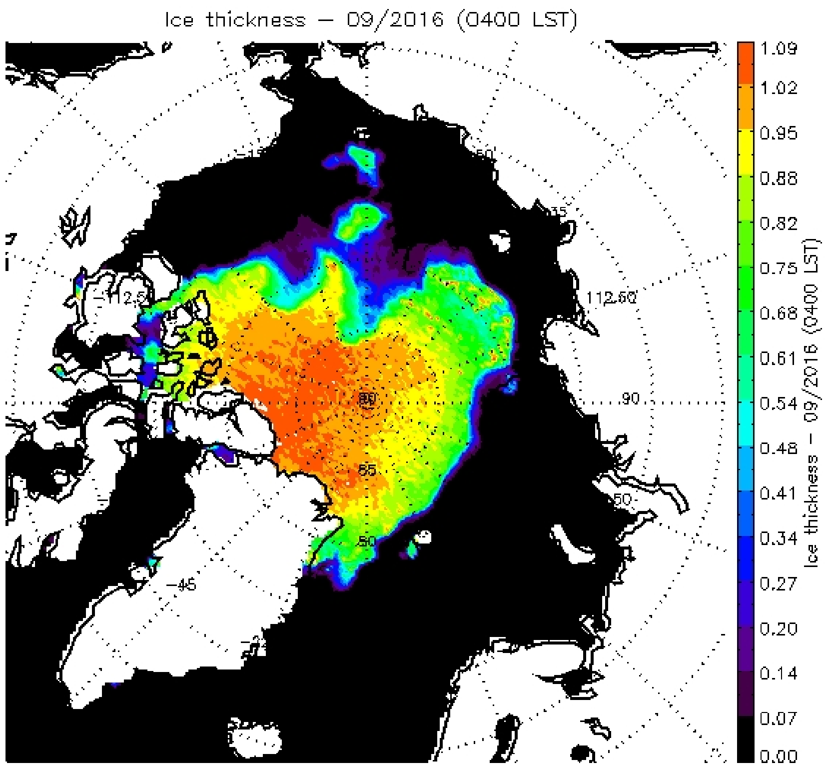
Validation has been done with upward-looking sonar from submarines and moored buoys in situ thickness measurements ICESat, CryoSat-2, IceBridge, and an ice-ocean model.

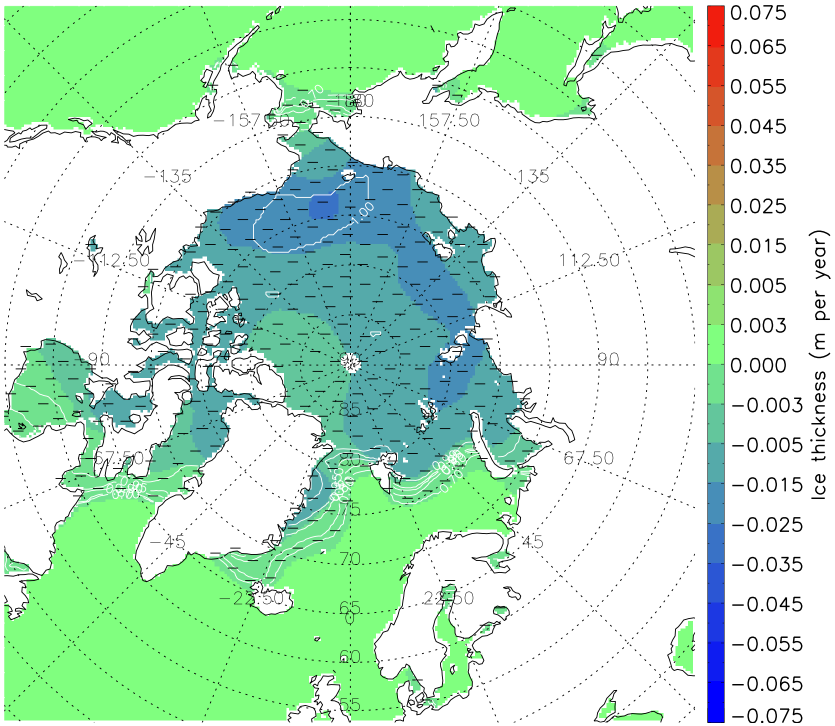


Right: Validation with submarine sonar and modeled ice thicknesses.

	OTIM	Submarine
Thickness Mean (m)	1.55	1.51
Bias (m)	0.04	
RMS difference (m)	0.52	

Trends in Sea Ice Thickness





Left: Arctic sea ice thickness from OTIM in **September 2016**. Center: Arctic sea ice thickness trends from OTIM in Autumn (Sept. – Nov.) over 1982-2016.

AVHRR TRENDS CAN BE EXTENDED INTO THE VIIRS ERA AND THAT THE ALGORITHM USED WITH AVHRR IS THE SAME AS THE VIIRS ALGORITHM.

JPSS-1 Readiness

- Significant algorithm changes from S-NPP to JPSS-1:
  - Daytime-nighttime consistency has been significantly improved.
- Post-Launch Cal/Val Plans
  - Most important new dataset will be ICESat-2 (delayed until early 2018) and CryoSat-2.
  - IceBridge flights will continue to be important
  - Near real-time validation will be set up using Cryosat-2 and SMOS
- Accomplishments and Highlights Moving Towards J1
  - Improvements to the model, e.g., residual heat flux that for better daytime (sunlit) retrievals
  - Near real-time generation
  - Application to 30+ years of AVHRR
- Major Risks/Issues/Challenges/ and Mitigation
  - Limitations need to be made clear to users, e.g., upper limit of ice thickness retrieval (~5 m) and larger uncertainty in melt conditions
  - Ultimately, either a VIIRS product adjusted by Cryosat-2/ICESat thicknesses, or a blended product may provide the best estimate.

Summary & Path Forward

- Summary
  - The **VIIRS Ice Thickness/Age product is ready for J1**
- Path Forward
  - FY17 Milestones: Add ICESat-2 to validation plans (CY 2018); begin to test regional bias corrections with altimeter-based ice thickness
  - Alternate Algorithms and Future Improvements: no alternate algorithms; add VIIRS surface radiation

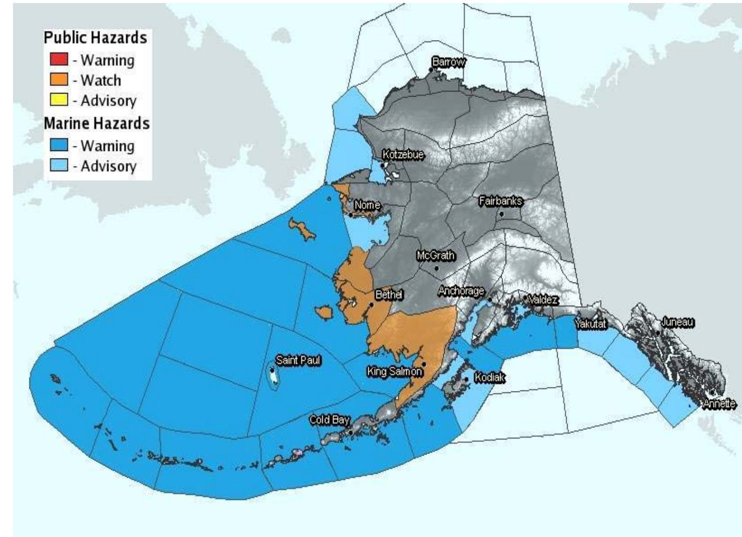
Snow and Ice Product Users (planned)

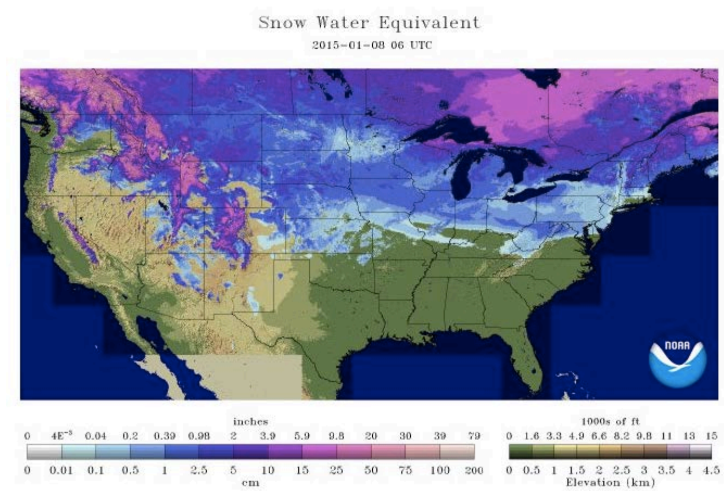
Operational Ice Services

- U.S. National Ice Service
- North American Ice Service
- NWS Alaska Sea Ice Program

Modeling

- (Need to set up collaborations and funding) Naval Research Lab, Arctic Cap Nowcast/Forecast System (ACNFS), NCEP
- Universities (Washington, Hamburg)





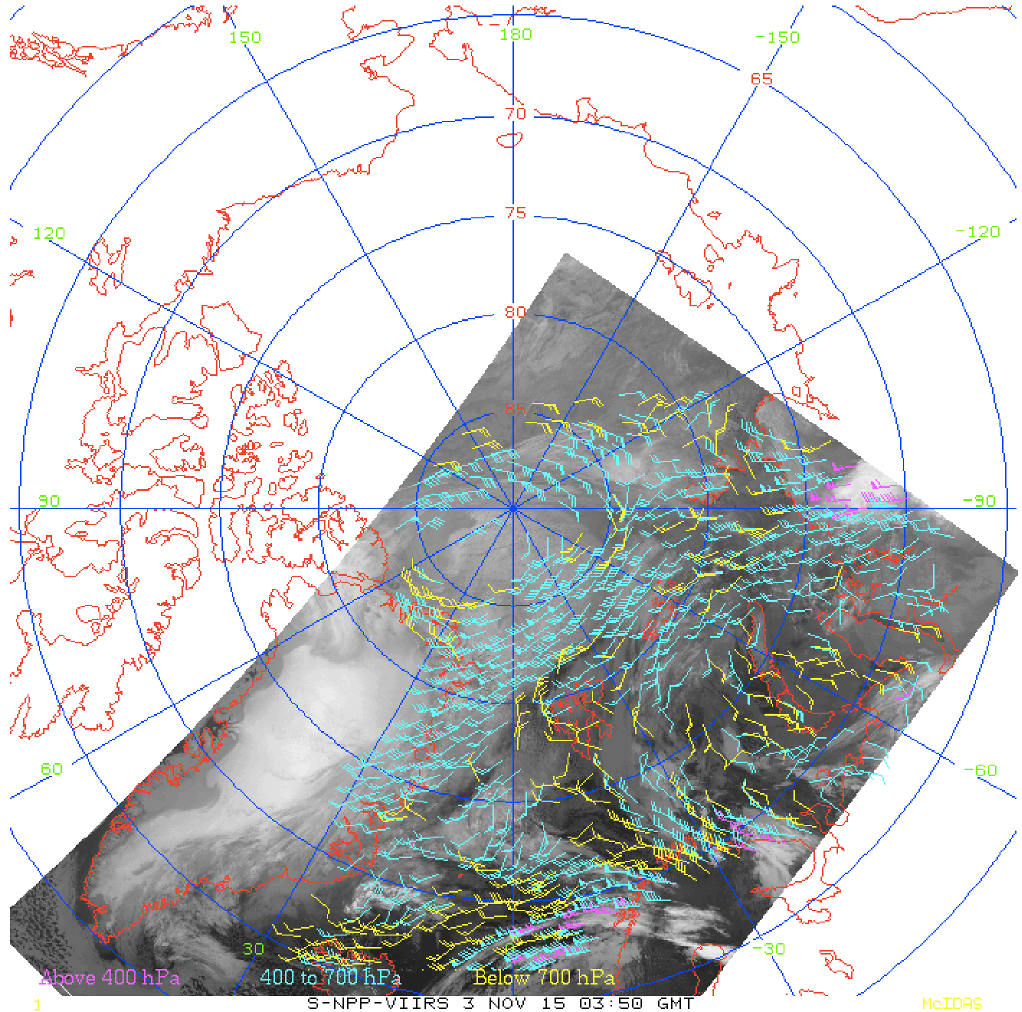
VIIRS POLAR WINDS

Jeff Key and Jaime Daniels
NOAA/NESDIS
608-263-2605, Jeff.Key@noaa.gov

VIIRS Polar Winds (VPW) in Brief

VIIRS Polar Winds are derived by tracking clouds features in the VIIRS longwave infrared channel

- Wind speed, direction, and height are determined throughout the troposphere, poleward of approximately 65 degrees latitude, in cloudy areas only
- Wind information is generated in both the Arctic and Antarctic regions
- The algorithm utilizes the Enterprise cloud height, phase, and (soon) mask



VIIRS Polar Winds Team

Name	Organization	Major Task
Jeff Key	STAR	Project management, DB winds
Jaime Daniels	STAR	Project management, algorithm development and testing
Wayne Bresky	IMSG	Algorithm development and testing
Andrew Bailey	IMSG	Algorithm development and testing
Dave Santek	CIMSS	Algorithm and product testing
Steve Wanzong	CIMSS	Algorithm and product testing
Hongming Qi	OSPO	Operations
Walter Wolf and others	STAR, AIT	Implementation

Requirements

JPSS L1RD supplement (threshold) requirements versus observed

Attribute	Threshold	Observed/validated
Geographic coverage	~70^{o} latitude to poles	~65^{o} to poles
Vertical Coverage	Surface to tropopause	same
Vertical Cell Size	At cloud tops	same
Horizontal Cell Size	10 km (should be ~19 km, CCR Aug 2015)	same
Mapping Uncertainty	0.4 km (nadir); 1.5km (edge of scan)	0.57 km
Measurement Range	Speed: 3 to 100 m s^{-1}; Direction: 0 to 360 degrees	same
Measurement Accuracy	Mean vector difference: 7.5 m/s	5.7-7.0 m/s (w/raobs)
Measurement Precision	Mean vector difference: 4.2 m/s (was 3.8 m/s)	2.7-3.8 m/s (w/raobs)
Measurement Uncertainty	Not specified	Not applicable

AMV Performance Metrics

AMVs (QI>60) are matched and compared against RAOBS or GFS model analysis winds. Metrics:

$$Accuracy = \frac{1}{N}\sum_{i=1}^{N}(VD_i)$$

$$\text{Pr}\,ecision = \sqrt{\frac{1}{N}\sum_{i=1}^{N}((VD_i)-(MVD))^2}$$

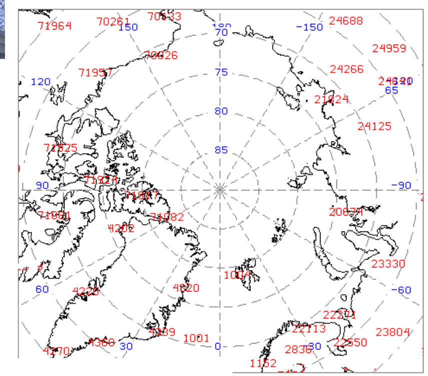
where:

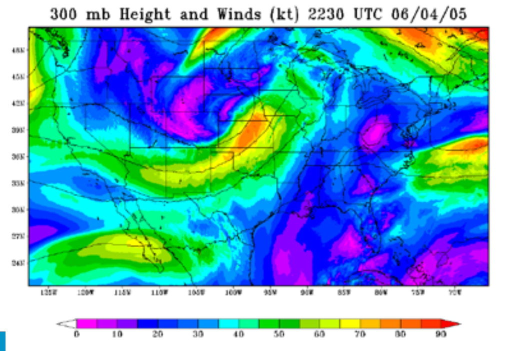
$$(VD)_i = \sqrt{(U_i - U_r)^2 + (V_i - V_r)^2}$$

U_i and V_i ---> AMV
U_r and V_r ---> “Truth”

Derived Motion Winds Test Plan – Offline Validation: Truth Data

- Radiosonde wind observations serve as a key validation data source for derived motion wind products
  - Used by all operational satellite processing centers that generate satellite derived motion winds
- Aircraft wind observations
- GFS Model Analysis Wind Fields





Status

Error Budget:

Attribute Analyzed	L1RD Threshold	Analysis/Validation Result	Meets spec?
Accuracy	7.5 m/s	5.7-7.0 m/s	Y
Precision	4.2 m/s	2.7-3.8 m/s	Y
Horizontal cell size	10 km	19 km (inherent to the algorithm)	N; Change the requirement as it is an error
Mapping uncertainty	0.4 km nadir; 1.5 km EOS	0.57 km	Y

- **The VIIRS Polar Winds product has been operational since May 2014.**
- **Validated Maturity, October 2016**
- VPW is also generated at direct broadcast sites and delivered to NWP centers.

Users

- **13 NWP centers in 9 countries use polar winds** (MODIS, AVHRR, VIIRS); some using VIIRS winds operationally.
- U.S. Users:
  - NCEP (Dennis Keyser)
  - NRL/FNMOC (Randy Pauley)
  - GMAO/JCSDA
- Foreign Users:
  - UK Met Office (Mary Forsythe)
  - JMA (Masahiro Kazumori)
  - ECMWF (Jean-Noel Thepaut)
  - DWD (Alexandar Cress)
  - Meteo-France (Bruno Lacroix)
  - CMC (Real Sarrazin)
  - BOM (John LeMarshall)
  - EUMETSAT (Simon Elliott)
  - Russian Hydrometcenter (Mikhail Tsyrulnikov)
  - CMA (China)

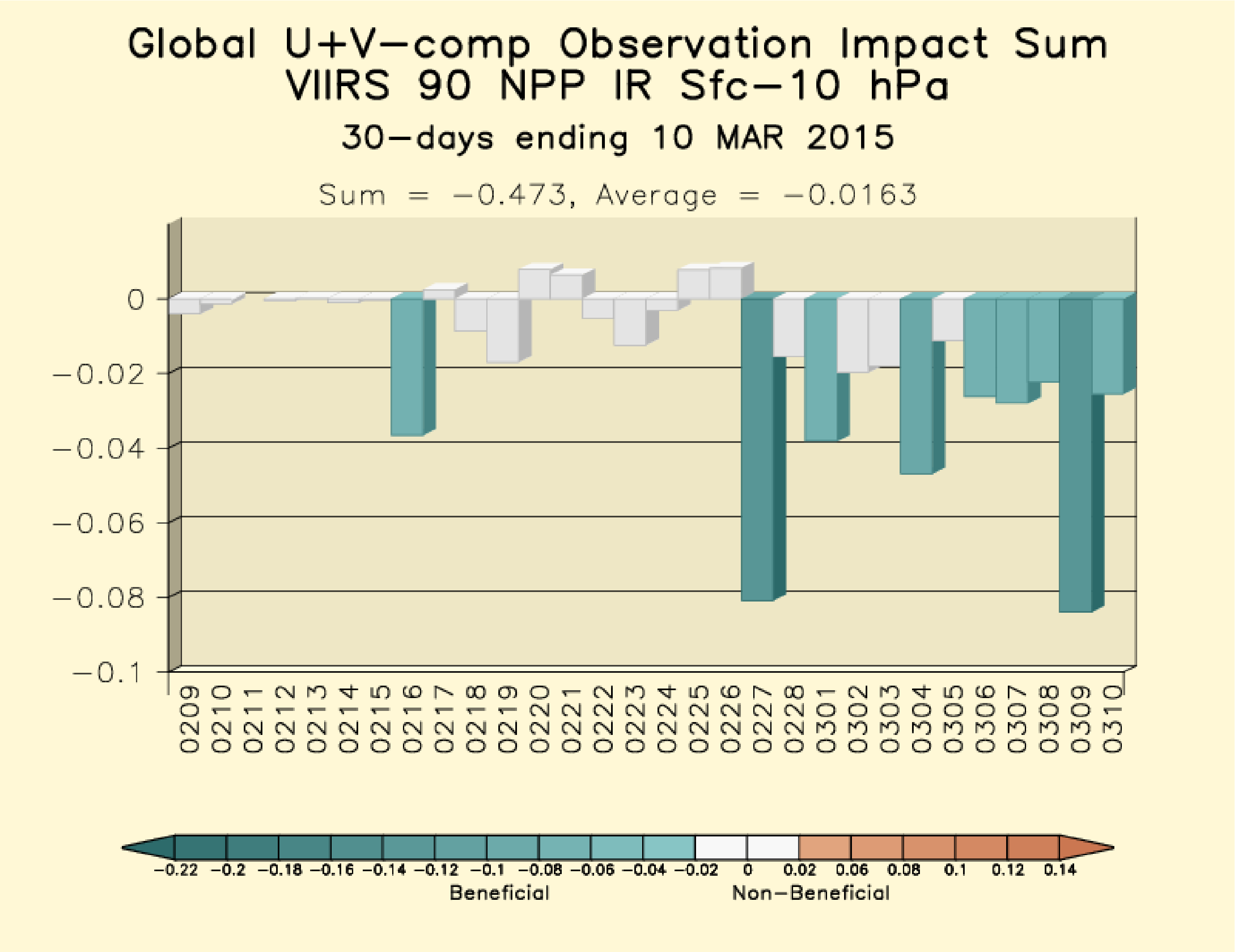
User Feedback

- Over the last decade, model impact studies at >10 major NWP centers have demonstrated that model *forecasts for the NH and SH extratropics are improved when the MODIS polar winds are assimilated. Forecasts can be extended 2-6 hrs, depending on the location.*
- *NWP users have reported similar results for the VIIRS Polar Winds*, as reported at the most recent International Winds Workshop (2016, Monterey) and at other venues.

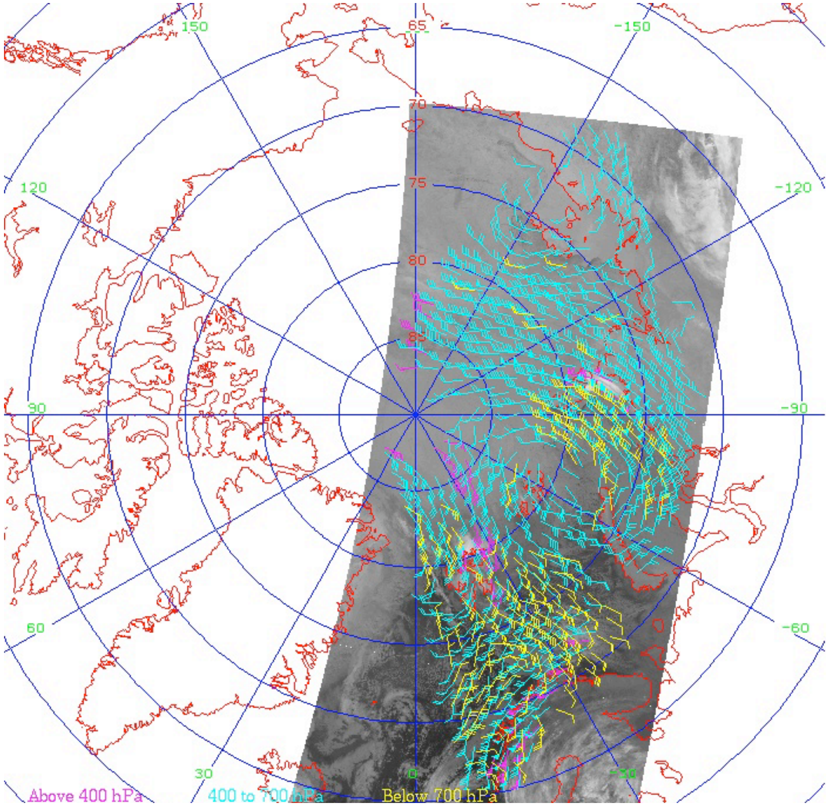
Organization	Use VPW operationally	Currently monitoring	Plan to use?
NCEP		Yes	Yes (2017)
DWD	Yes		
Navy	Yes		
ECMWF	Yes		
Met Office		Yes	Yes
CMC	Yes		
MeteoFrance		Yes	Yes

Awaiting information from the other NWP centers.

Users, cont.



Courtesy of Naval Research Lab



Thank you!

NDE AND IDPS PRODUCT NOTES

Jeff Key
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IDPS and NDE Products

Variable	IDPS	NDE
Sea ice concentration	IP (not EDR)	✓
Ice surface temperature	✓	✓
Sea ice characterization	No ice, New/young ice, Other ice	Thickness estimate plus age categories
Snow cover: binary	✓	✓
Snow cover: fractional	Average of 2x2 binary	Sub-pixel fraction
Polar winds	n/a	✓
AMSR2: snow cover, depth, and SWE; sea ice characterization	n/a	✓

NDE Product Availability

Cryosphere products:

- went operational in NDE on July 5;
- CLASS started archiving on July 7;
- CLASS indicates they need until the end of Aug to make the search and accessibility updates in the CLASS interface so that users can access.

The JPSS program is working with OSPO and CLASS to determine the timeline for turning off the archive and distribution of the IDPS versions (likely to be 3-6 months as there are some DOD users that need to transition (and they've indicated they need up to 6 months). *Users are encouraged to transition to the NDE products as soon as possible.*

For JPSS-1, the JPSS Program Office is working with NCEI and CLASS. The Program feels it is prudent for them to not archive any of the "enterprise products" from IDPS. This means none of the EDRs except VIIRS imagery. This has not been decided by management yet, but it is the likely scenario.

VIIRS RIVER ICE MAPPING

Peter Romanov
CREST/CUNY at NOAA/STAR
peter.romanov@noaa.gov

Outline

– Project overview
– Algorithm and product
– Recent enhancements
– Product verification
– Plans

Motivation

- Operational needs for river ice information
  - Water management, transportation, recreation, safety
- Current VIIRS products are insufficient
  - Inadequate algorithm, coarse land/water mask
- Better characterization of the river ice is possible with
  - Algorithm specifically focused on the river ice
  - More detailed and accurate land/water mask

Project Overview

- Objective:
  - Provide near real-time information on the state of the ice cover over rivers and coastal areas
    - Focus on wide (> 375m) rivers in Alaska and CONUS
    - Support for NOAA River Forecast Centers (RFCs) and US Coast Guard operations

- Funding: JPSS Risk Reduction

- Project started in 2014, Phase II started in 2016.

Team

Development and implementation

- Naira Chaouch (PI) , Marouane Temimi, Peter Romanov, Paul Alabi (all NOAA-CREST, CCNY, New York)

Operational support

- Jay Hoffman, Dave Santek (CIMSS/SSEC, UW Madison)

Users

- Ed Capone (North East RFC), Mike DeWeese (North Central RFC), Erik Holloway, Tim Szeliga (Alaska-Pacific RFC), Aaron Bisig (US Coast Guard)

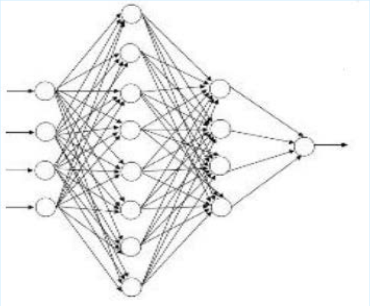
Technique

Initial ice identification
(Threshold-based decision-tree)

VIIRS R1, R2, R3, T5

Ice and water reflectance prediction
(ANN-based Band 2 BRDF model)

SatZenith
SatAzimuth
SolZenith
SolAzimuth



$\mathbf{R_{ice}}$

$\mathbf{R_{water}}$

Ice concentration estimate
(Linear unmixture technique)

$$\text{IceConc} = (R_{ice}-R_{obs})/(R_{ice}-R_{water})$$

Input:

VIIRS SDR (Bands 1-3,5)
VIIRS cloud mask
VIIRS geolocation
River Masks

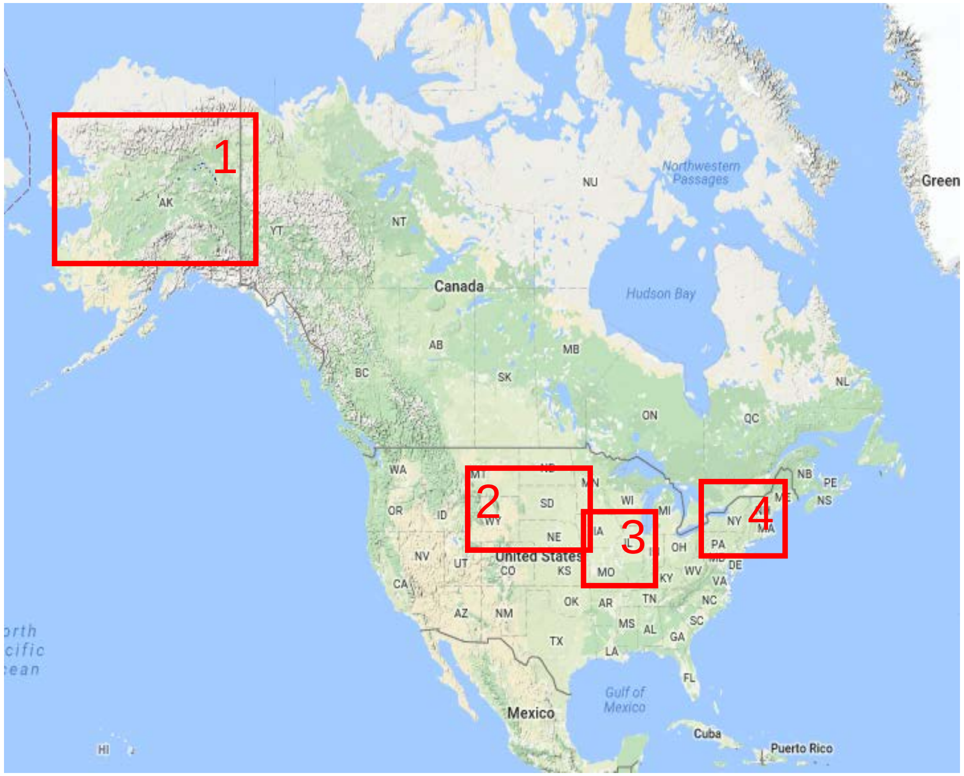
Algorithm is applied only to VIIRS observations over river channels

Output:

Ice concentration map

- -Overpass-based
- -Limited to selected rivers
- -Geographic projection
- ~375m grid cell size

Geographical coverage



1. APRFC (Alaska-Pacific
2. MBRFC (Missouri Basin)
3. NCRFC (North-Central)
4. NERFC (North-East) & MARFC(Mid-Atlantic)

Rivers covered

Pre-2017	*Starting 2017*
Alaska	
Yukon	Yukon
Kuskokwim	Kuskokwim
	Tanana
	Sustina
North East	
Hudson	Hudson
Mohawk	Mohawk
Lake Champlain	Lake Champlain
	Merrimack
	Connecticut
	Androscoggin
	Penobscot
	Kennebec
	Piscataqua
	Great Bay
	Damariscotta
	Saco
North Central	
Mississippi	Mississippi
Illinois	Illinois
Missouri	
Missouri	Missouri

Product Generation and Accessibility

River Ice Concentration maps are routinely produced at CIMSS/SSEC, UW

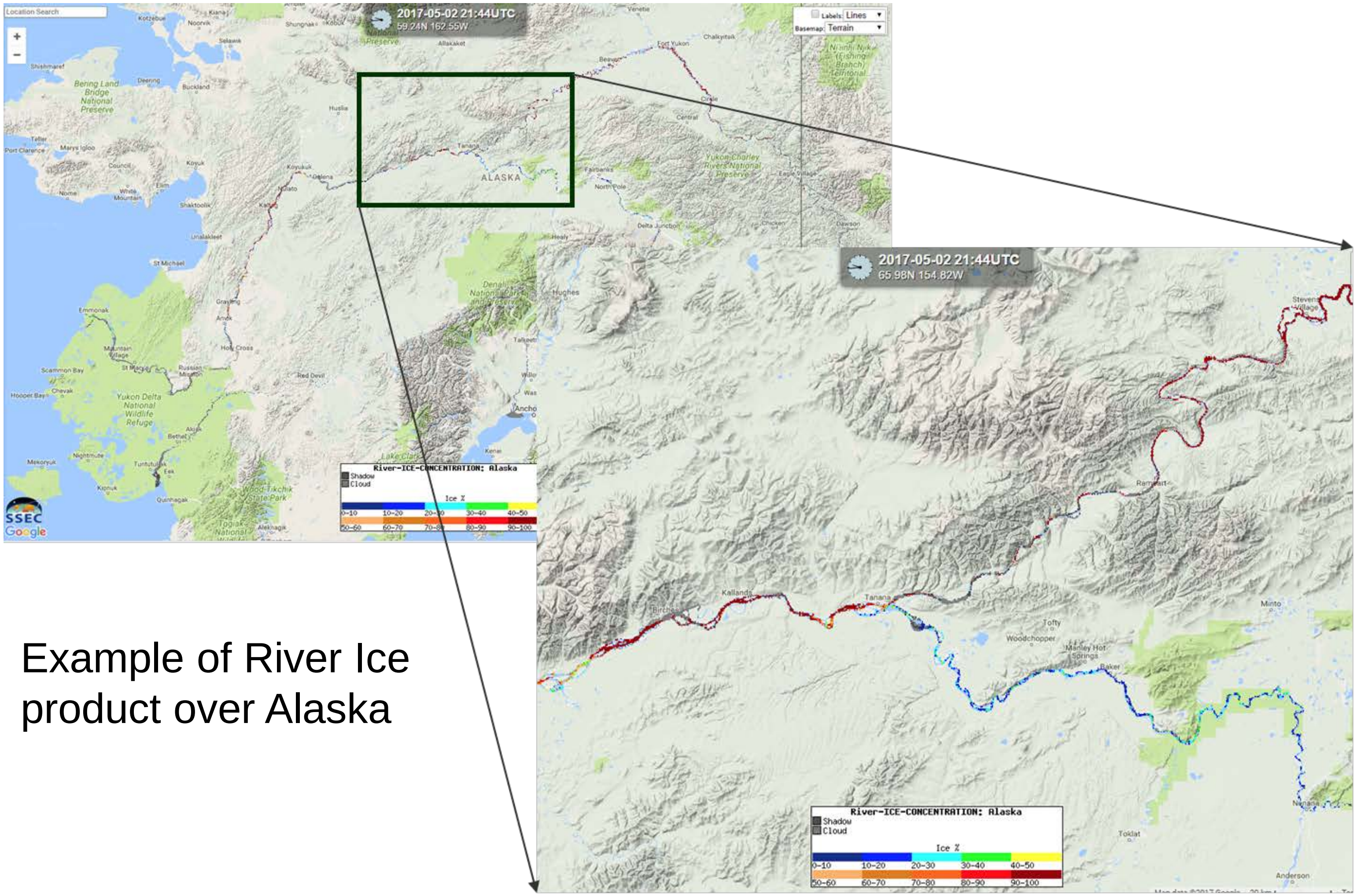
Maps are displayed on AWIPS II and SSEC Real Earth:

- North Central: http://realearth.ssec.wisc.edu/?products=RVER-ICEC-NC
- North East: http://realearth.ssec.wisc.edu/?products=RVER-ICEC-NE
- Missouri Basin: http://realearth.ssec.wisc.edu/?products=RVER-ICEC-MB
- Alaska Pacific: http://realearth.ssec.wisc.edu/?products=RVER-ICEC-AP

SSEC Real Earth display system

- Geographic projection
- Image selection by time/overpass
- Zoom in and out
- Background selection
- Overlay labels
- Create/Operate layers of images

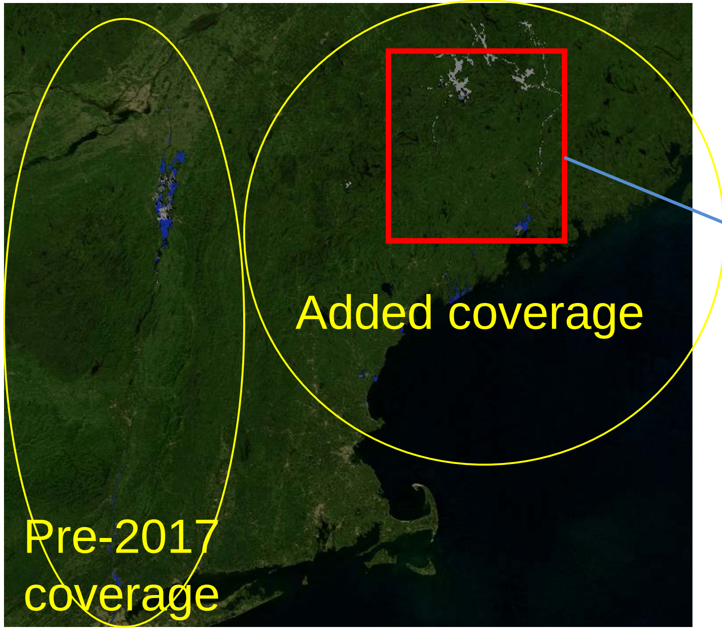
Example of Product

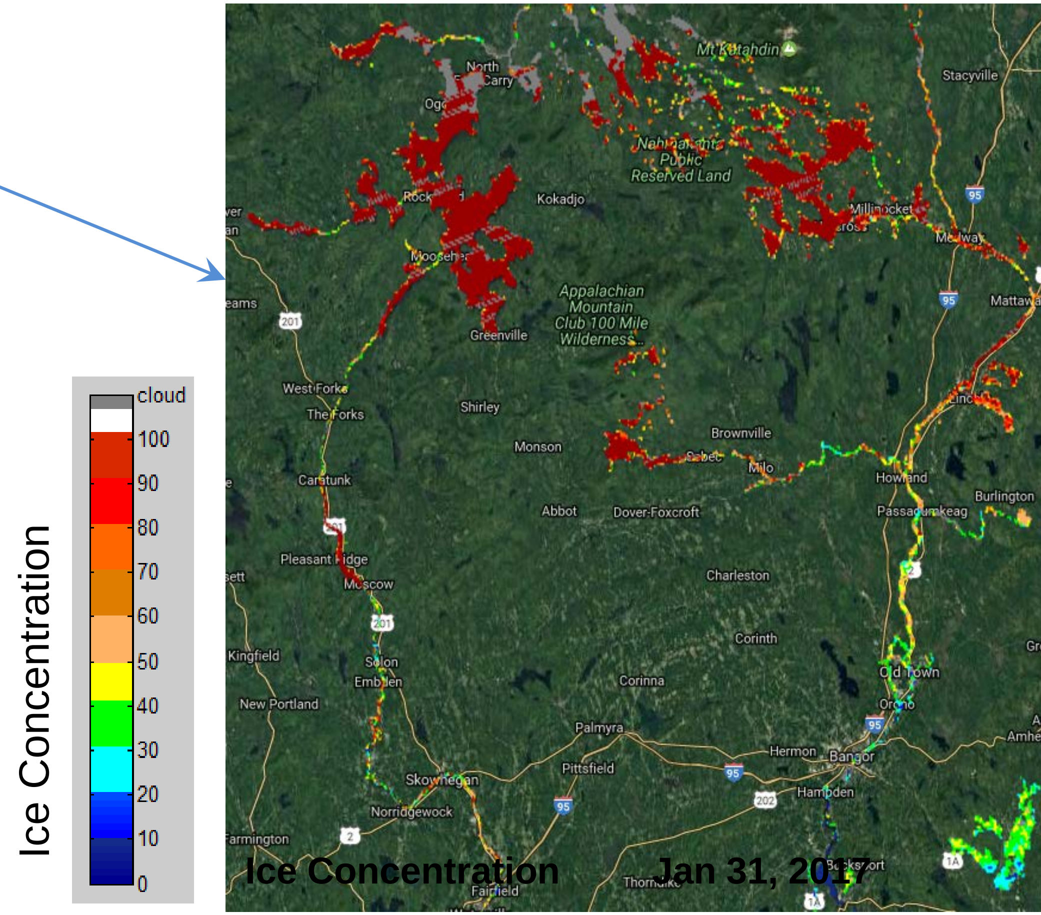


Example of River Ice product over Alaska

Example of Product

North-East





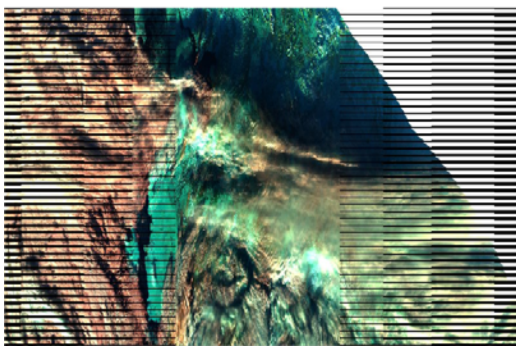
In 2017 the coverage in the North East was substantially expanded to cover coastal areas, rivers and lakes on the request of US Coast Guard.

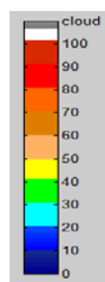
Recent Improvements: Cloud shadows

Why: **-** Unaccounted cloud shadows cause ice misses

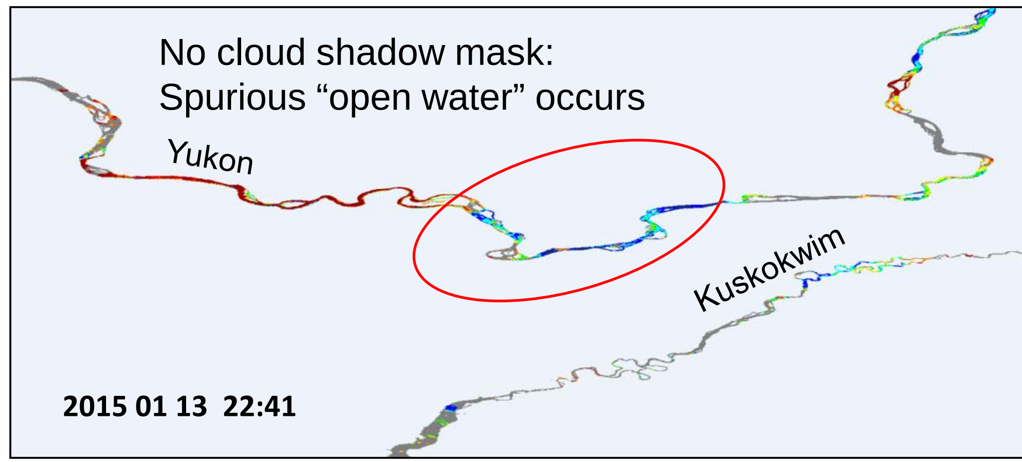
- VIIRS IDPS cloud shadows are derived at $\theta_{sol} < 75^0$

Algorithm: Geometry-based, fixed lapse rate for cloud height, $\theta_{sol} < 88^0$





Red: clouds, yellow: cloud shadow



Recent Improvements: Terrain shades

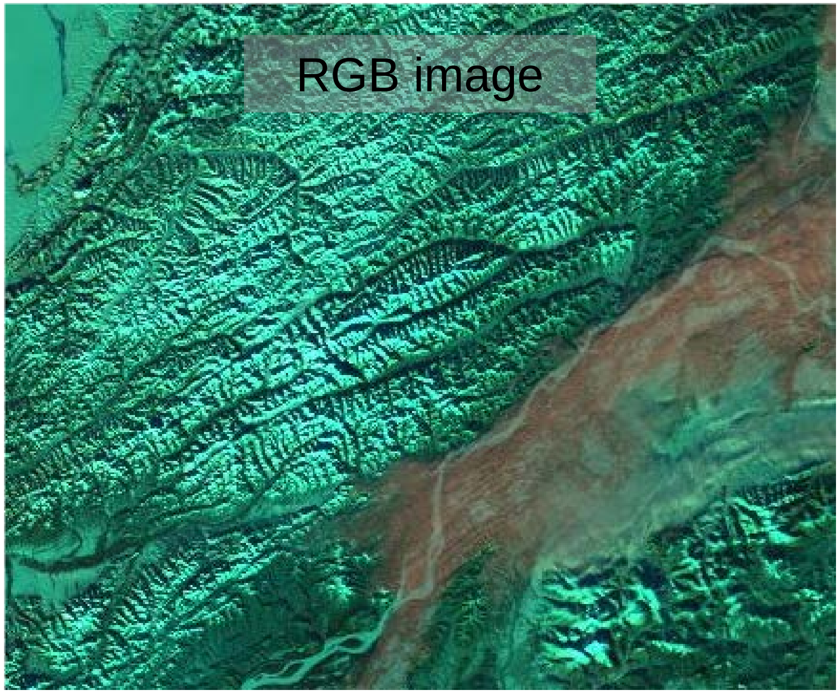
Motivation:

Cause underestimated ice concentration

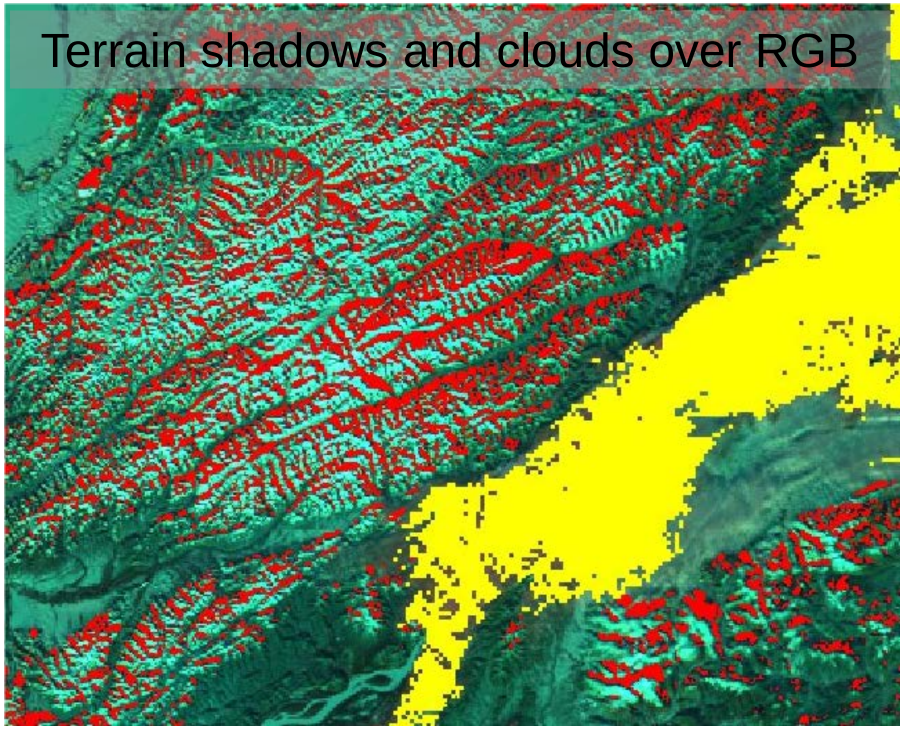
Not available in VIIRS IDPS EDRs

Algorithm:

Geometry-based, 200 m USGS elevation dataset used, up to 88^0 solar zenith

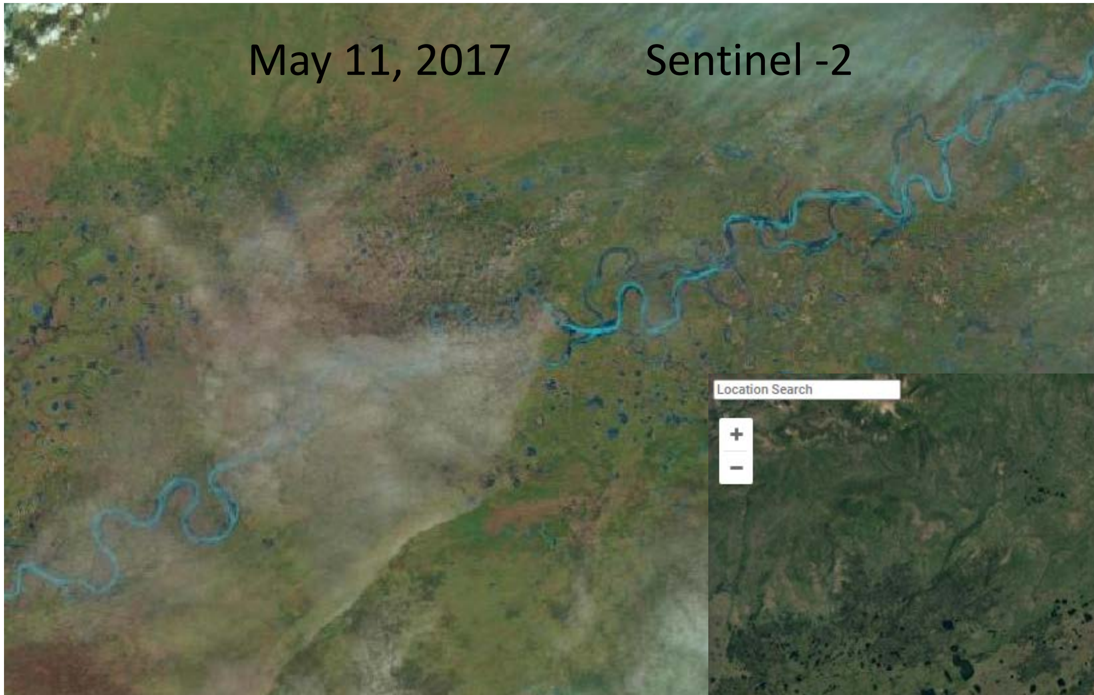


Feb 02, 2017

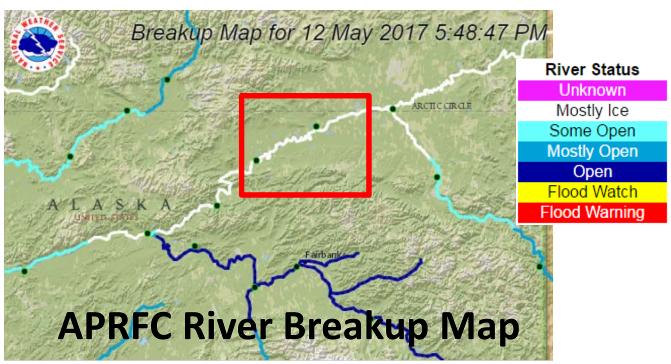


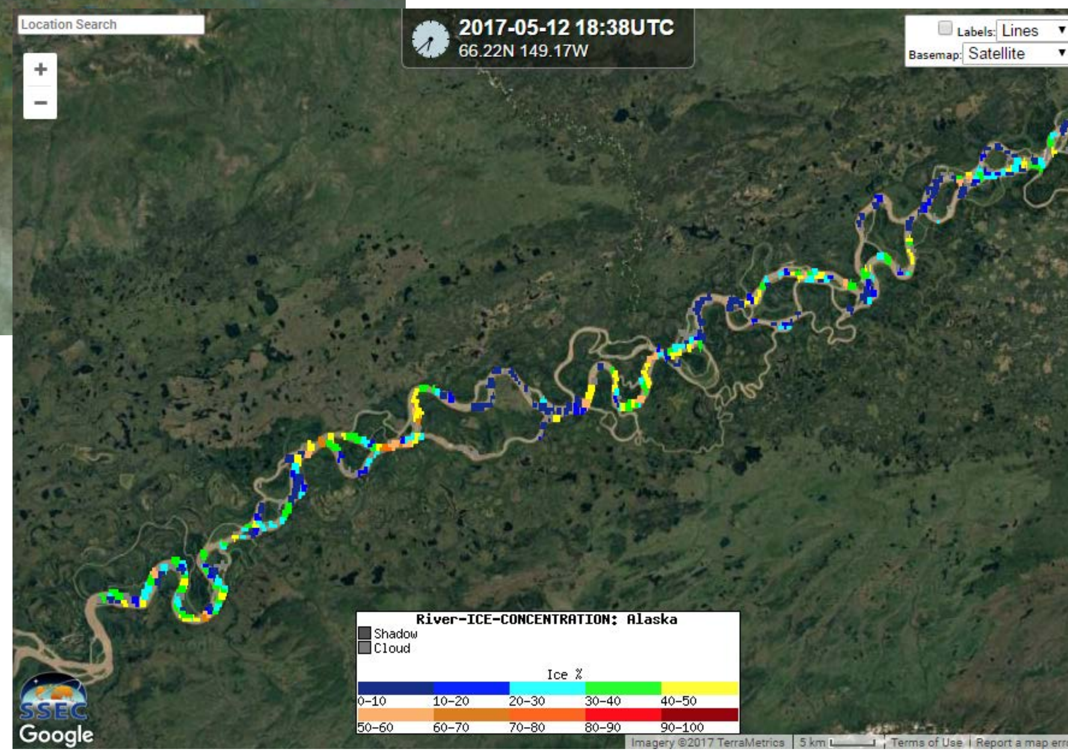
Yellow: Clouds
Red: Terrain shades

Product verification

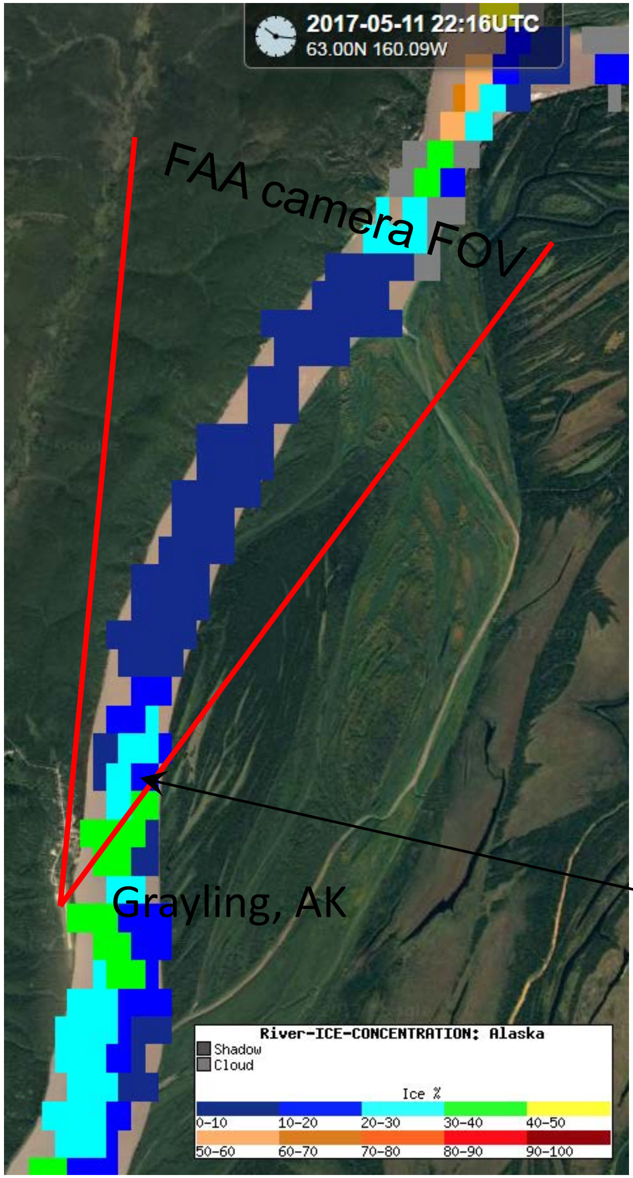


1. Qualitative comparison with high resolution imagery and operational river ice charts

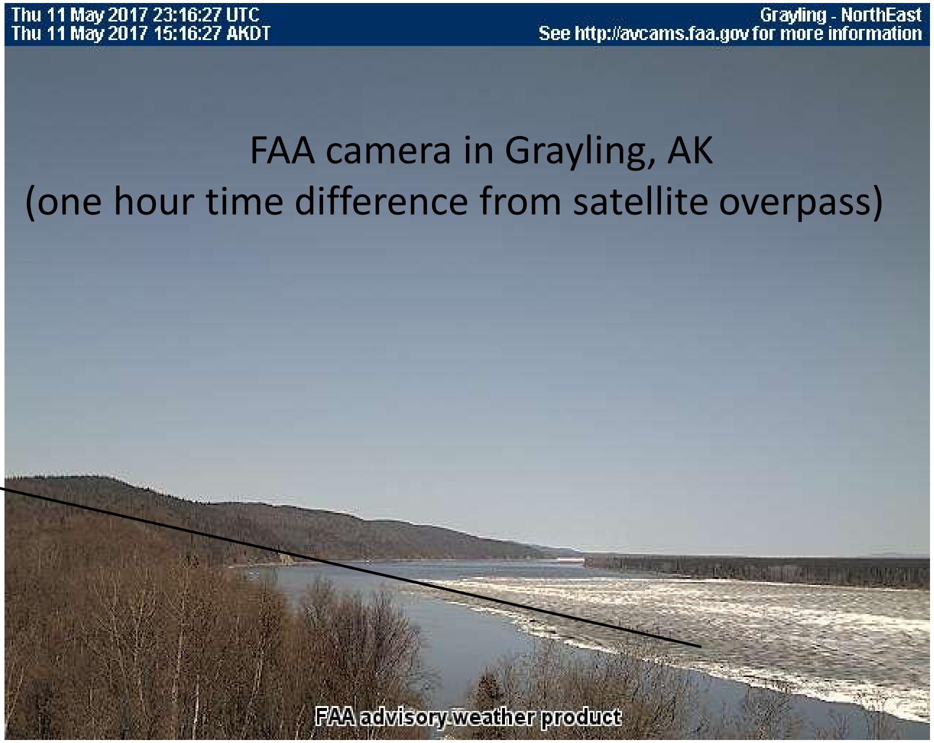




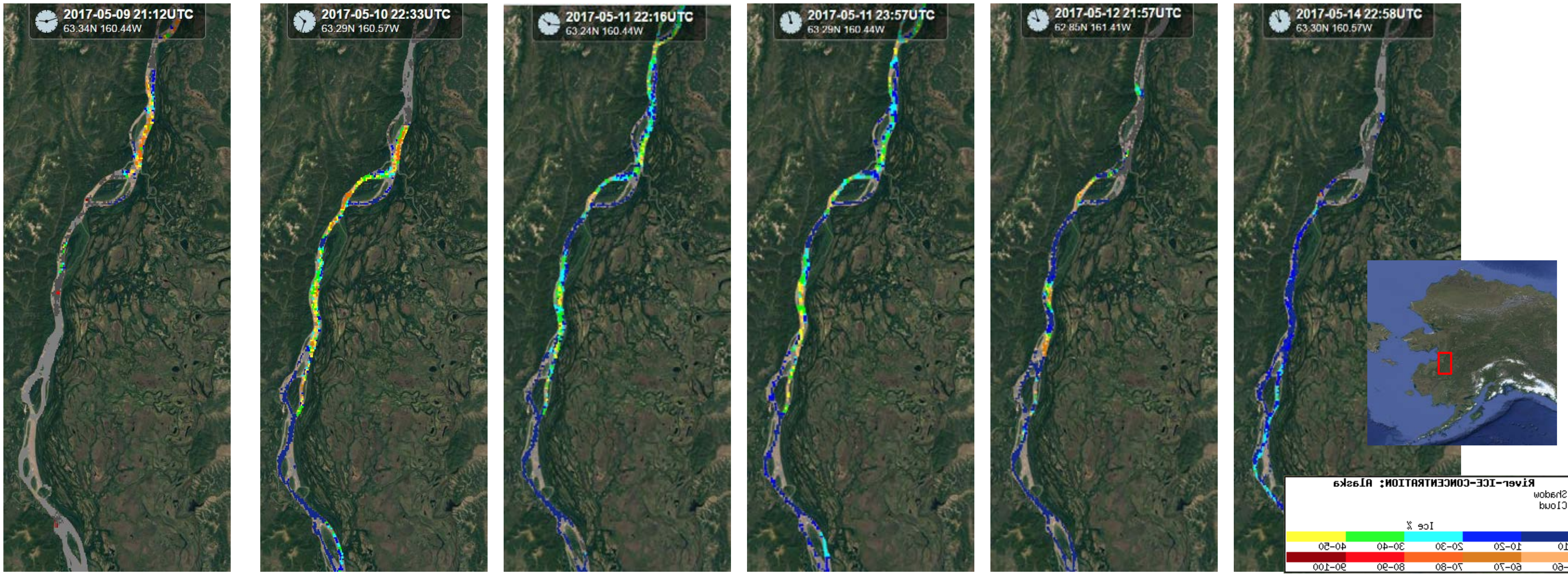
Product verification



2. With FAA, DOT web cameras, airborne imagery, surface reports



Monitoring River Ice Cover



Consecutive images provide information on the river ice dynamics

Clouds hamper continuous monitoring of the state of the river ice

What's next

- Expand the area coverage to the whole CONUS and Alaska area
- Extend the coverage to narrow rivers with less than 375m width
    - Need water fraction data at 375m
- Validation with all available in situ and remote sensing data
- Operational implementation at OSPO

8/23/2017

AMSR2+VIIRS ICE MOTION

Aaron Letterly[1] and Jeff Key[2]

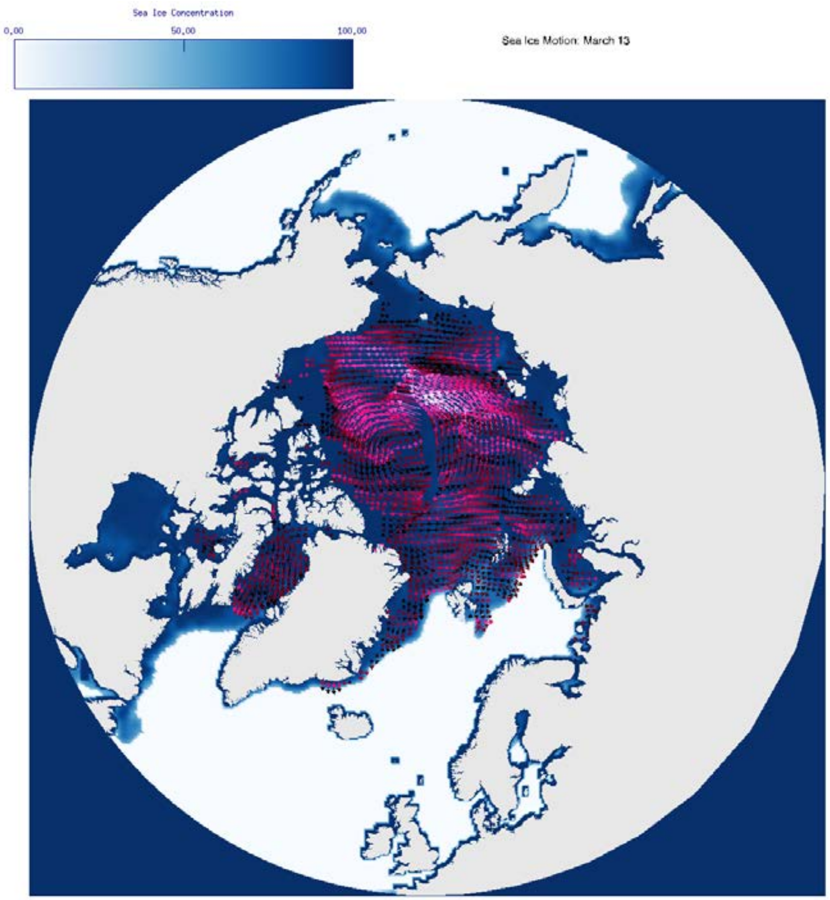
[1]Cooperative Institute for Meteorological Satellite Studies, U. Wisconsin-Madison, aaron.letterly@ssec.wisc.edu

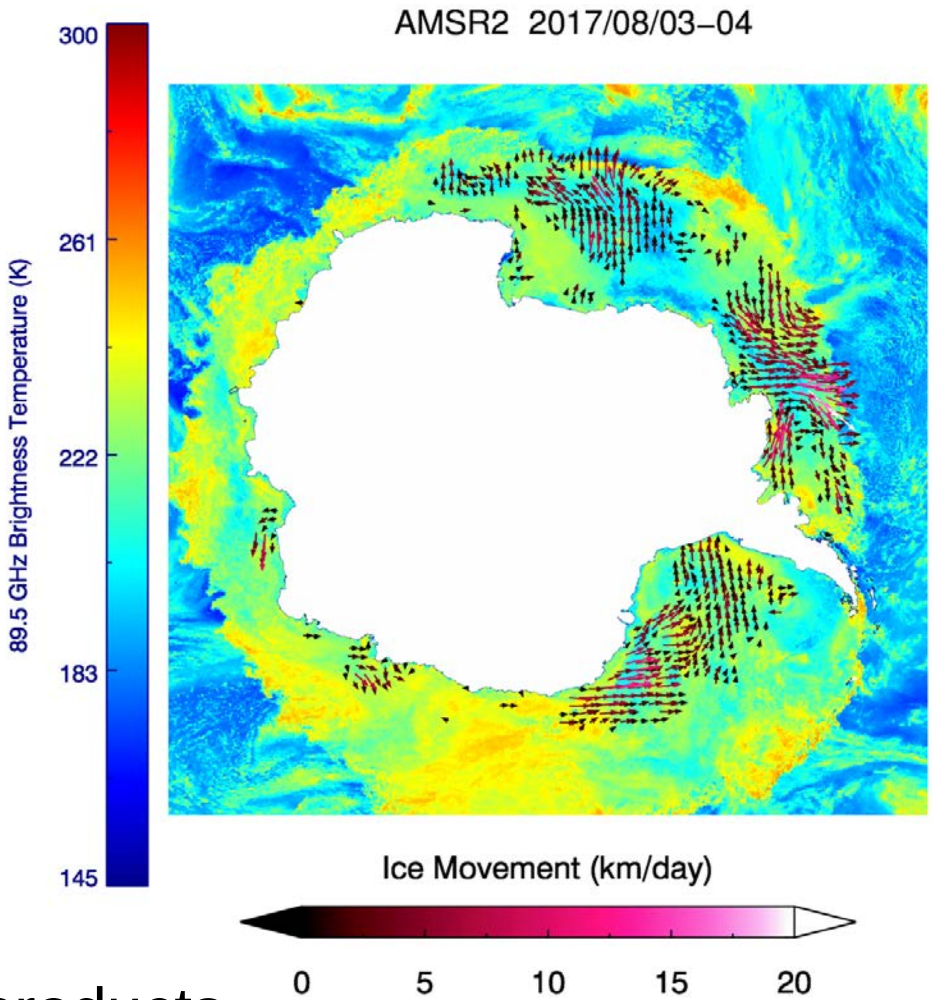
[2]NOAA Satellite and Information Services, Madison, Wisconsin

Ice Motion Team

PI	Organization	Team Members	Roles and Responsibilities
J. Key	NESDIS	A. Letterly (CIMSS)	AMSR2+VIIRS ice motion development and testing
		Y.K. Lee (CIMSS)	AHI ice motion development & quality assurance
		Y. Liu (CIMSS)	Original ABI code development

Ice Motion Products Overview





- Blended and single-sensor products for the Arctic and Antarctic

Ice Motion Products Overview

Sensor	Channel	Cell Resolution	Geographic Coverage
AMSR2	89.5GhZ, h-polarized	~5km	Arctic, Antarctic
VIIRS	M15 band	~1 km	Arctic (Antarctic in development)
AMSR2+VIIRS	Blended	~1km	Arctic

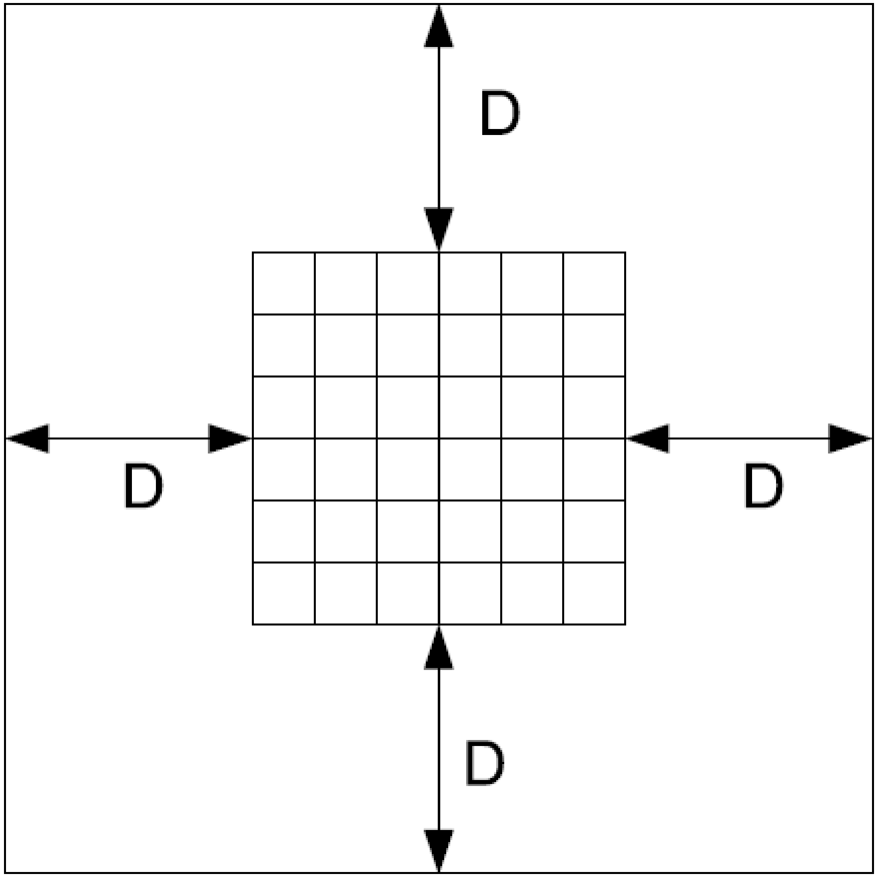
Ice Motion Products Overview

- Ice motion products include brightness temperature data from AMSR2, VIIRS, or both
- Ice motion products are updated daily over their region of geographic coverage
- Weekly- and monthly-averaged ice motion vectors are available for blended products
- Future tasks include running ice motion code on additional VIIRS channels (day-night band and NCC) for blending and comparison

Measuring Ice "Motion"

- Ice motion computed from satellite imagery represents the displacement between acquisition times of the two images

- An automated, maximum cross-correlation (MCC) procedure is used to track displacements over Arctic/Antarctic composites



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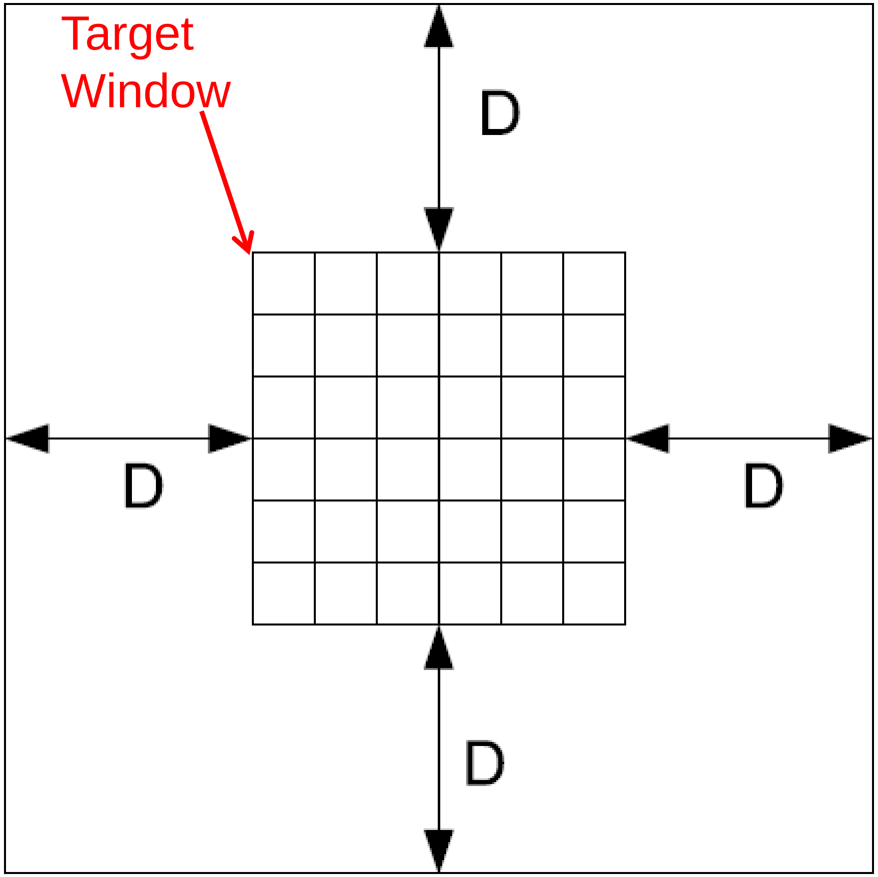

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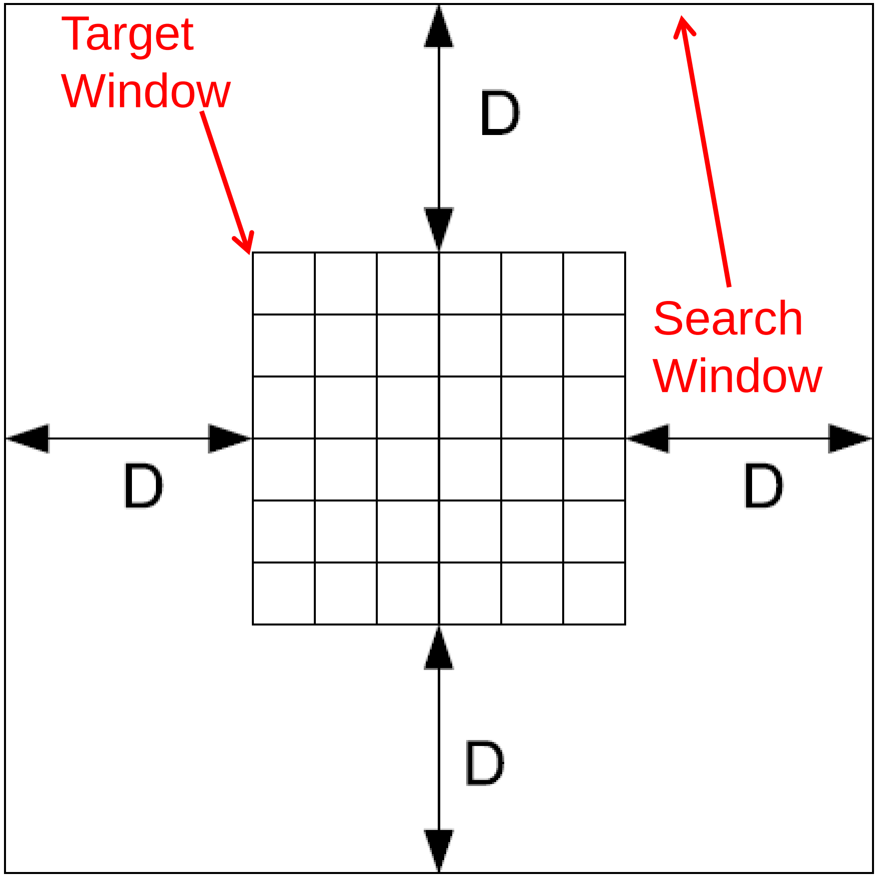

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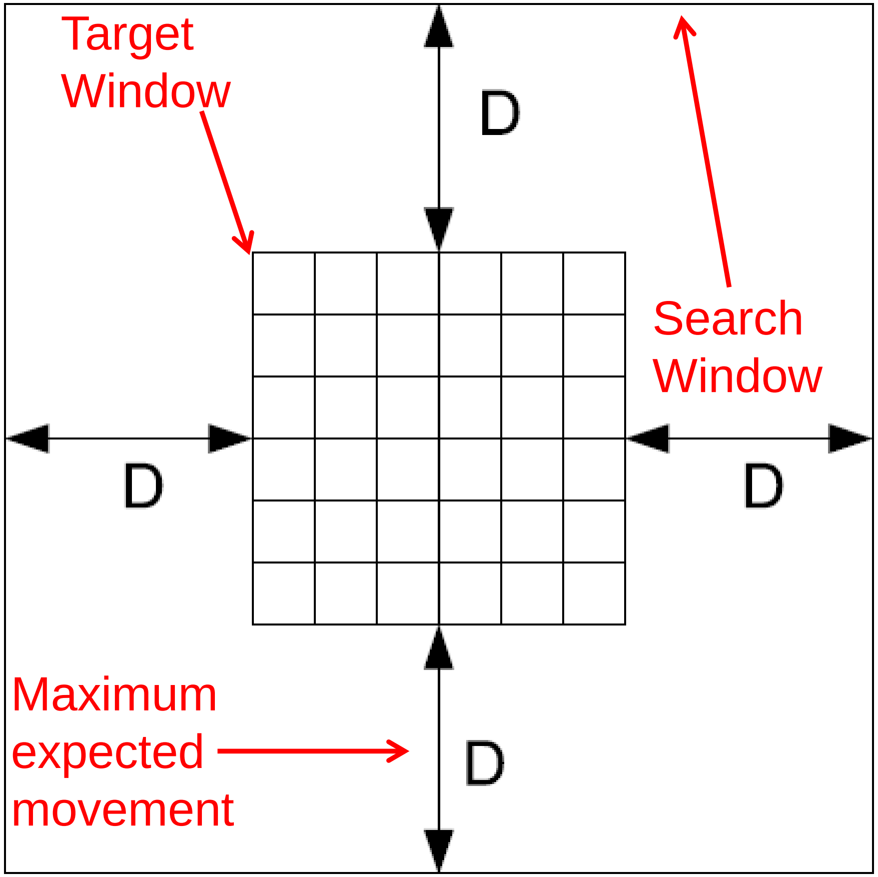
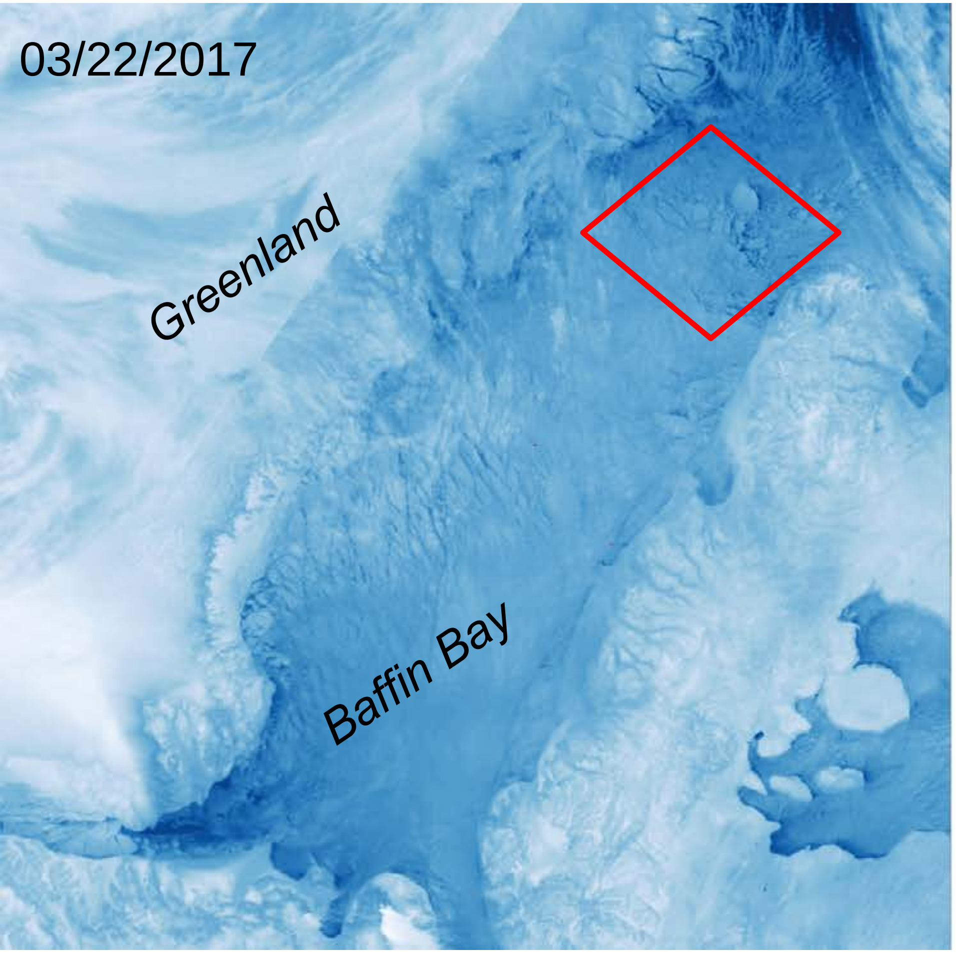
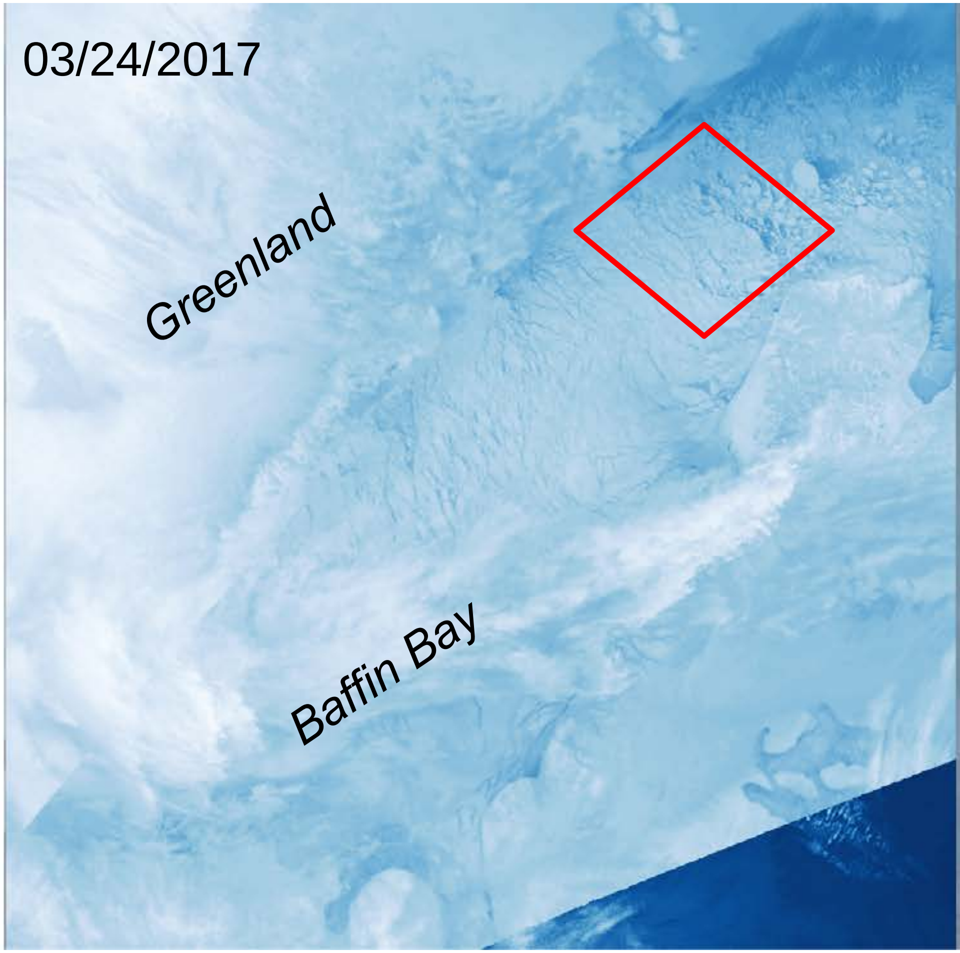


Measuring Ice "Motion"

- The MCC procedure assumes that ice found within the target window will not deform or rotate within the range of the search window.
- This assumption is generally valid over short distances in marginal ice areas, away from constrained ice zones.
- Computation time increases exponentially as the range of the maximum expected movement increases. Knowing typical ice speeds is crucial to efficient processing.

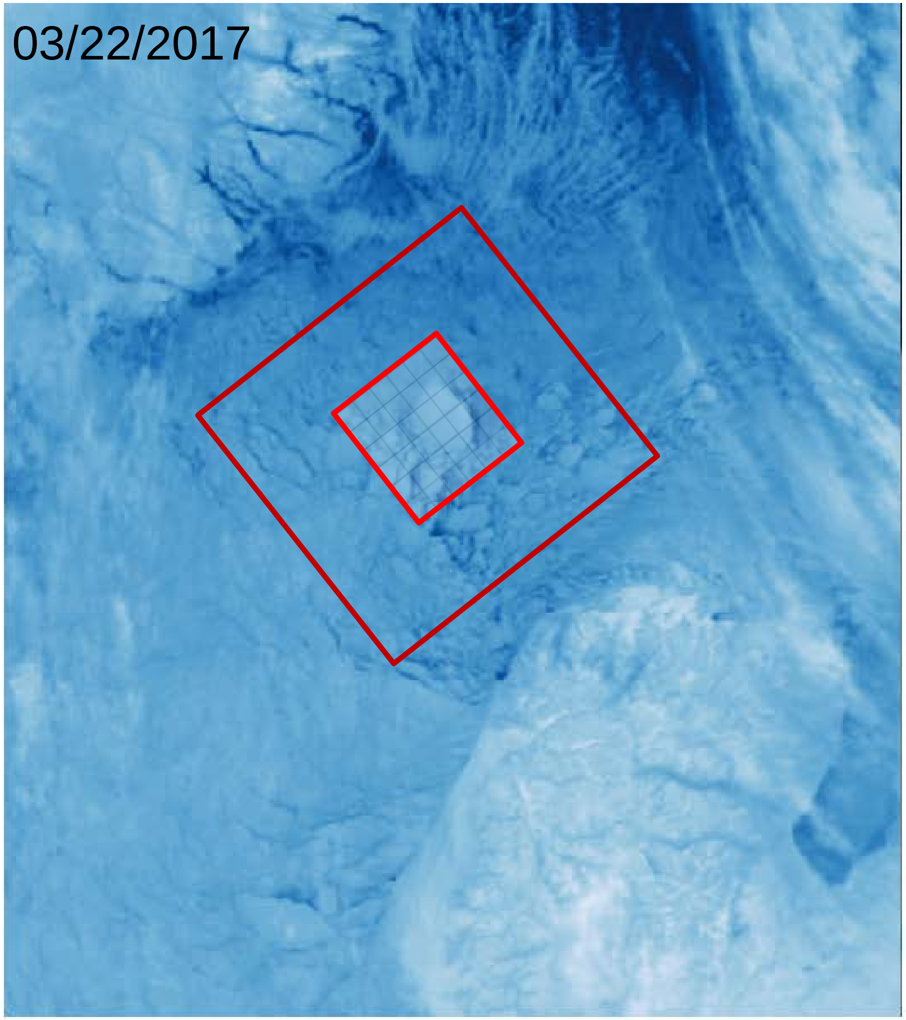
Ice Motion Example

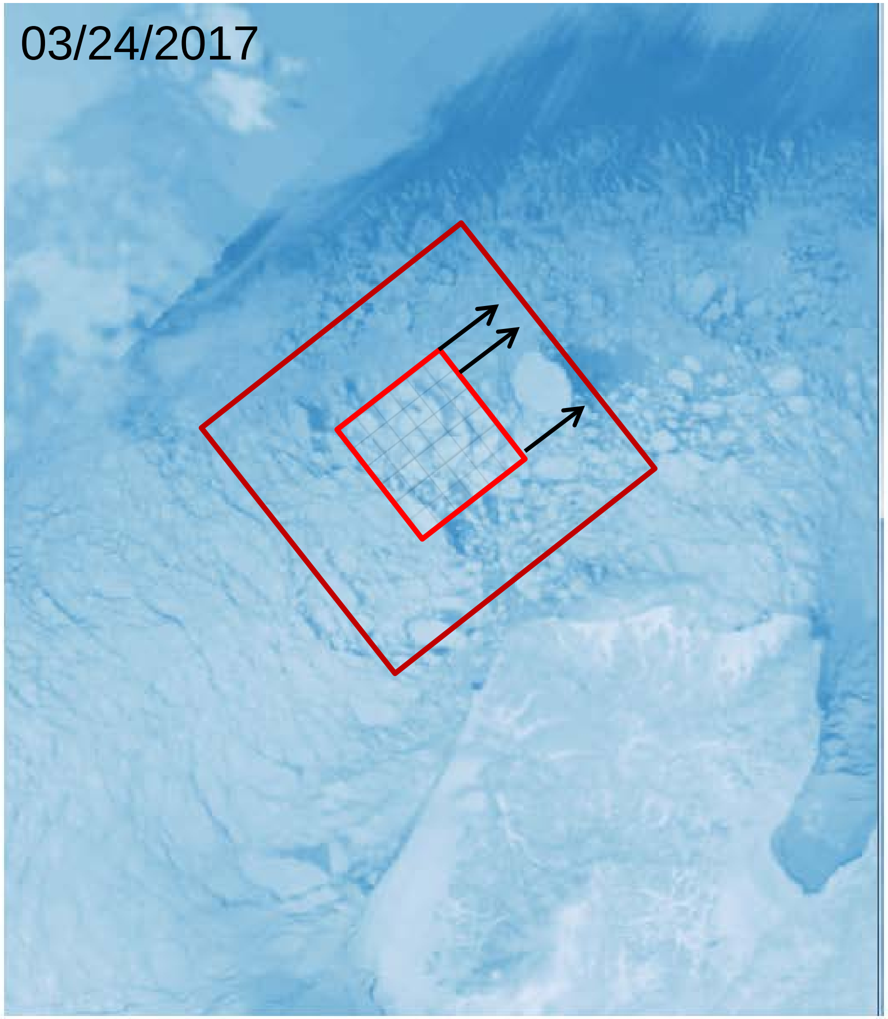




- VIIRS M15 imagery, 48 hours apart showing ice exiting Baffin Bay

Ice Motion Example

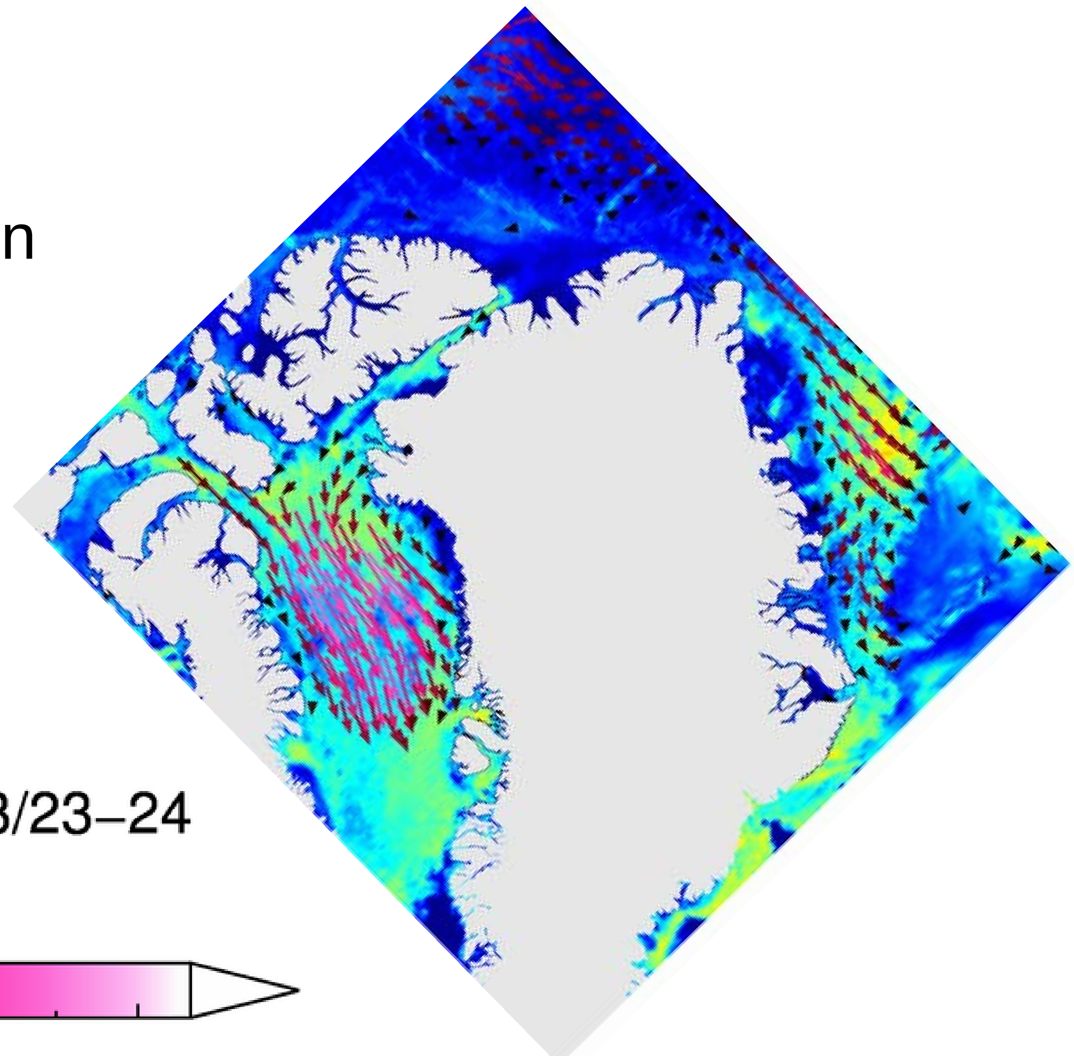




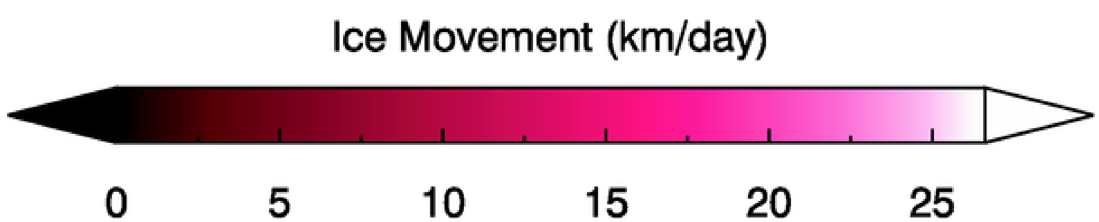
- The ice floe feature within the smaller red rectangle should be tracked leaving Baffin Bay

Ice Motion Example

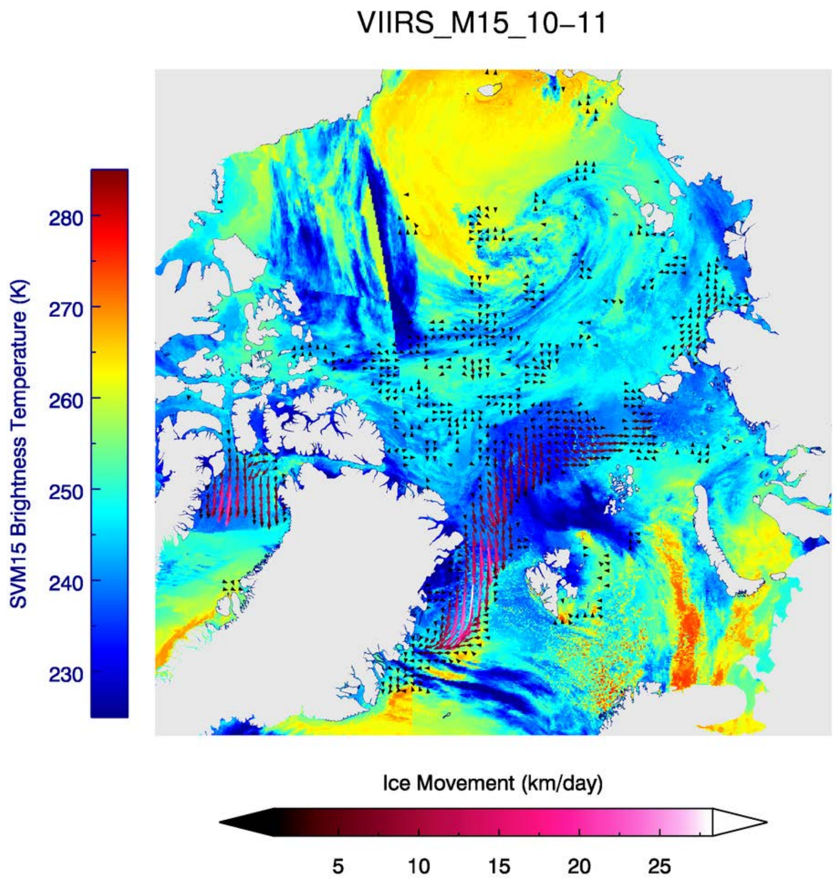
- Blended AMSR2+VIIRS output showed ice motion southward on the same days

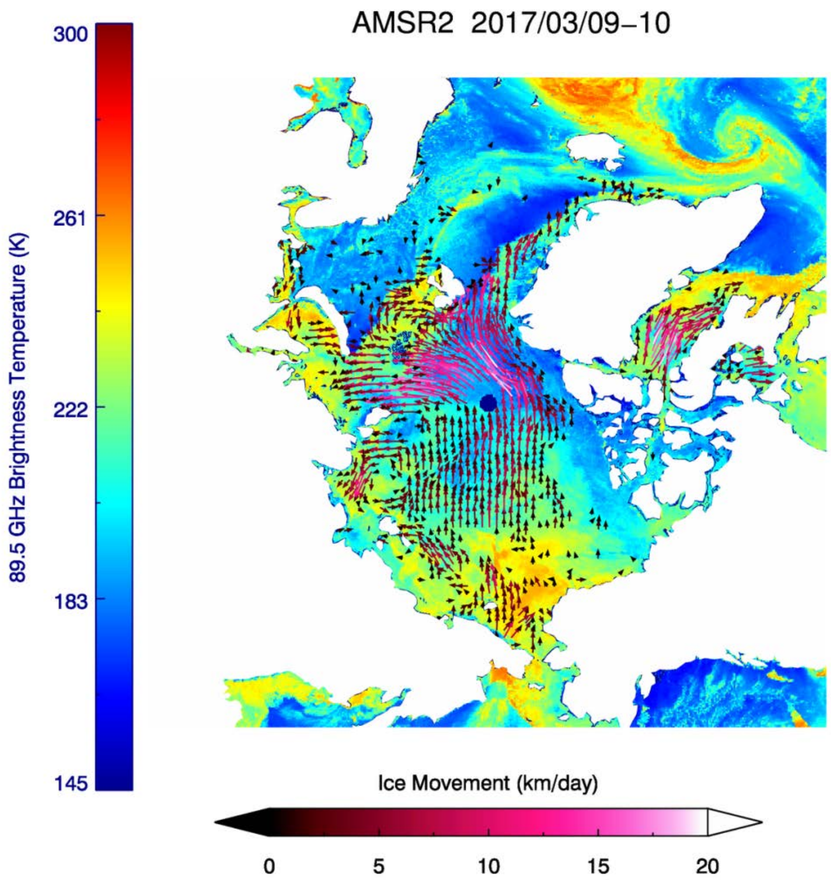


Blended Ice Motion 2017/03/23–24



VIIRS+AMSR2 Ice Motion



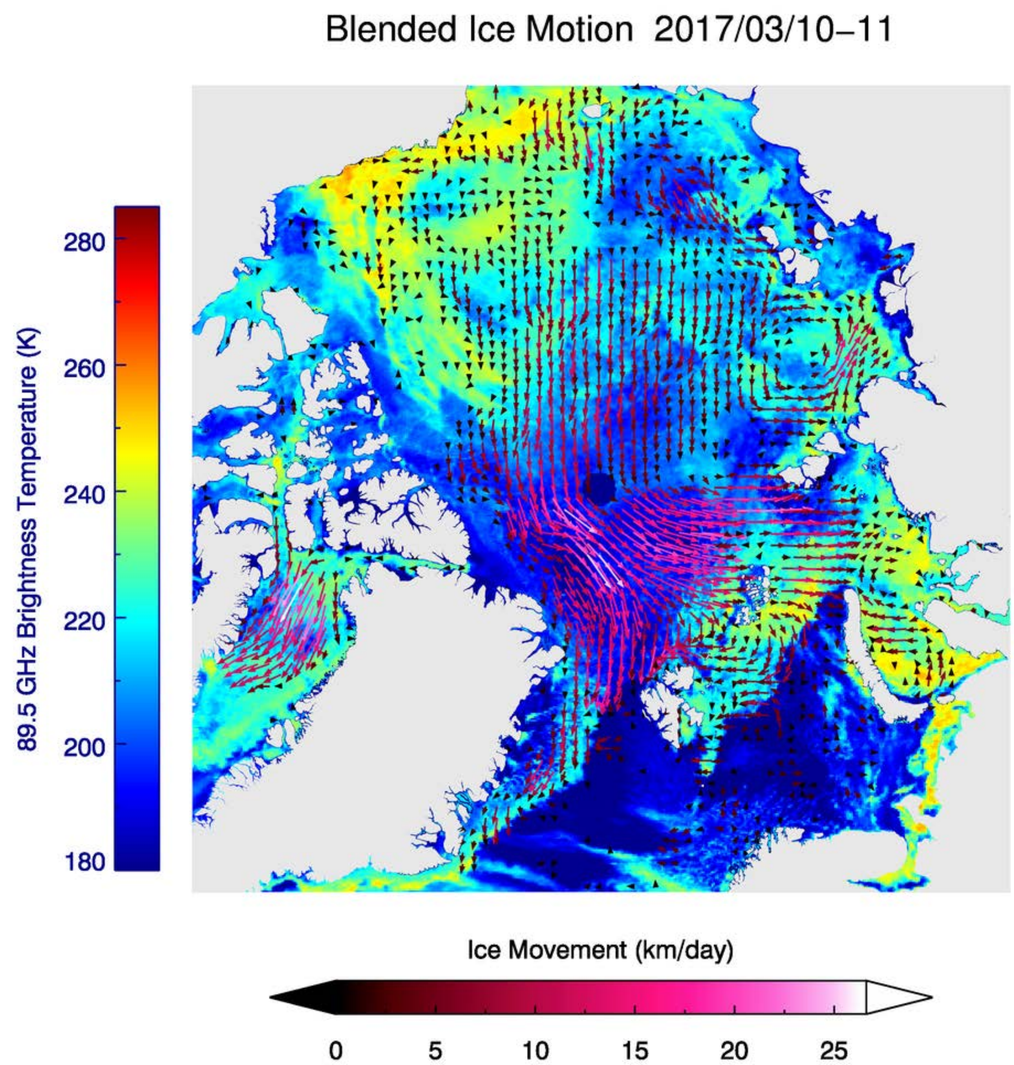


- VIIRS provides high spatial resolution, but clouds opaque in M15 band
- AMSR2 passive microwave data added for blending

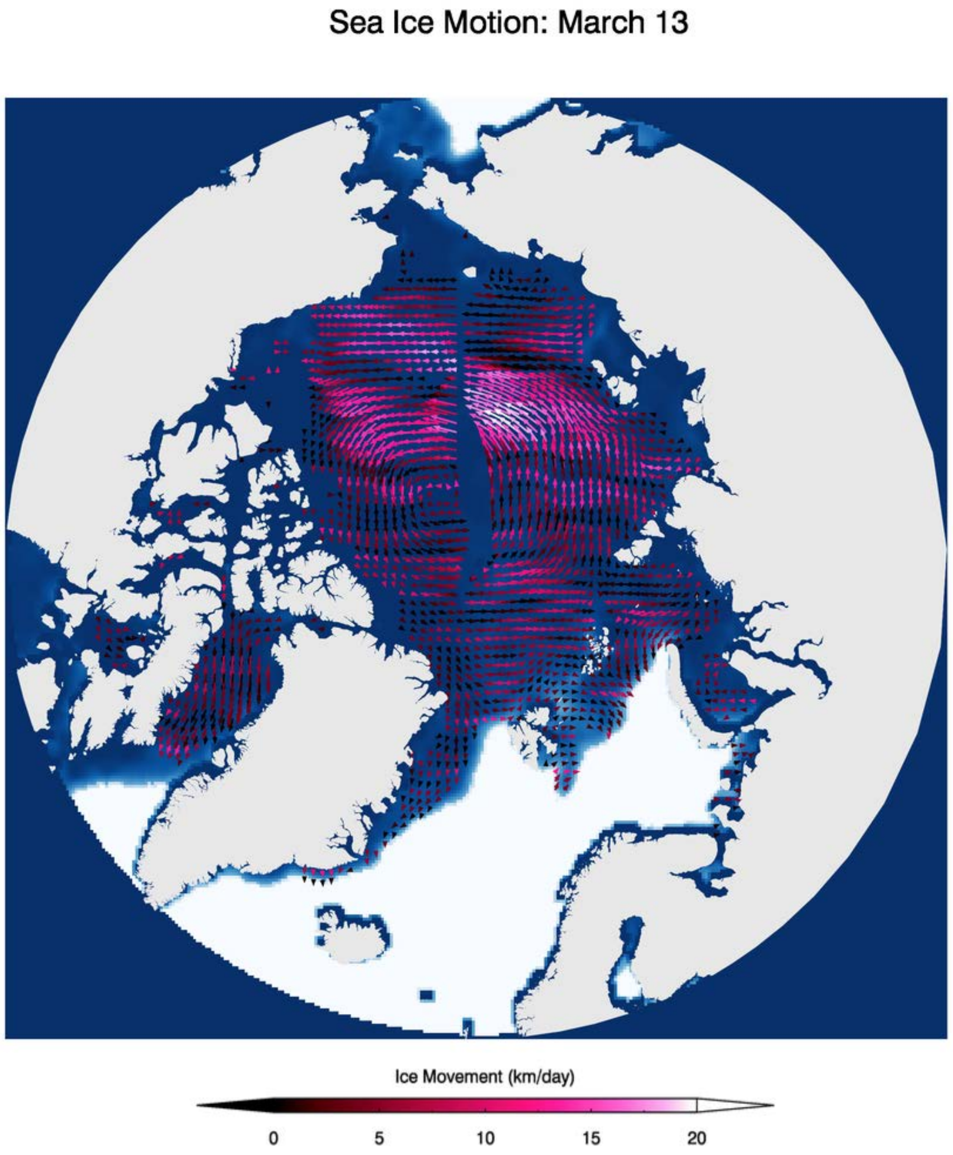
VIIRS+AMSR2 Ice Motion

- Combining AMSR2+VIIRS ice motion vectors creates output with high spatial resolution, full Arctic coverage

- VIIRS only, AMSR2 only, and blended products available for Arctic

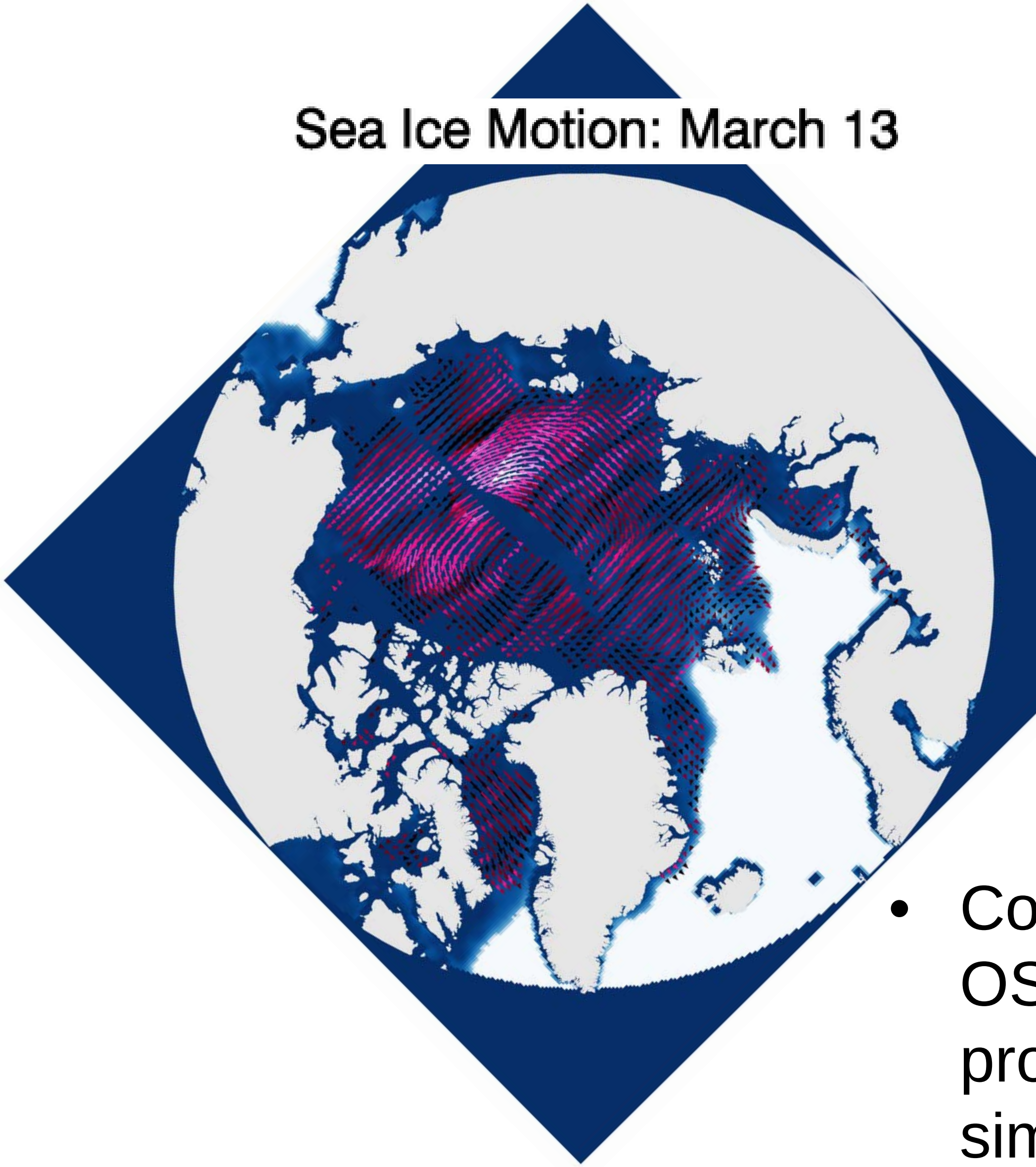


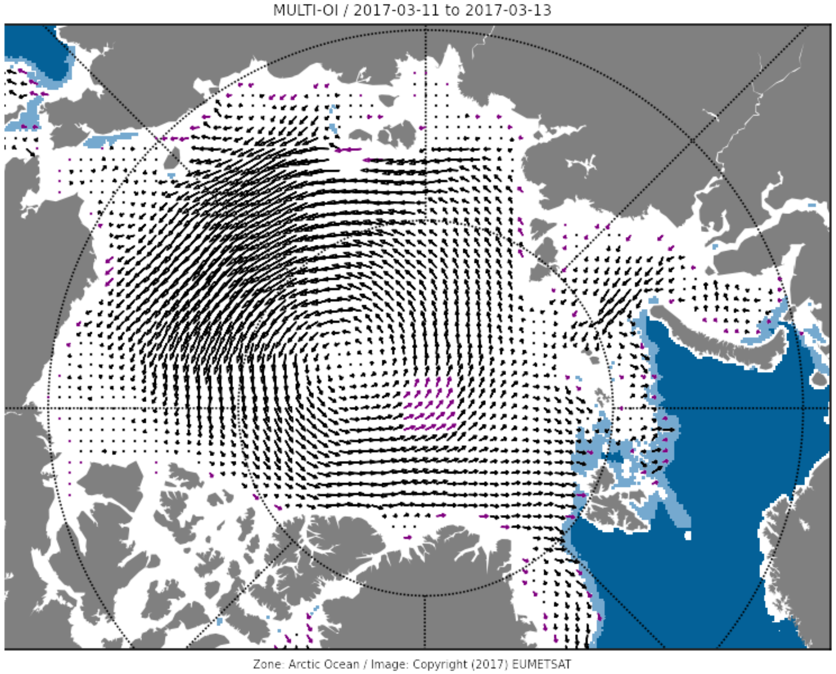
VIIRS+AMSR2 Ice Motion



- March 13 AMSR2+VIIRS motion vectors are shown, combined with sea ice concentration from passive microwave
- Filtering vectors using ice concentration may improve spring, summer performance

Initial Validation, Path Forward



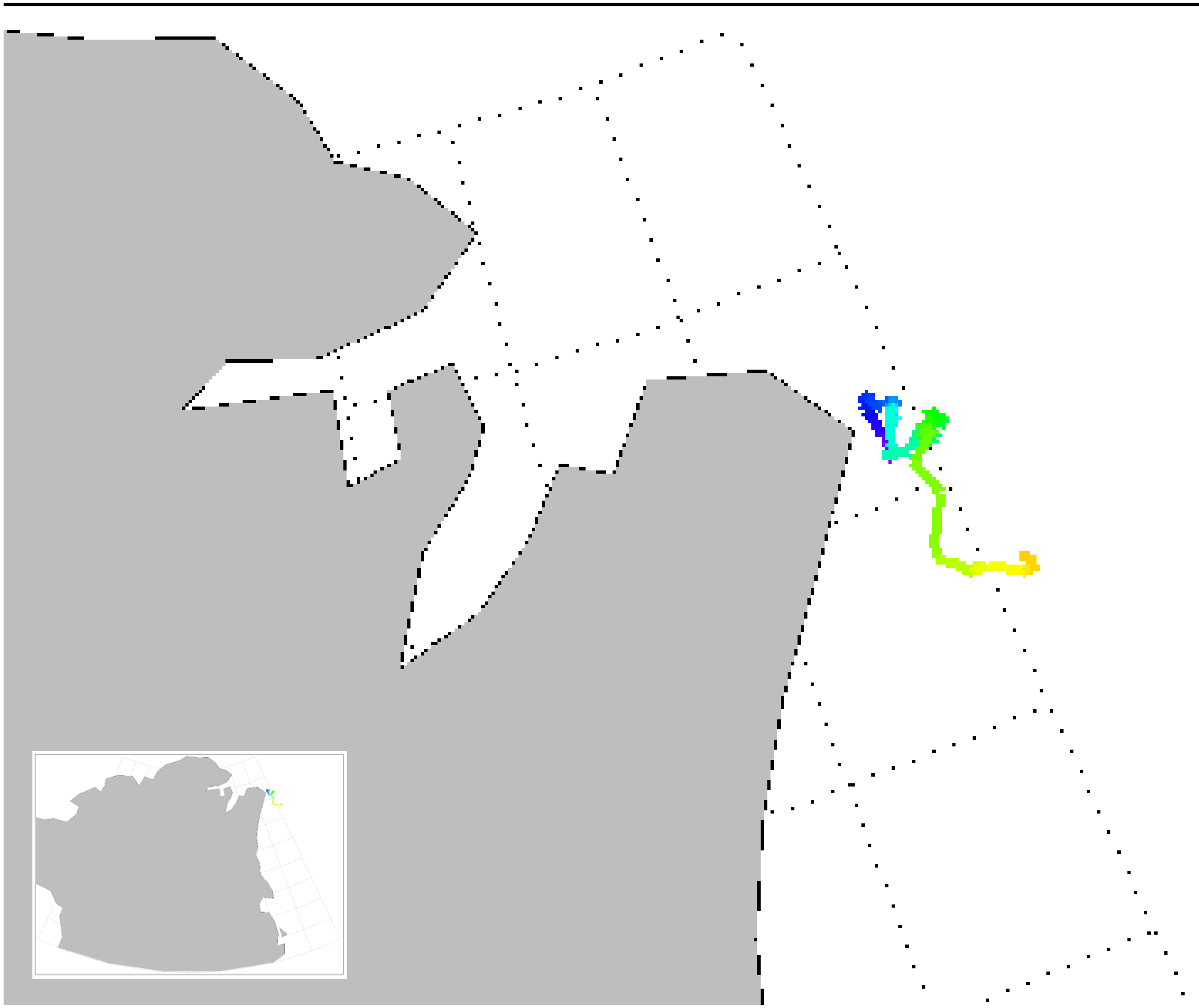


- Comparing AMSR2+VIIRS with OSI SAF low-resolution drift product shows qualitative similarities

Initial Validation, Path Forward

- Future capabilities include LaGrangian tracking

- Eastern Greenland: head-to-tail summation of daily vector motions (March-July)



Initial Validation, Path Forward

- Future products will be expanded to other VIIRS(+) channels:
  - Day-Night Band, NCC product

- Utilize extended suite of products to create weekly/monthly ice motion climatology.

- Establish zones of intensive ice monitoring in certain regions:
  - Alaskan coastline, oil and gas exploration sites

Data Access

- Product imagery and ice motion vectors (ASCII) are available for download
  - AMSR2+VIIRS blended ice motion (ftp://stratus.ssec.wisc.edu/pub/aletterly/blended_AMSR2_VIIRS/)
  - VIIRS standalone ice motion (ftp://stratus.ssec.wisc.edu/pub/viirs_icemotion/arctic/)
  - AMSR2 ice motion (ftp://stratus.ssec.wisc.edu/pub/amsr2_icemotion/24_hour/images/Arctic/)

BLENDED VIIRS+MICROWAVE ICE CONCENTRATION

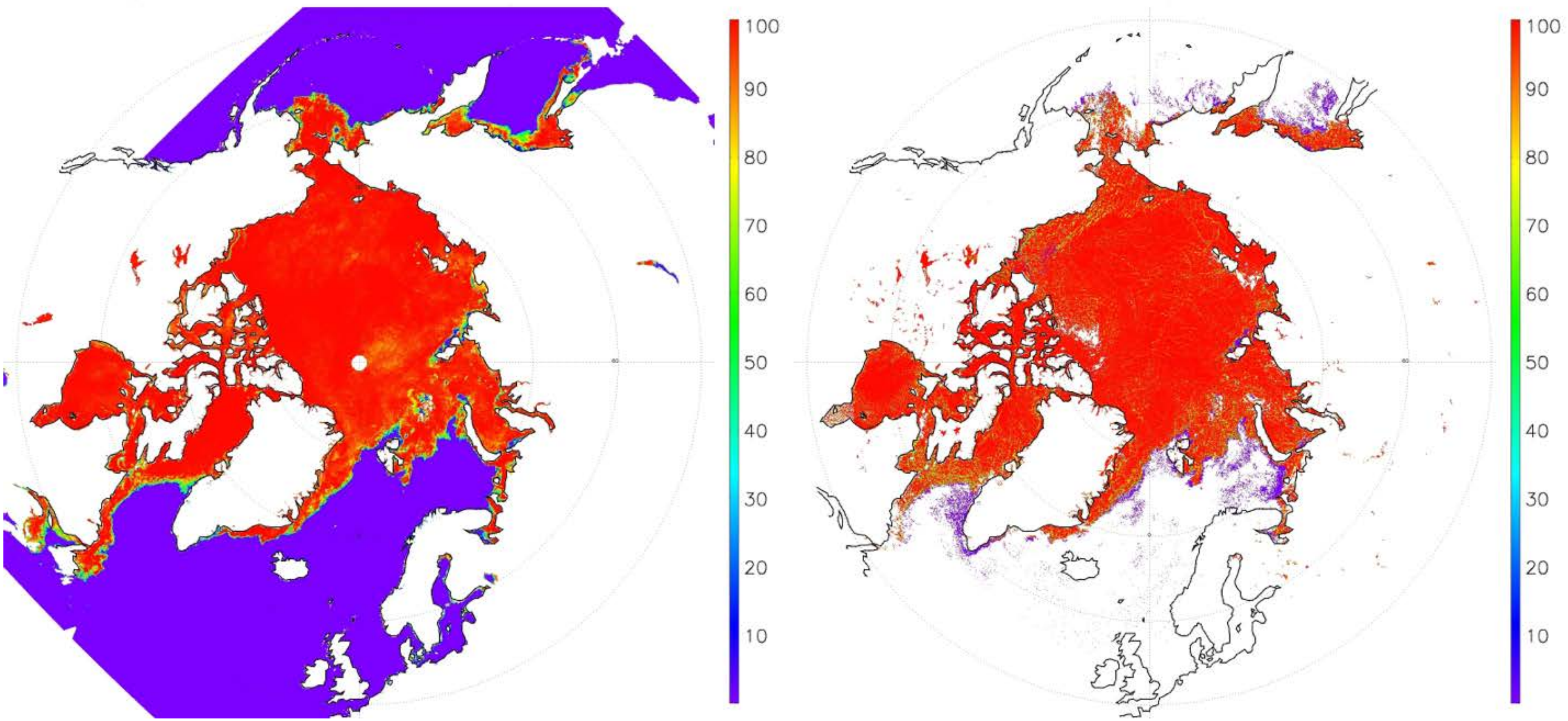
Yinghui Liu, CIMSS, University of Wisconsin at Madison
608-890-1893; yinghuiliu@wisc.edu

Collaborators: Jeff Key, Rich Dworak

Ice Concentration Team

PI	Organization	Team Members	Roles and Responsibilities
J. Key	NESDIS	Y. Liu (UW/CIMSS) R. Dworak (CIMSS)	Algorithm Development and cal/val Ice concentration cal/val

Motivation



Ice concentration from SSMIS (left) and a daily ice concentration composite from VIIRS (right) over the Arctic on February 20, 2015.

1. VIIRS product shows more details than passive microwave product
2. VIIRS show more realistic ice concentration around the North Pole

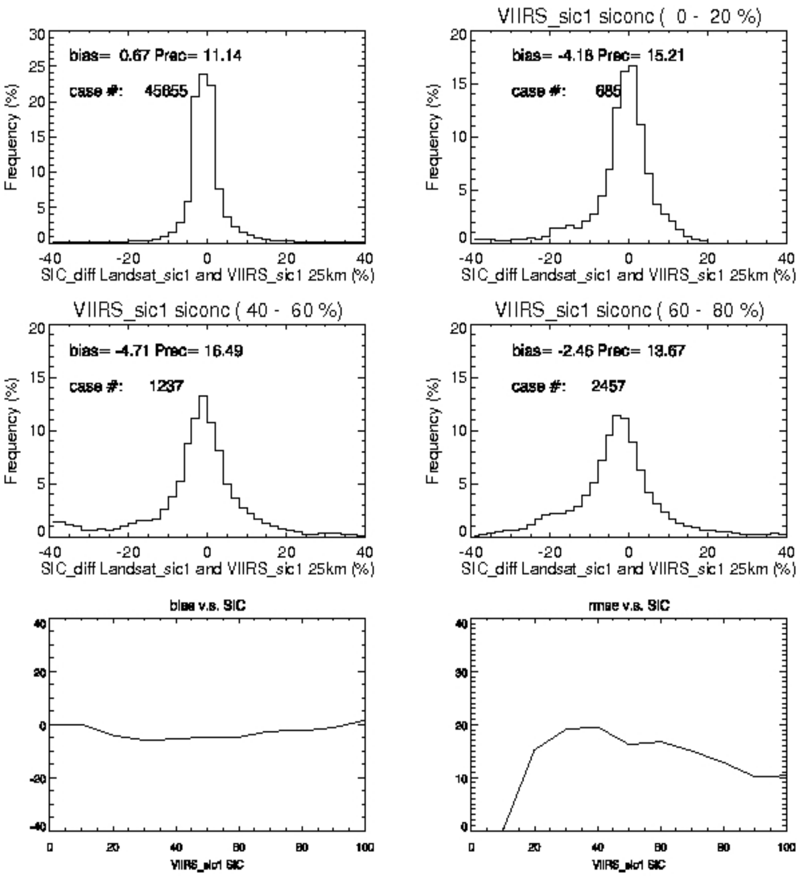
Algorithm Overview

The Best Linear Unbiased Estimator (BLUE) is then applied to derive the final ice concentration under clear sky conditions:

$$ICE\_CONC = \left(\frac{\sigma_2^2}{\sigma_1^2+\sigma_2^2}\right)\times(ICE\_CONC_1 - D_1) + \left(\frac{\sigma_1^2}{\sigma_1^2+\sigma_2^2}\right)\times(ICE\_CONC_2 - D_2)$$

where ICE_CONC, ICE_CONC1, and ICE_CONC2, are optimized ice concentration, and ice concentrations from the two products; D1 and D2 are measurement accuracy; σ1 and σ2 are the measurement precision.

Algorithm Overview



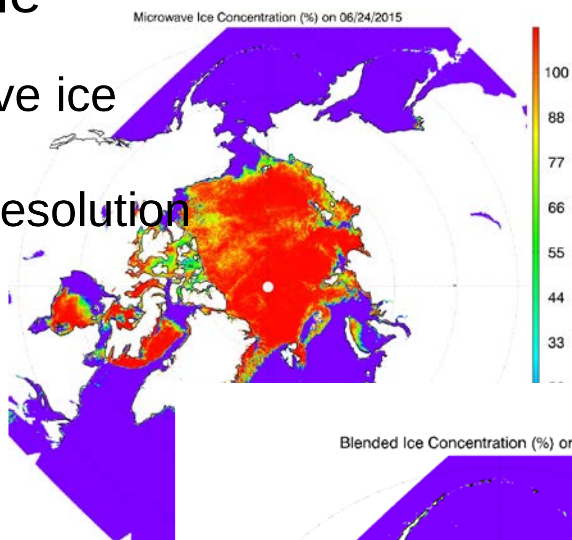
Comparison of VIIRS and Landsat ice concentrations for different concentration ranges/bins. Also shown are the differences overall (upper left) and the bias and root-mean-square (RMS) difference as a function of VIIRS ice concentration (bottom row).

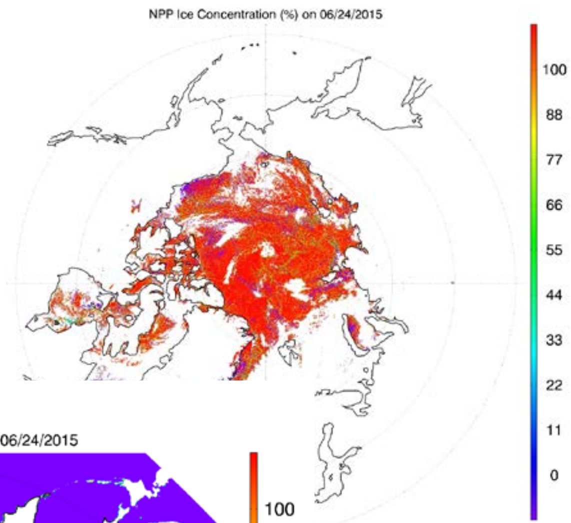
Same comparisons are made for AMSR2 ice concentration.

Algorithm Overview

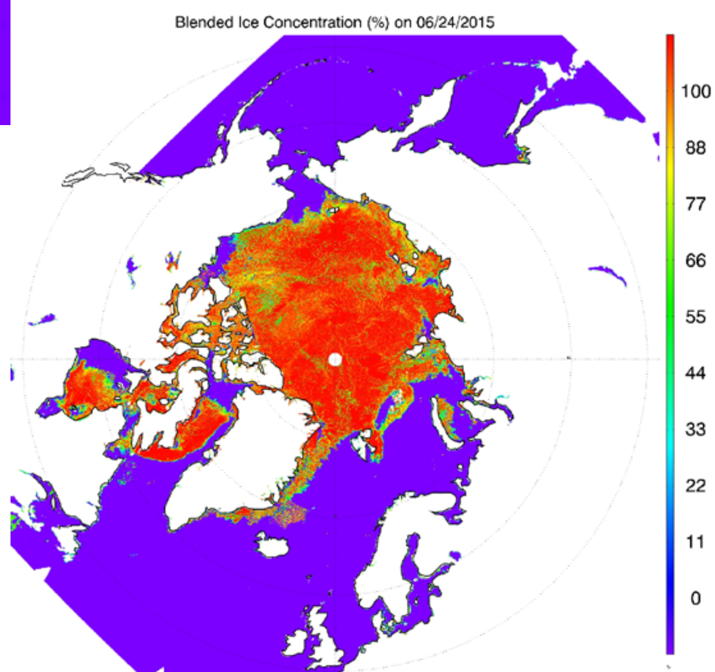
Blended sea ice concentration from passive Microwave and infrared/visible

Passive microwave ice concentration:
Con: low spatial resolution
Pro: all-weather





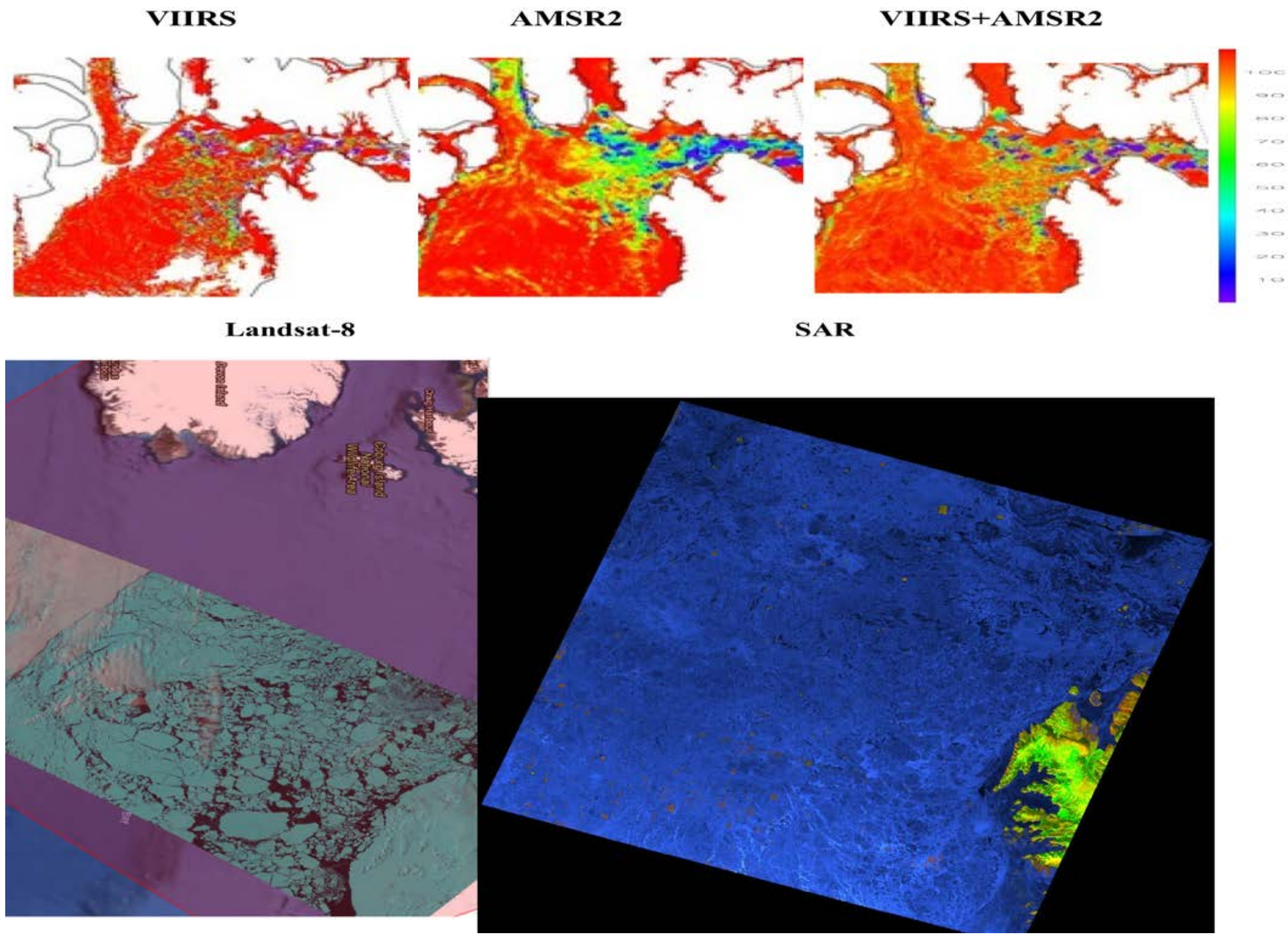
Passive infrared/visible ice concentration:
Con: clear-sky only
Pro: high spatial resolution



Blended sea ice concentration at 1 km resolution on June 24, 2015 using AMSR-2 and the Suomi NPP VIIRS ice concentration products

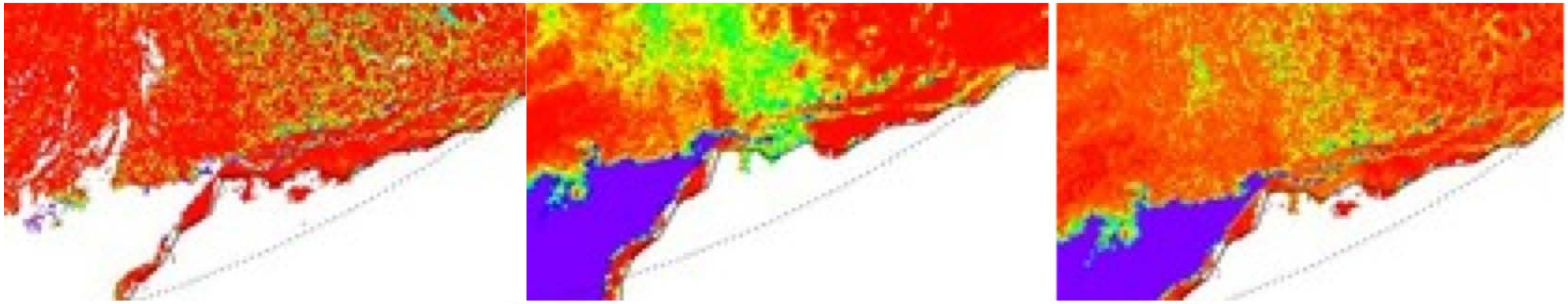
Blended ice concentration: high spatial resolution under all-weather conditions

Performance

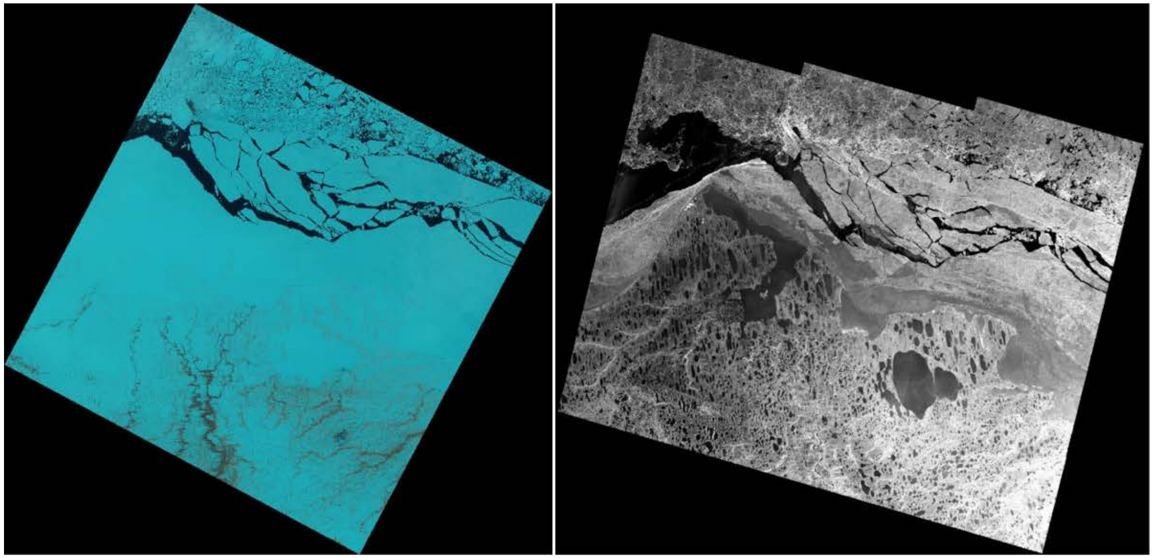


On May 11, 2017 over Baffin Bay VIIRS, AMSR2 and Blended SIC on top. Landsat-8 OLI/TIRS and SAR Sentinel-1B imagery on bottom

VIIRS AMSR2 VIIRS+AMSR2



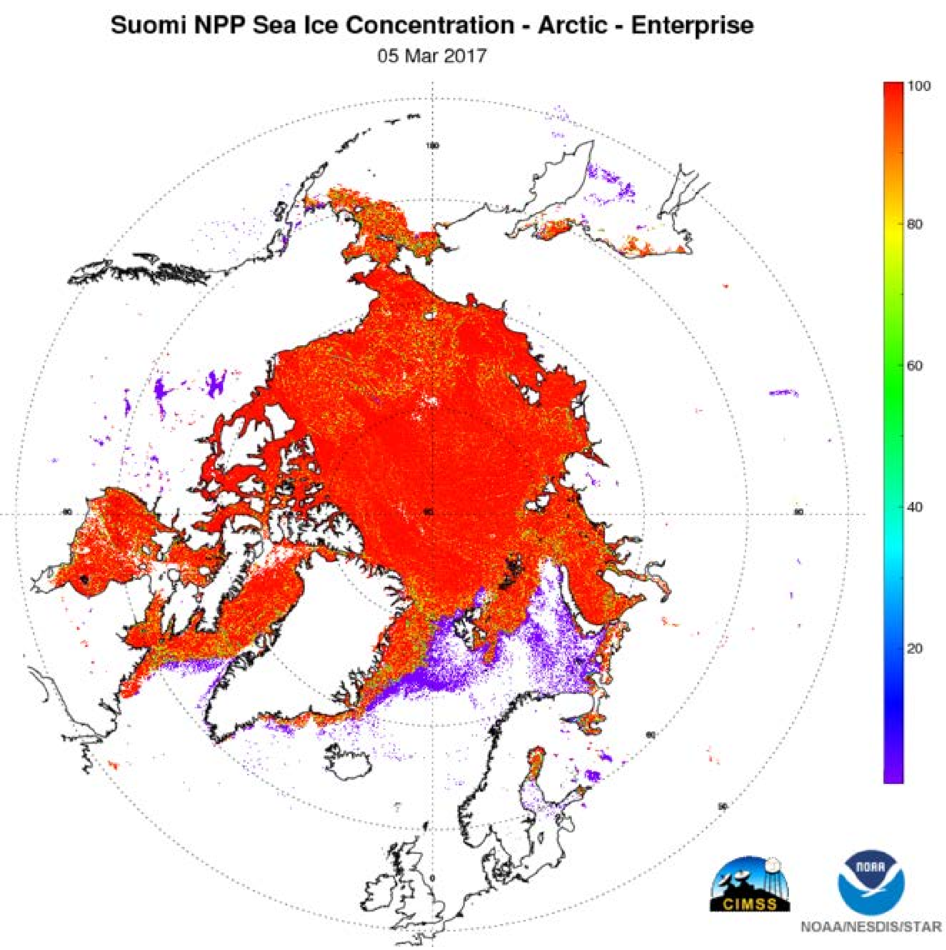
Landsat-8 SAR

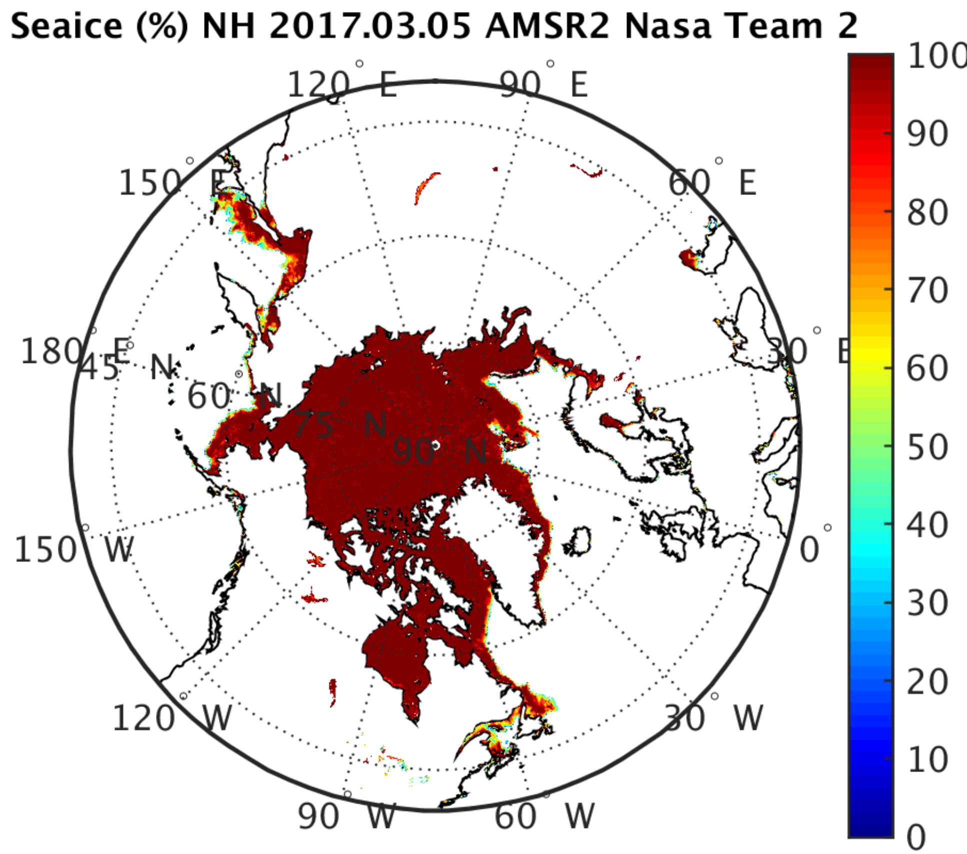


On May 27, 2017 near Alaskan Beaufort Sea Coast VIIRS, AMSR2 and Blended SIC on top. Landsat-8 OLI/TIRS and SAR Sentinel-1A imagery on bottom

Current Status

- Blended ice concentration is being generated daily for National Ice Center
- Data is in GeoTIFF format, over both Arctic and Antarctic

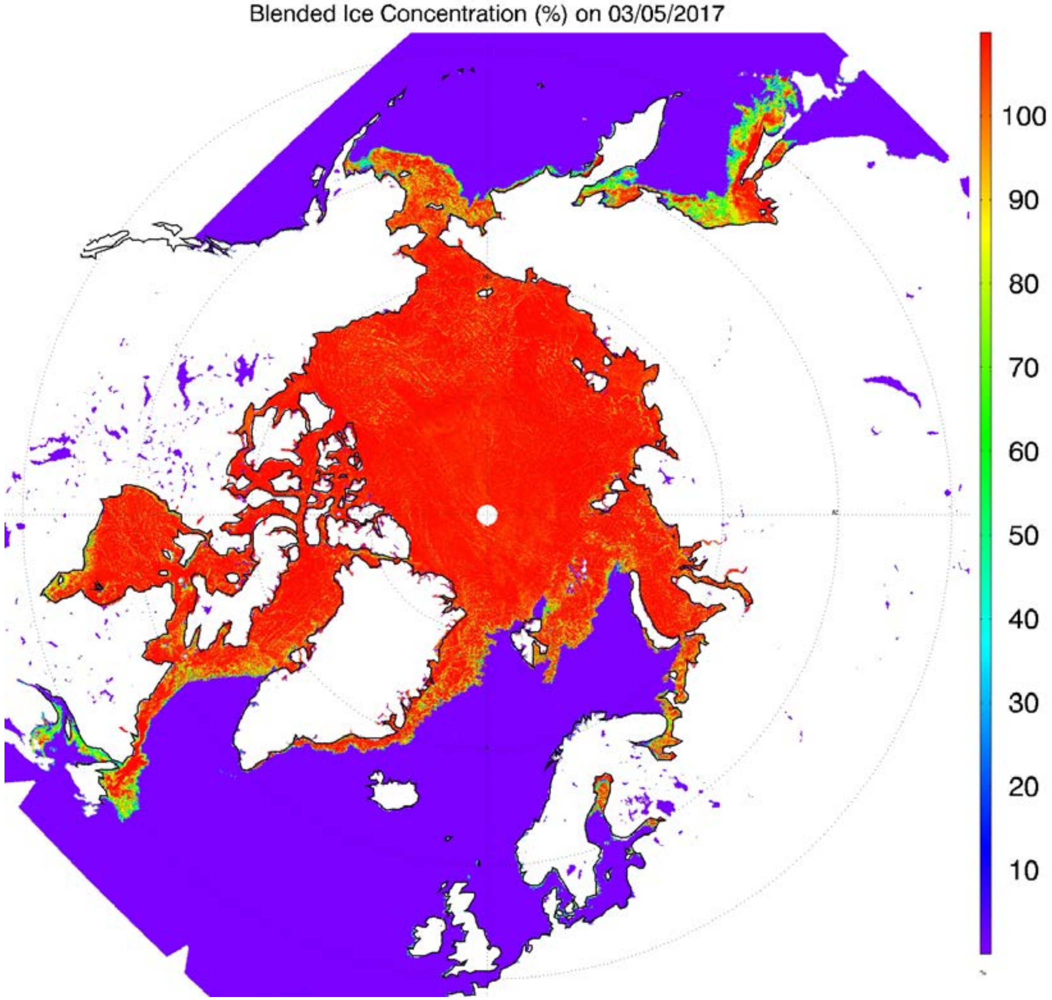




Daily Ice concentration (IC) composite from VIIRS (**left**); and IC AMSR2 (**right**) over the Arctic on March 5th 2017.

Current Status

- Blended ice concentration is being generated daily for National Ice Center
- Data is in GeoTIFF format, over both Arctic and Antarctic



Blended Daily Ice concentration (IC) over the Arctic on March 5th 2017.

User Interaction

- Blended ice concentration is currently archived for National Ice Center for evaluation

Summary and Path Forward

- Blended ice concentration from VIIRS and passive microwave provides high spatial resolution ice concentration under all-weather conditions;
- This product can benefit operational applications, and long-term scientific studies;
- Further improvement and evaluation is needed with new ice concentration products from sensors with very high spatial resolution onboard the newly launched European satellites.

SEA ICE LEADS

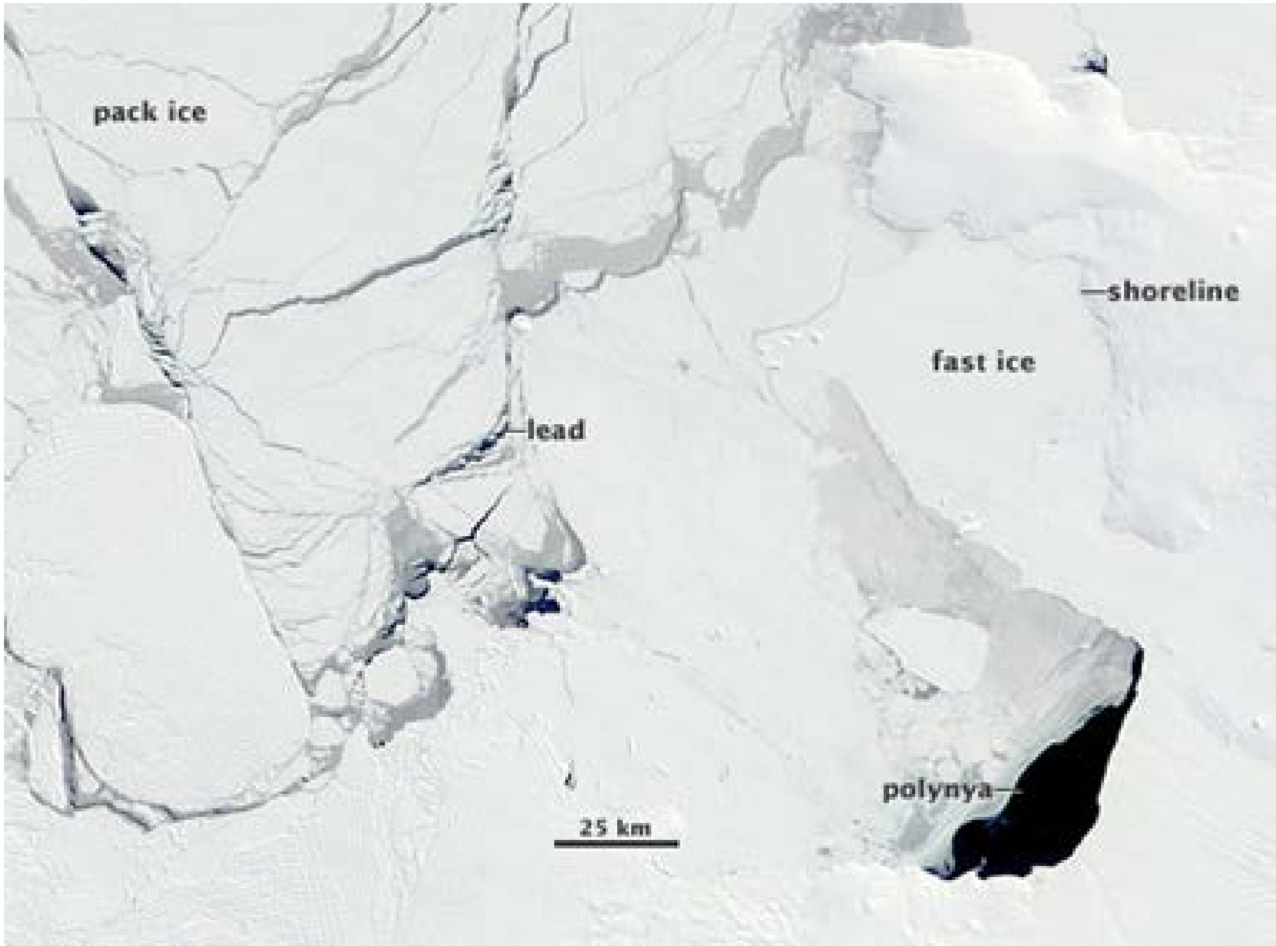
Jay P. Hoffman[1], S. Ackerman[1], Y Liu[1] and, J. Key[2]

[1]Cooperative Institute for Meteorological Satellite Studies
[2]NOAA/NESDIS Madison, WI

Background &

- Leads are elongated fractures in the sea ice cover. They form under atmospheric and oceanic stresses (Smith et al., 1990).

- Leads provide a source of heat and moisture to the Arctic atmosphere (Alam and Curry 1995, Maykut, 1987).



(From earthobservatory.nasa.gov)

Objective

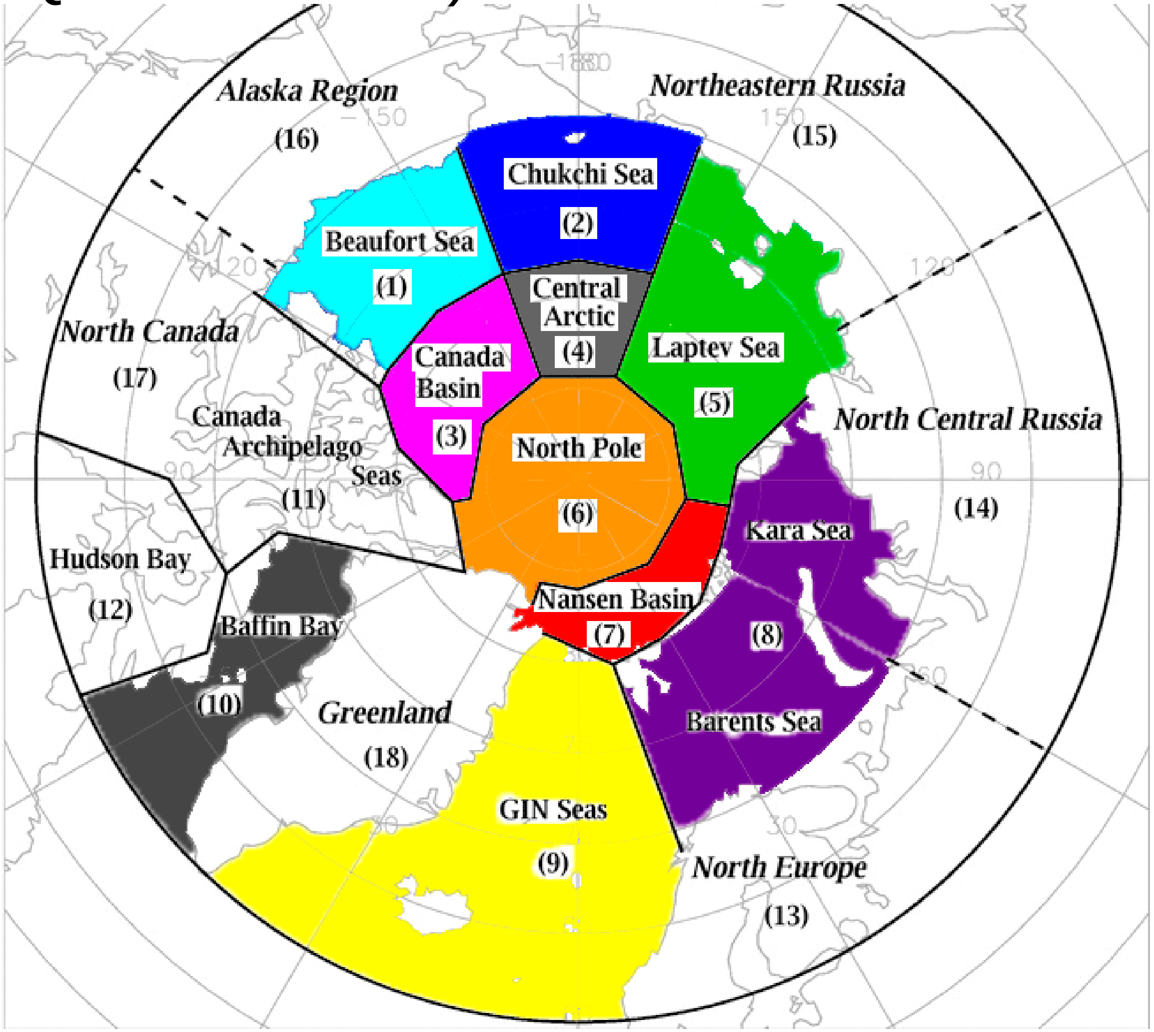
- Identify the spatial and temporal distributions of sea ice leads (fractures) in the Arctic
- Study trends in the lead distributions and properties (concentration, width, and orientation)

Image credit: National Ice Center

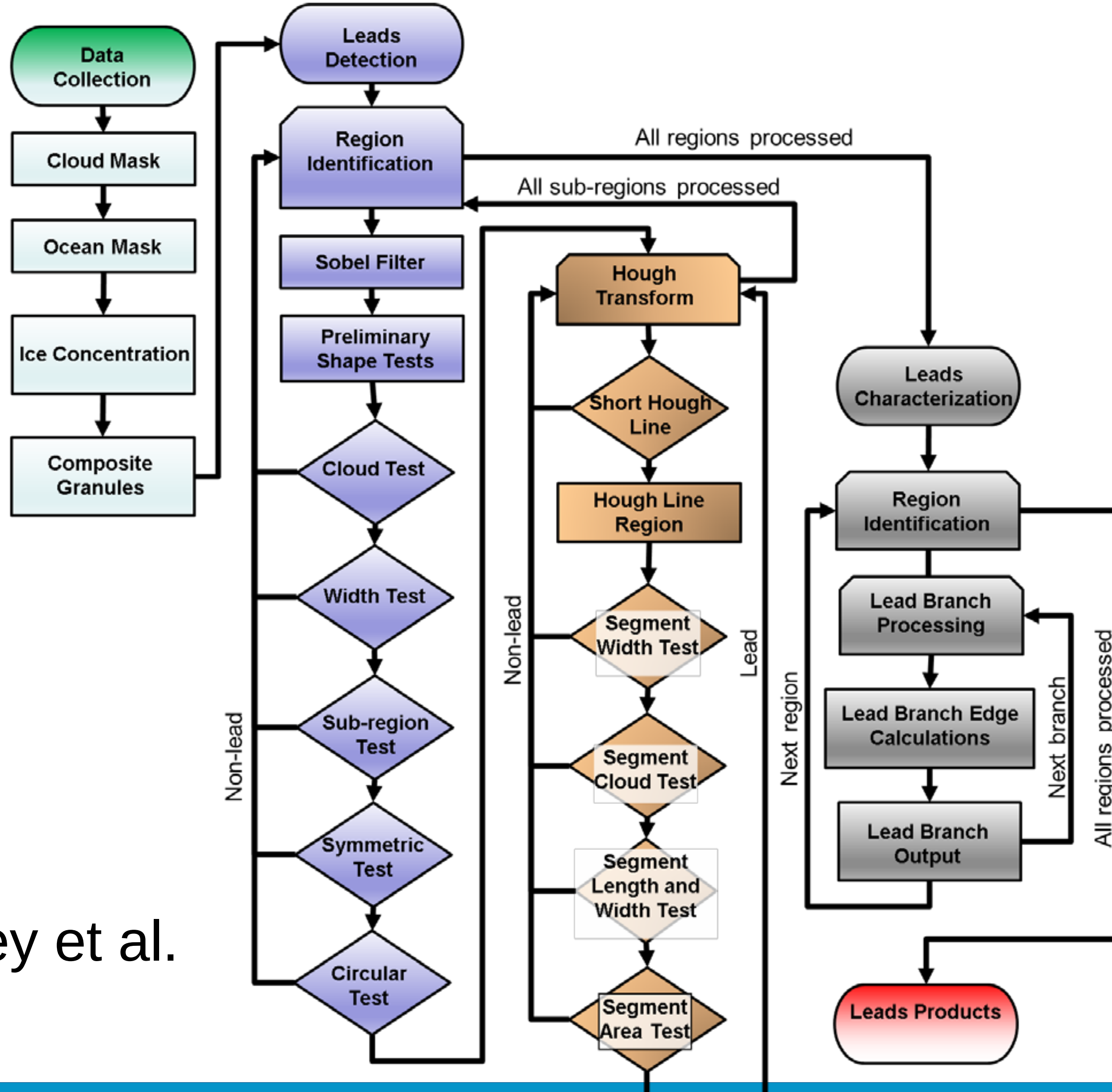
Study Area

2003 - 2017: MODIS (AQUA & TERRA)

- January - April
- 10 polar regions
  - Beaufort Sea
  - Chukchi Sea
  - Canada Basin
  - Central Arctic
  - Laptev Sea
  - North Pole
  - Nansen Basin
  - Kara & Barents Sea
  - GIN Seas
  - Baffin Bay



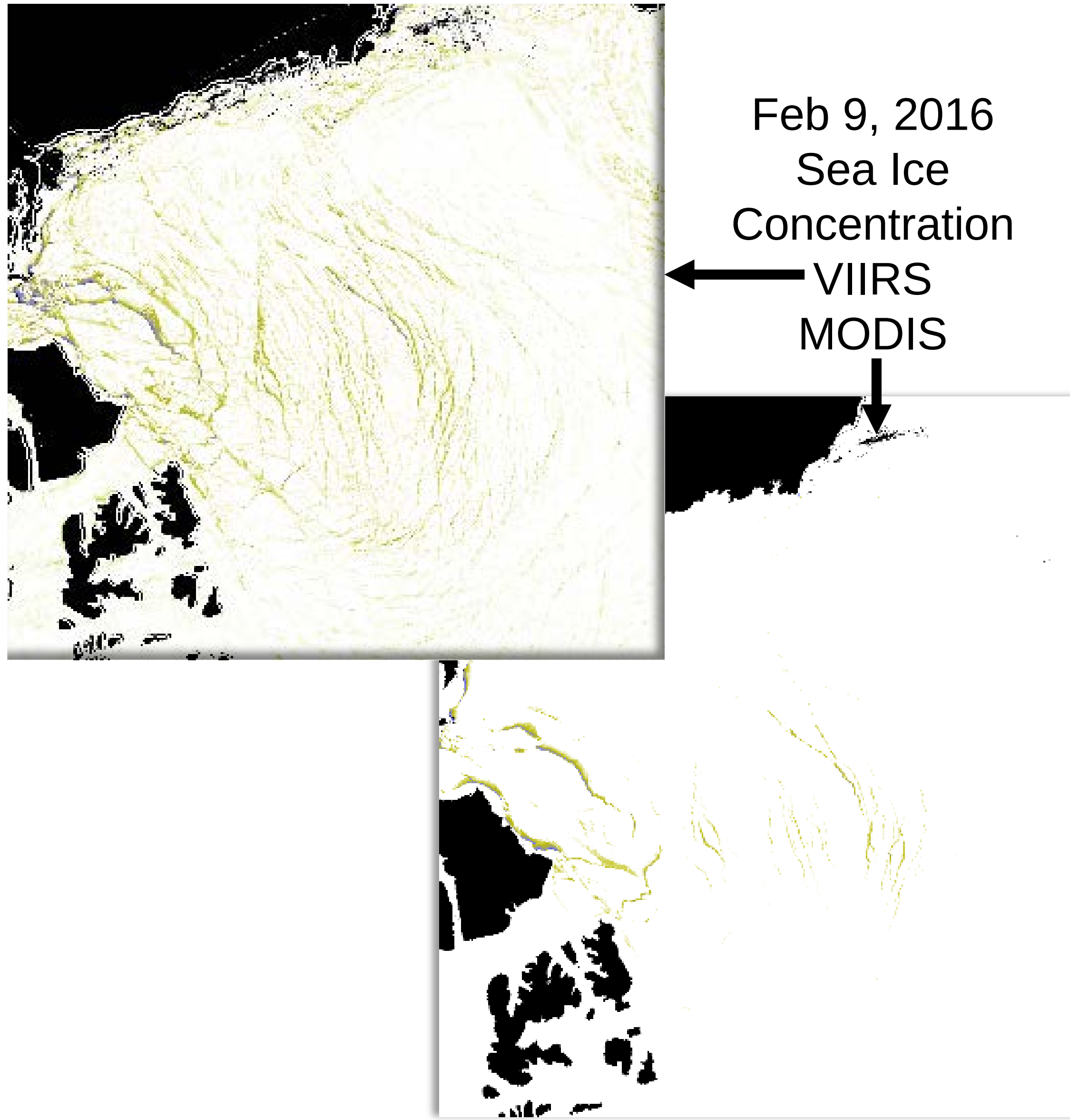
Algorithm Description



Adapted from Key et al. (1993 and 1994)

Ice Concentration

- VIIRS consistent along-swath resolution results in better ice concentration retrievals
  - More detail in sea ice concentration results in more leads detected



Leads Detection

- Lead detect appears as red the day it is detected.
- To show movement, leads fade from white to black on days it is not detected

Feb 9-13, 2016

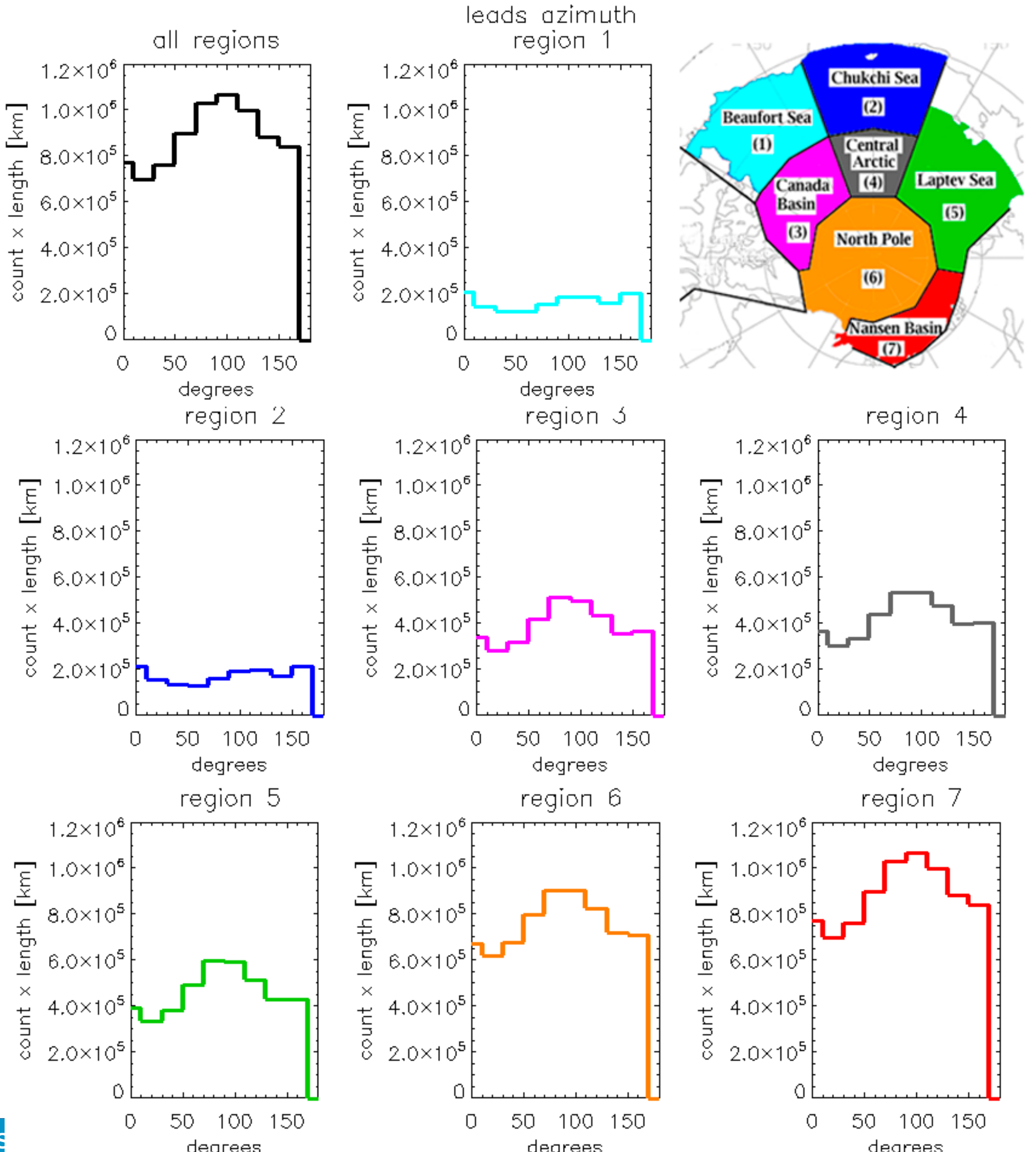
← VIIRS

MODIS ↓

- VIIRS detects more leads in regions where MODIS scan angles are greater than 30°

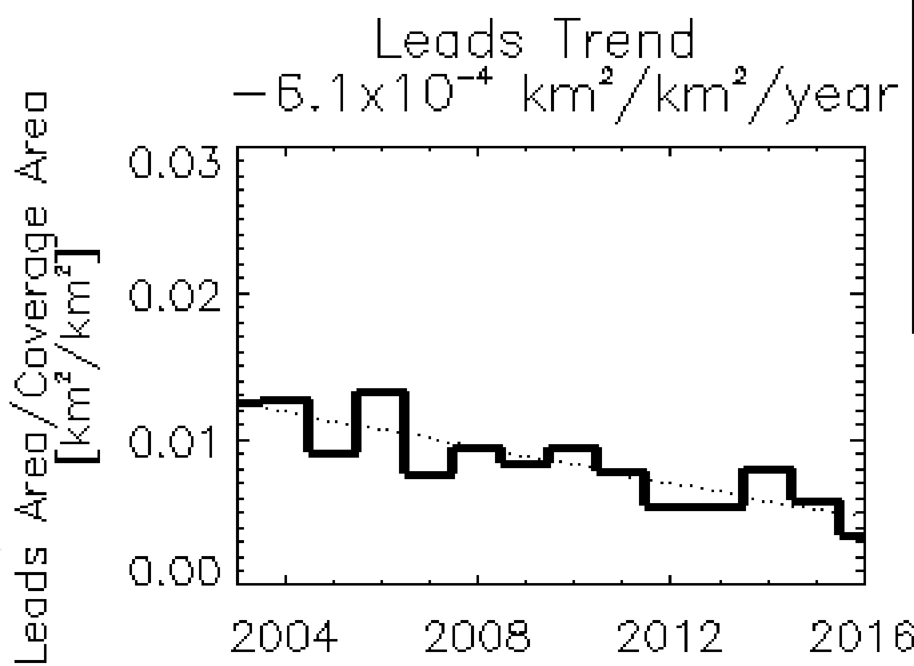
MODIS Leads Characterization

- Identify object start and end point
  - Length (great-circle distance)
  - Orientation(shown)
- Area
  - Pixel count x pixel resolution
- Width
  - Area/length



Annual Trends

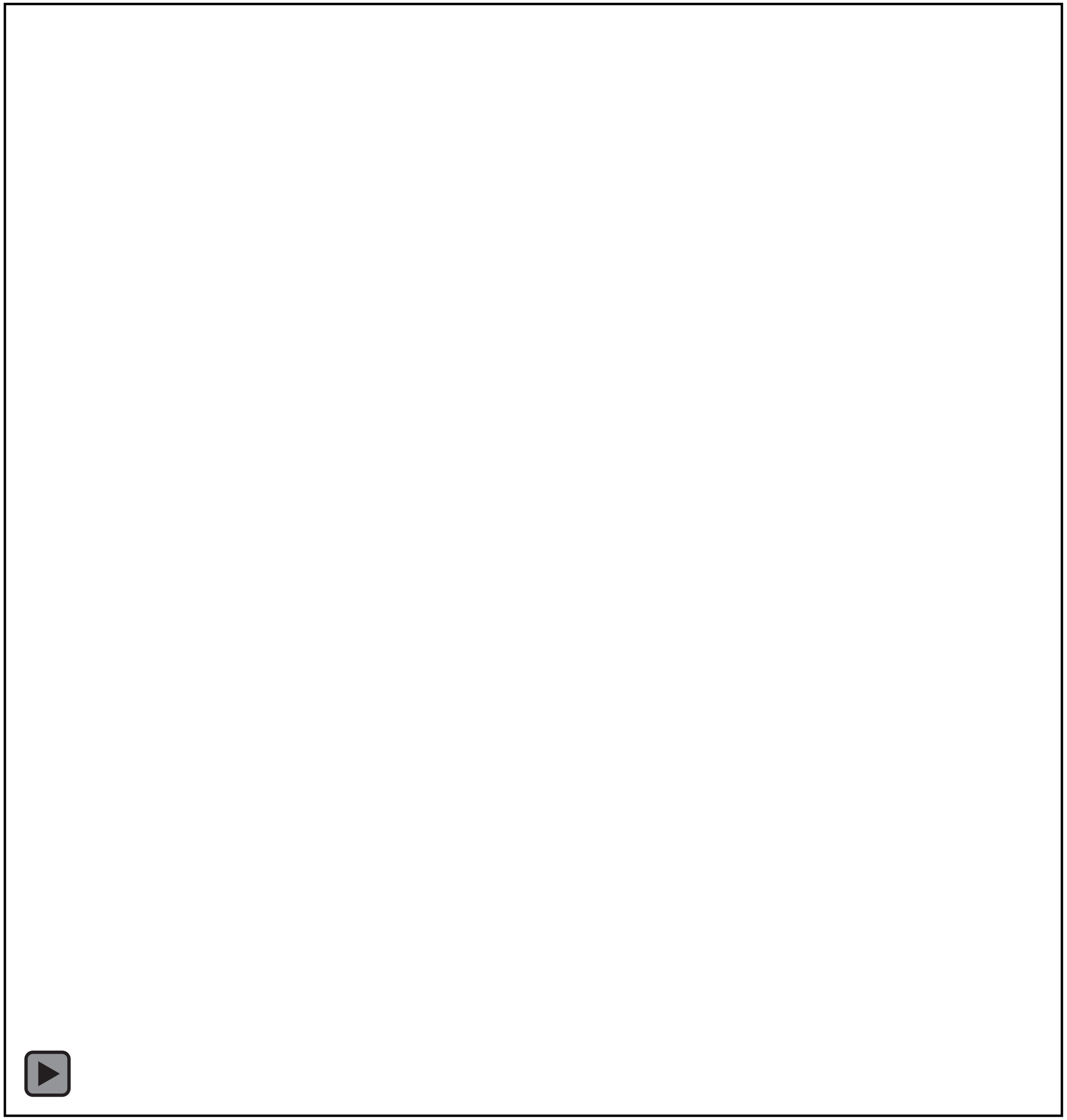
- Slight decreasing trend in MODIS leads area
- Improved spatial coverage from VIIRS will help detect more leads where MODIS has poor spatial coverage



Summary

Daily leads
Jan-Apr 2003-2017

- 15 year archive
- Ongoing work
  - Investigate trends
  - Write documentation
- Future steps
  - Real-time product
  - Extend algorithm to VIIRS



Cloud coverage
-Blue/green
Leads
-Red on the day of detection
-Fade from white to grey

Assimilation of Satellite Snow Products into NCEP Operational CFS/GFS System

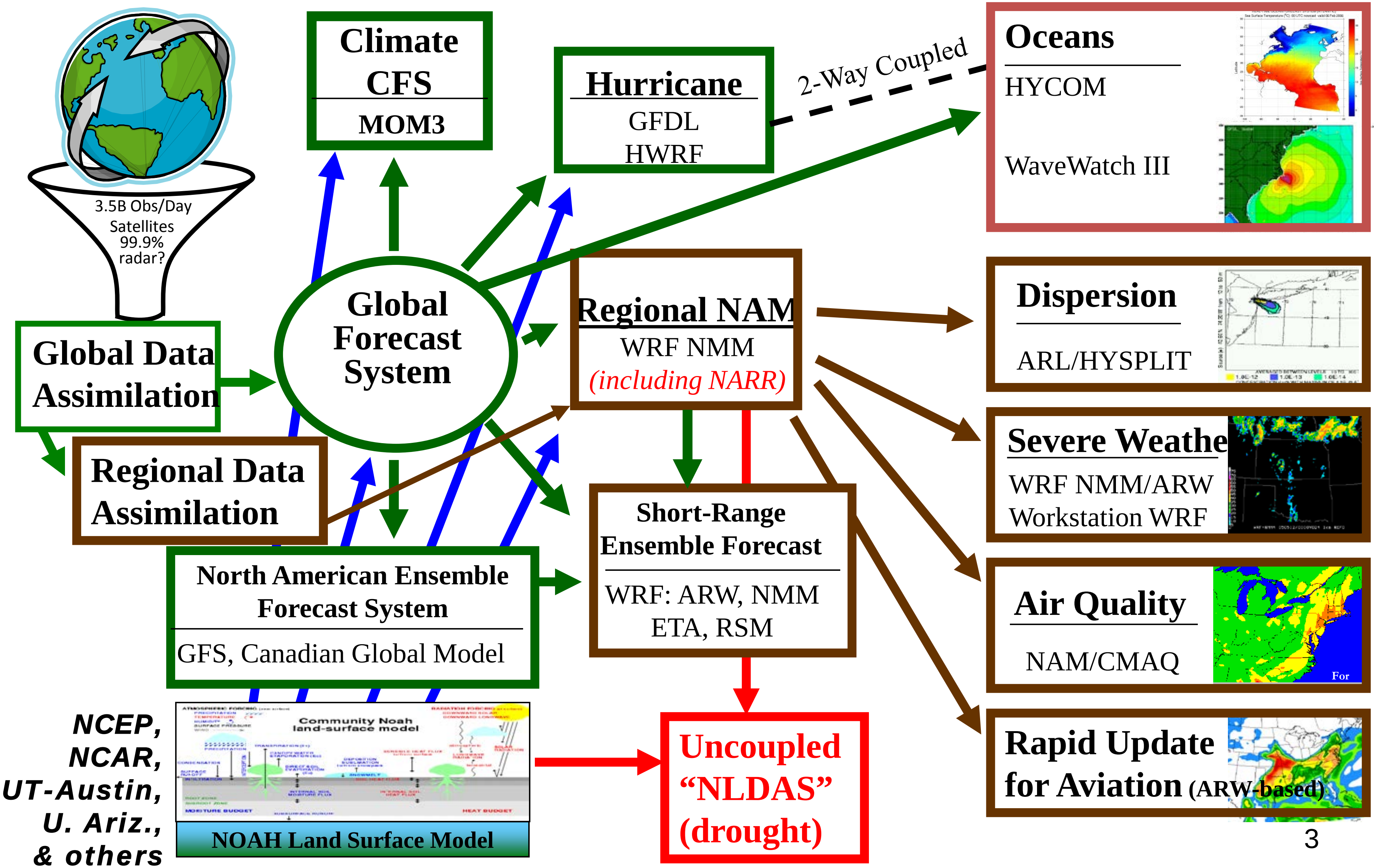
Michael B. Ek and Jiarui Dong
NOAA/NCEP/EMC, College Park, Maryland, USA

STAR JPSS Science Team Meeting
August 17, 2017, NCWCP, College Park MD

Outline

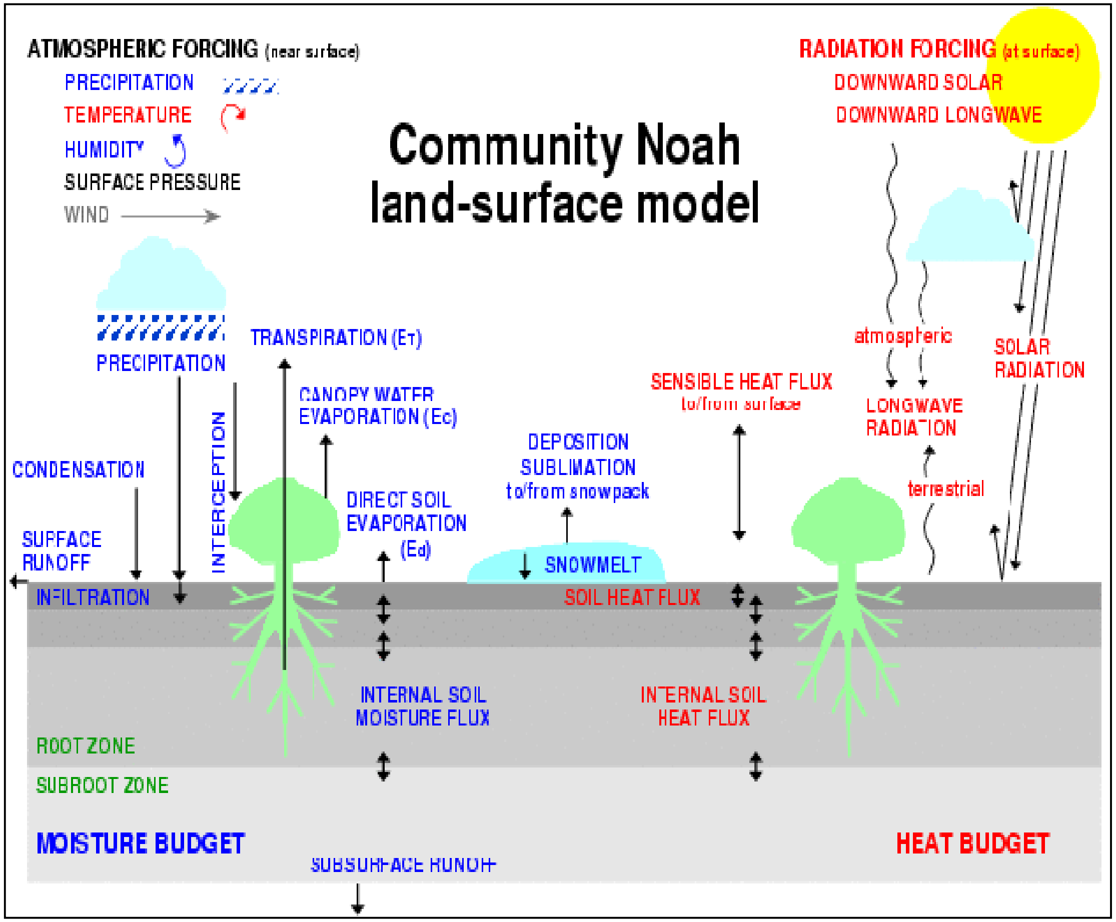
- NCEP Land Data Assimilation Systems
- NASA Land Information System Applications
- Land Data Assimilation Experiments
- Summary

Noah Land Model Connections in NOAA's NWS Model Production Suite



Unified NCEP-NCAR Noah Land Model

- Four soil layers (shallower near-surface).
- Numerically efficient surface energy budget.
- Jarvis-Stewart “big-leaf” canopy conductance with associated veg parameters.
- Canopy interception.
- Direct soil evaporation.
- Soil hydraulics and soil parameters.
- Vegetation-reduced soil thermal conductivity.
- Patchy/fractional snow cover effect on sfc fluxes.
- Snowpack density and snow water equivalent.
- Freeze/thaw soil physics.

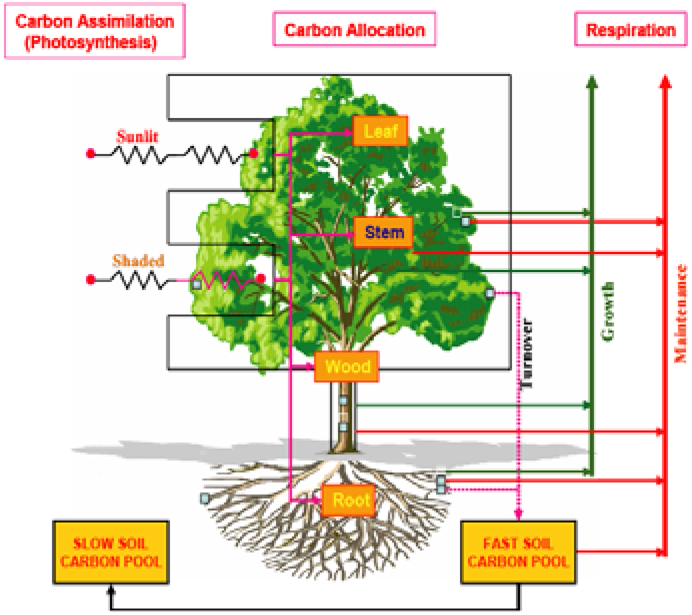


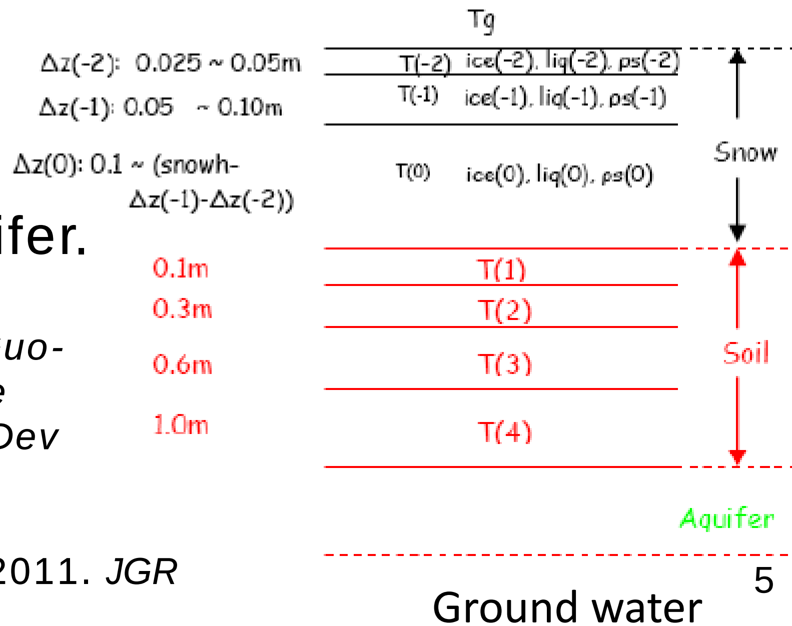
- Noah coupled with NCEP model systems: short-range NAM, medium-range GFS, seasonal CFS, HWRF, uncoupled NLDAS, GLDAS.

Noah Multi-Physics (Noah-MP)

Noah-MP is an extended version of the Noah LSM with enhanced multi-physics options to address shortcomings in Noah.

- Canopy radiative transfer with shading geometry.
- Separate vegetation canopy layer.
- Dynamic vegetation.
- Ball-Berry canopy resistance.
- Multi-layer snowpack.
- Snow albedo treatment.
- New snow cover.
- Snowpack liquid water retention.
- New frozen soil scheme.
- Interaction with groundwater/aquifer.



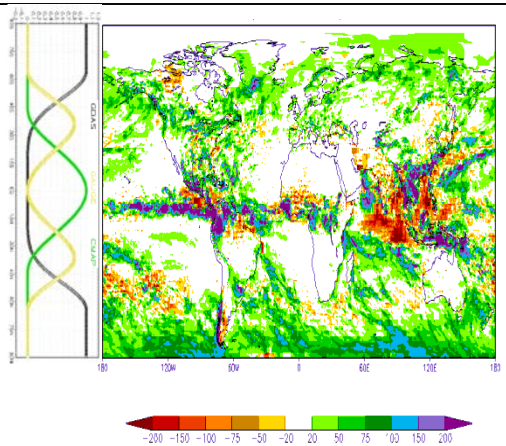


Main contributors: Zong-Liang Yang (UT-Austin); Guo-Yue-Niu (U. Arizona); Fei Chen, Mukul Tewari, Mike Barlage, Kevin Manning (NCAR); Mike Ek (NCEP); Dev Niyogi (Purdue U.); Xubin Zeng (U. Arizona)

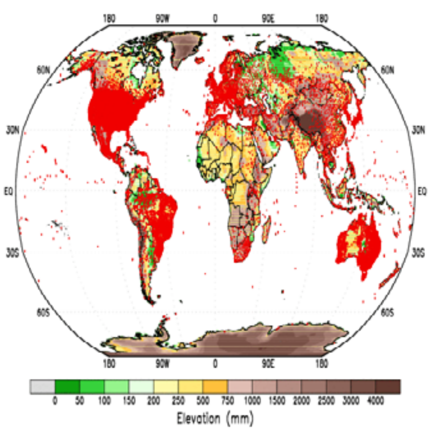
Noah-MP references: Niu et al., 2011, Yang et al., 2011. *JGR*

Global Land Data Assimilation System (GLDAS)

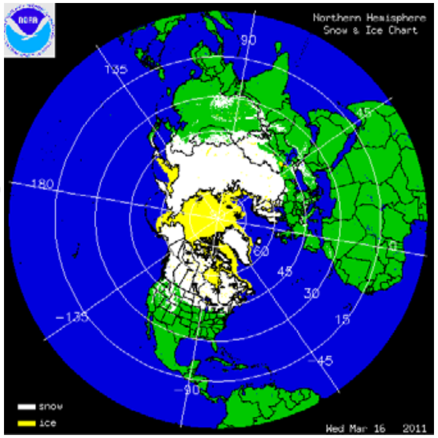
- Uses **Noah land model** running under NASA Land Information System forced with **Climate Forecast System** (CFS) atmos. data assimil. cycle output, & **"blended" precipitation** (gauge, satellite & model), "semi-coupled" –daily updated land states.
- **Snow** cycled if snow from Noah land model within a 0.5x/2.0x envelope of observed value (IMS snow cover, AFWA depth).
- GDIS: GLDAS soil moisture climatology from 30-year runs provides **anomalies** for **drought monitoring**.
- GLDAS land "re-runs", with updated forcing, physics, etc.



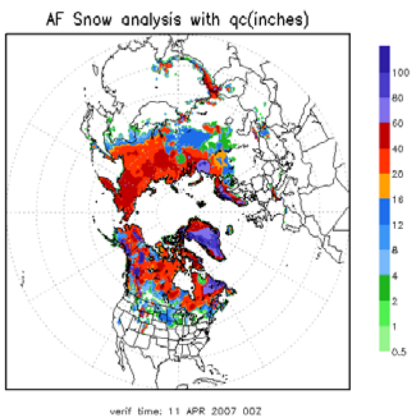
GDAS-CMAP precip



Gauge locations



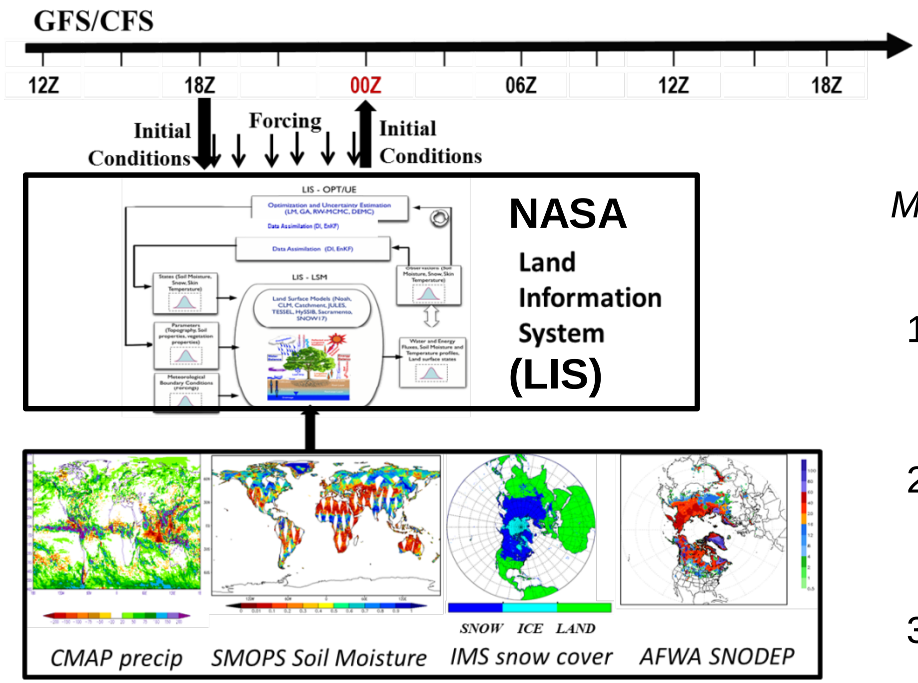
IMS snow cover



AFWA snow depth

Satellite-based Land Data Assimilation in NWS GFS/CFS Operational Systems

- Use NASA Land Information System (LIS) to serve as a global Land Data Assimilation System (LDAS) for both GFS and CFS.
- LIS EnKF-based Land Data Assimilation tool used to assimilate soil moisture from the NESDIS global Soil Moisture Operational Product System (**SMOPS**), snow cover area (**SCA**) from operational NESDIS Interactive Multisensor Snow and Ice Mapping System (**IMS**) and AFWA snow depth (**SNODEP**) products.



NGGPS Project: Land Data Assimilation

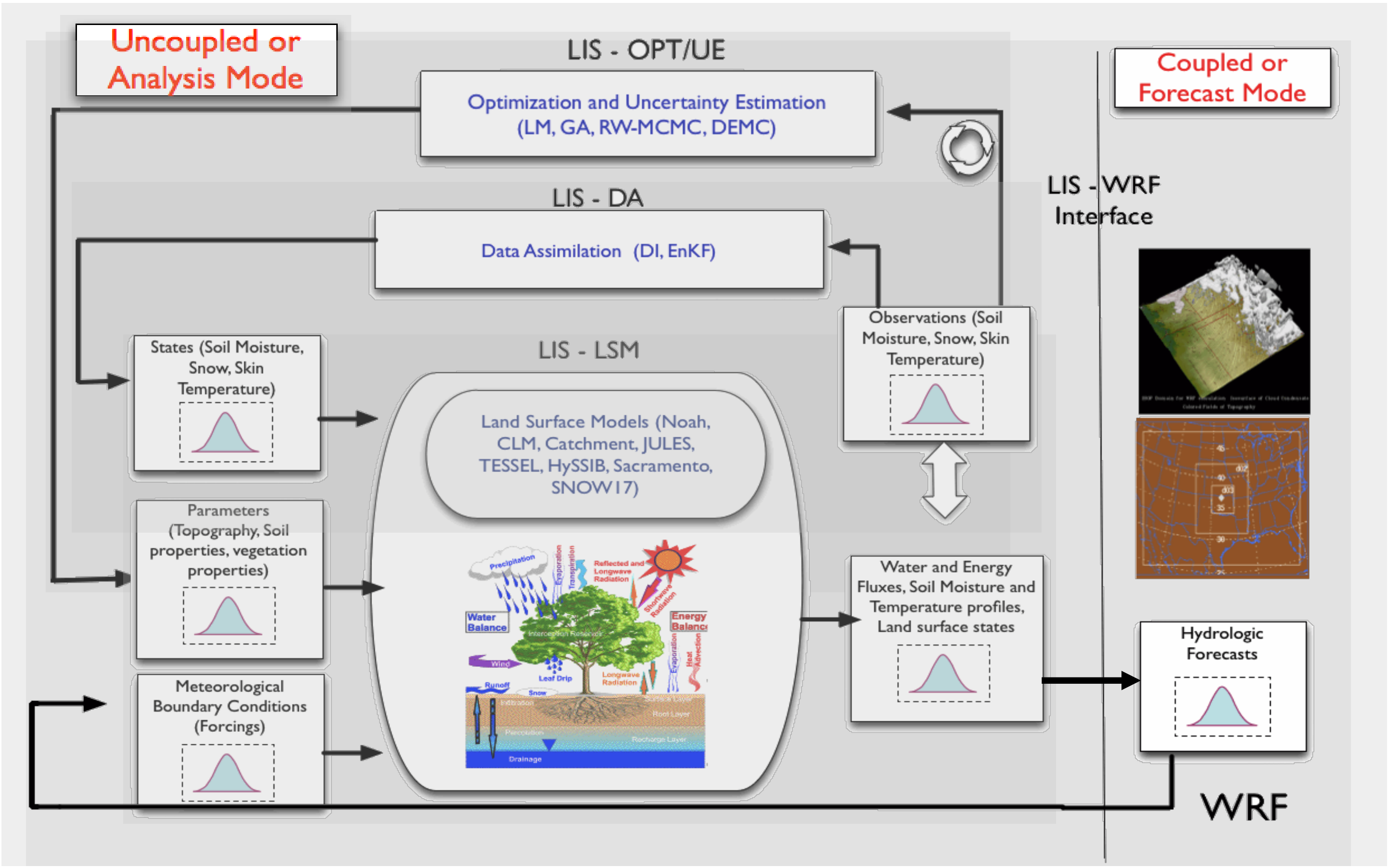
Michael Ek, Jiarui Dong, Weizhong Zheng (NCEP/EMC)
Christa Peters-Lidard, Sujay Kumar (NASA/GSFC)

1. Build NCEP's GFS/CFS-LDAS by incorporating the NASA Land Information System (LIS) into NCEP's GFS/CFS (left figure)
2. Offline tests of the existing EnKF-based land data assimilation capabilities in LIS driven by the operational GFS/CFS.
3. Coupled land data assimilation tests and evaluation against the operational system.

NASA Land Information System (LIS)

- LIS is a flexible land-surface modeling and data assimilation framework developed with the goal of integrating satellite- and ground-based observed data products with land-surface models.

Data Assimilation of: Soil Moisture, SWE, SCF, TWS



NCEP/EMC Land Team and DA Partners

NCEP/EMC Land Team: *Michael Ek*, Jiarui Dong, Weizhong Zheng, Helin Wei, Jesse Meng, Youlong Xia, Rongqian Yang, Yihua Wu, Anil Kumar, Roshan Shresth, working with:

Land Data Assimilation Algorithm:

- NASA/GSFC: *Christa Peters-Lidard*, Sujay Kumar et al. (LIS)
- NASA/GMAO: Rolf Rechelie et al. (EnKF)
- University of Maryland: Ning Zeng, Steve Penny (LETKF)
- NESDIS/STAR: Xiwu Zhan et al. (EnKF)
- Monash University, Australia: Jeffrey Walker (EKF)

Remotely-sensed Land Data Sets:

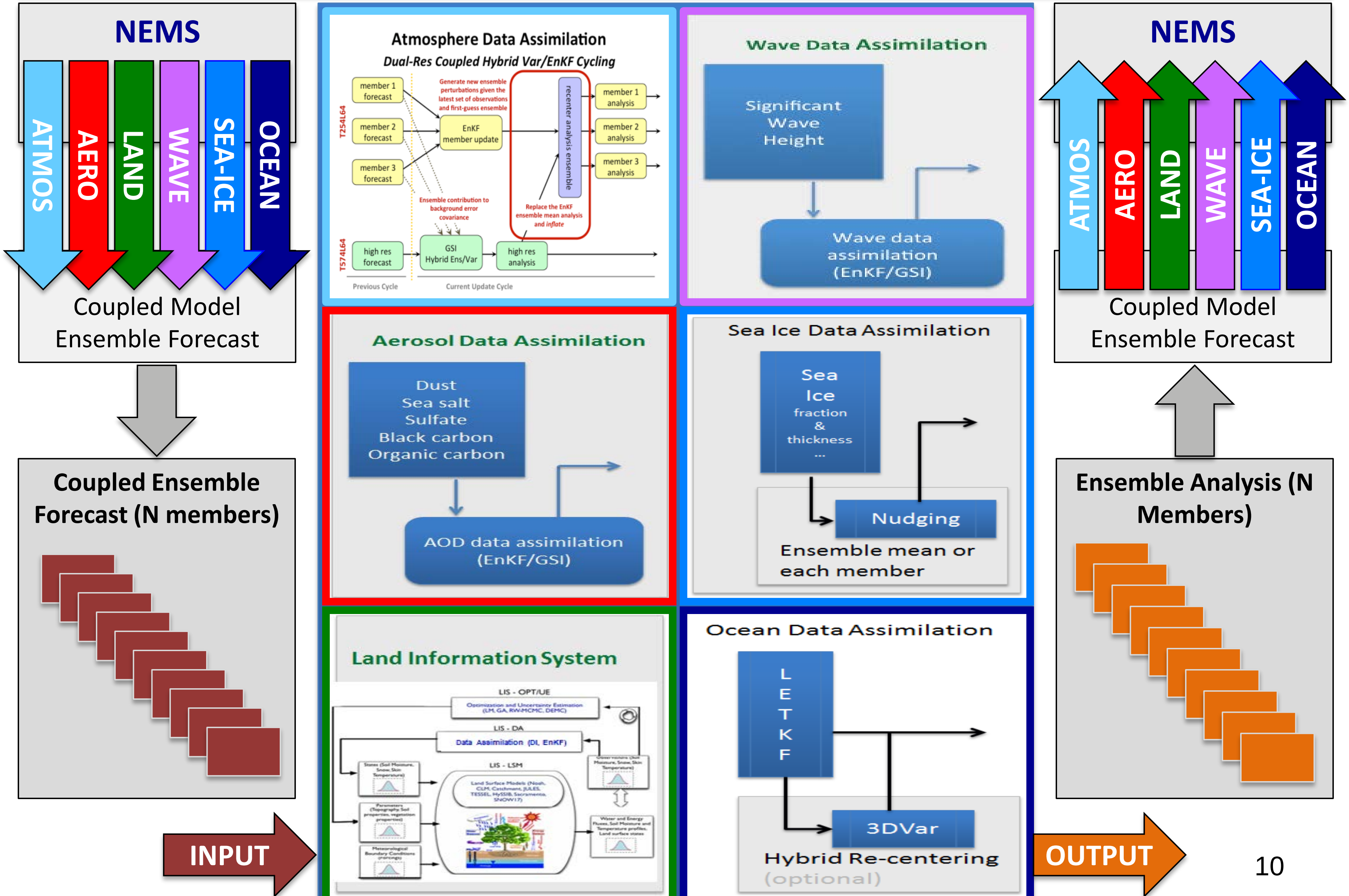
- NESDIS/STAR land group: Ivan Csiszar, Xiwu Zhan (soil moisture), Bob Yu (Tskin), Marco Vargas (vegetation) et al.
- NESDIS/OSPO: Sean Helfrich (IMS snow cover)
- 557th Weather Wing: Jeffrey Cetola (snow depth)
- NASA/GSFC: Dorothy Hall (MODIS snow cover), James Foster (SWE)

Verification:

- GEWEX/GLASS, GASS projects: Land model benchmarking,

land-atmosphere interaction exp. with international partners.

NCEP Coupled Hybrid-EnKF Data Assimilation System



Snow Products Received at NCEP

The **Air Force 557th Weather Wing (557WW)** snow depth is estimated daily by merging satellite-derived snow cover data with daily snow depth reports from ground stations.

Snow depth reports are updated by additional snowfall data or decreased by calculated snowmelt.

The **Interactive Multisensor Snow and Ice Mapping System (IMS)** snow cover product is a snow cover analysis at 4-km resolution manually created by looking at all available satellite imagery, several automated snow mapping algorithms, and other ancillary data.

Regions covered by cloud during the 24-hour analysis period take lower resolution passive microwave data and surface observations into account where possible. There are no missing values over the mapped region.

Experiment Design

1. Forcing:

|-------- **Spinup** --------|

2009010100 **Oper. GFS/GDAS** 2012010100 **Operational GFS/GDAS** 2013053123

2013060100 **Parallel GFS/GDAS** 2015010113

2015011400 **Operational GFS/GDAS** 2017013123

|------------------- T574 --------------------‖----------------------- T1534 ----------------------->

2. Initial conditions:

Spinup run three times over GFS forcing from 01/01/2009 to 12/31/2011

Control Run: Starting at 00Z 01/01/2012 with initial condition from spinup run

Direct Replacement: Starting at 01/01/2014 with the initial condition from the Control Run.

EnKF: With 20 ensemble members starting at 01/01/2014 with the initial condition from the Control Run.

3. Model configuration:

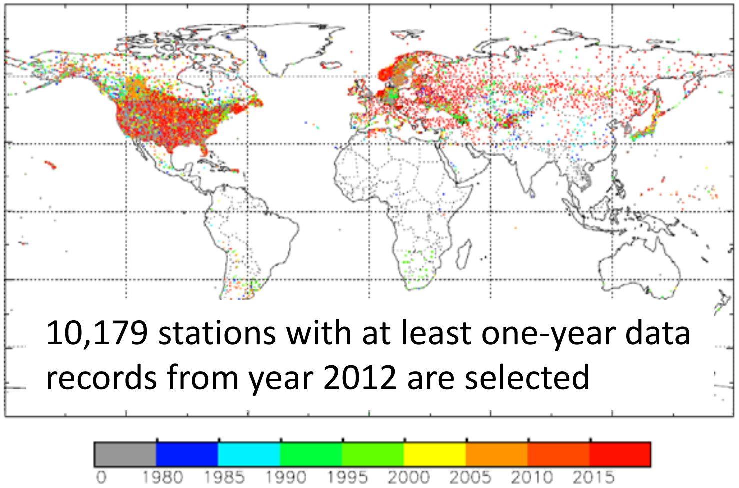
Model is configured at T1534 (3072 by 1536) globally

Verification Data and Method

POD_S **measures the fraction of observed snow cover presence that were correctly detected in AFWA/IMS/GFS**

POD_N **measures the fraction of observed snow-free land that were correctly detected in AFWA/IMS/GFS**

FAR **measures the fraction of observed snow-free land that were incorrectly detected as snow cover in AFWA/IMS/GFS**



10,179 stations with at least one-year data records from year 2012 are selected

$$POD_S = \frac{SS}{NS + SS}$$

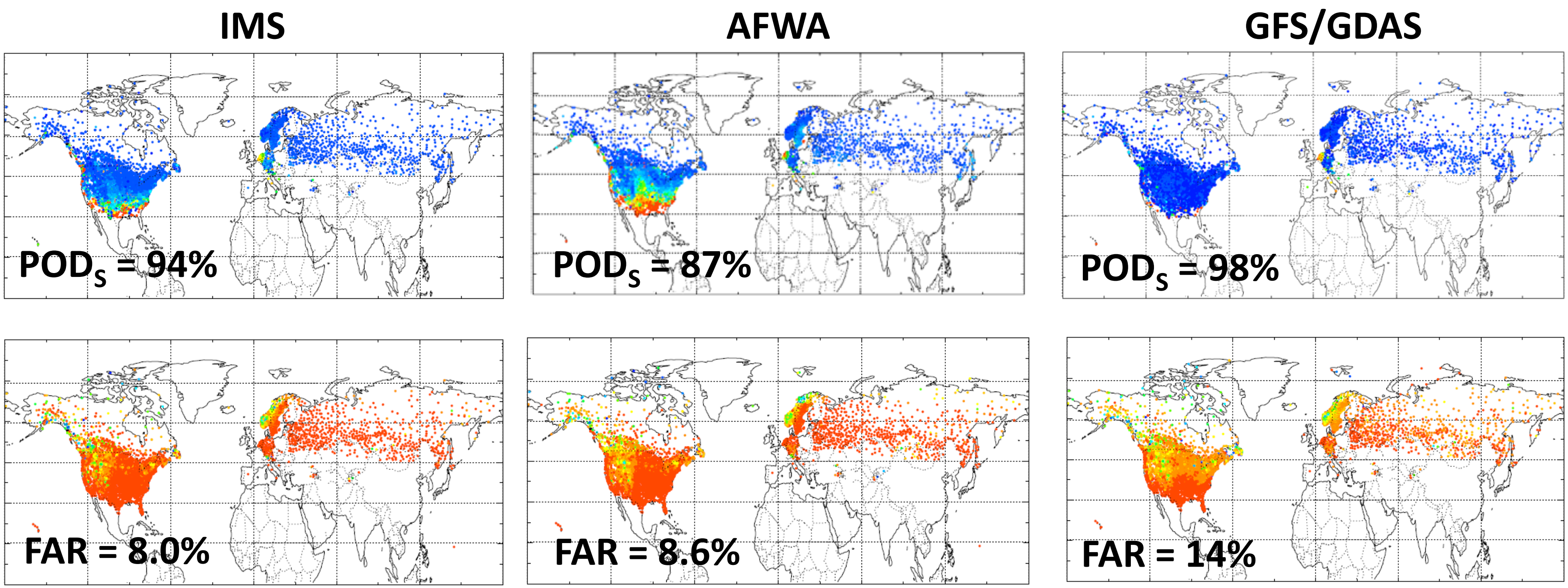
$$POD_N = \frac{NN}{NN + NS}$$

$$FAR = \frac{SN}{SN + NN}$$

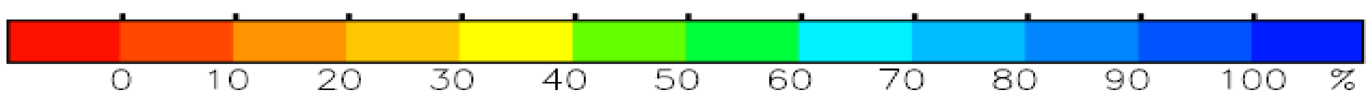
		OBS	
		SNOW	NO SNOW
AFWA IMS GFS LIS	SNOW	SS	SN
	NO SNOW	NS	NN

***POD*: Probability of Detection**
***FAR*: False Alarm Ratio**

Statistics of Snow Cover Mapping



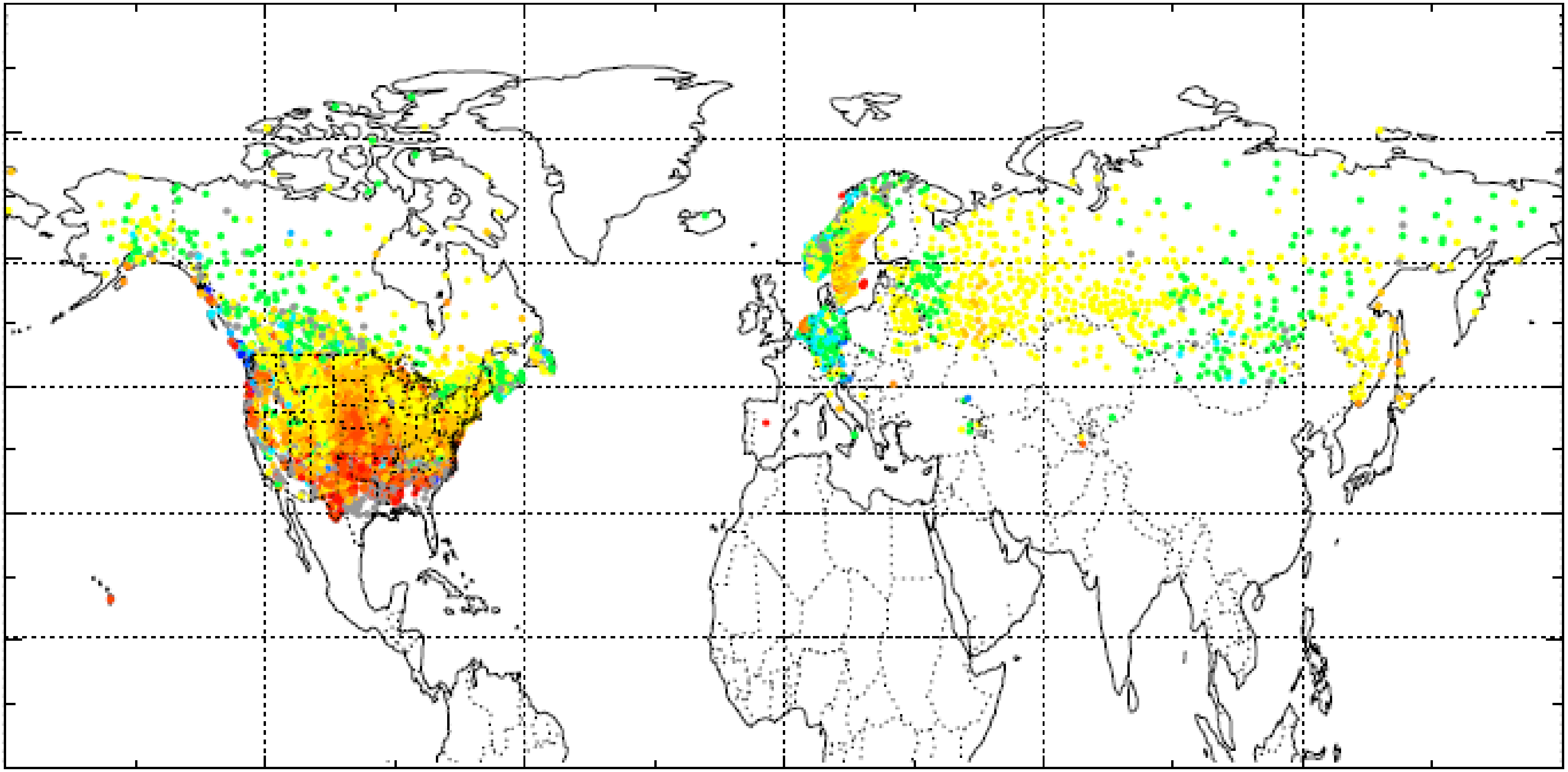
POD and FAR statistics of IMS SCA, AFWA snow depth and GFS snow depth



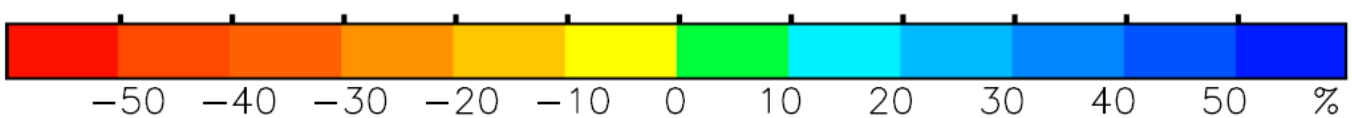
$$POD_S = \frac{SS}{NS + SS} \qquad FAR = \frac{SN}{SN + NN}$$

GFS/GDAS Product: Higher *POD* (98%) everywhere, but larger *FAR* (14%) in Canada, Mountains in the US and Europe.
Satellite Products: Lower *POD* in the southern U. S. and larger *FAR* in mountains of the US and in Norway

POD_{afwa} - POD_{ims}

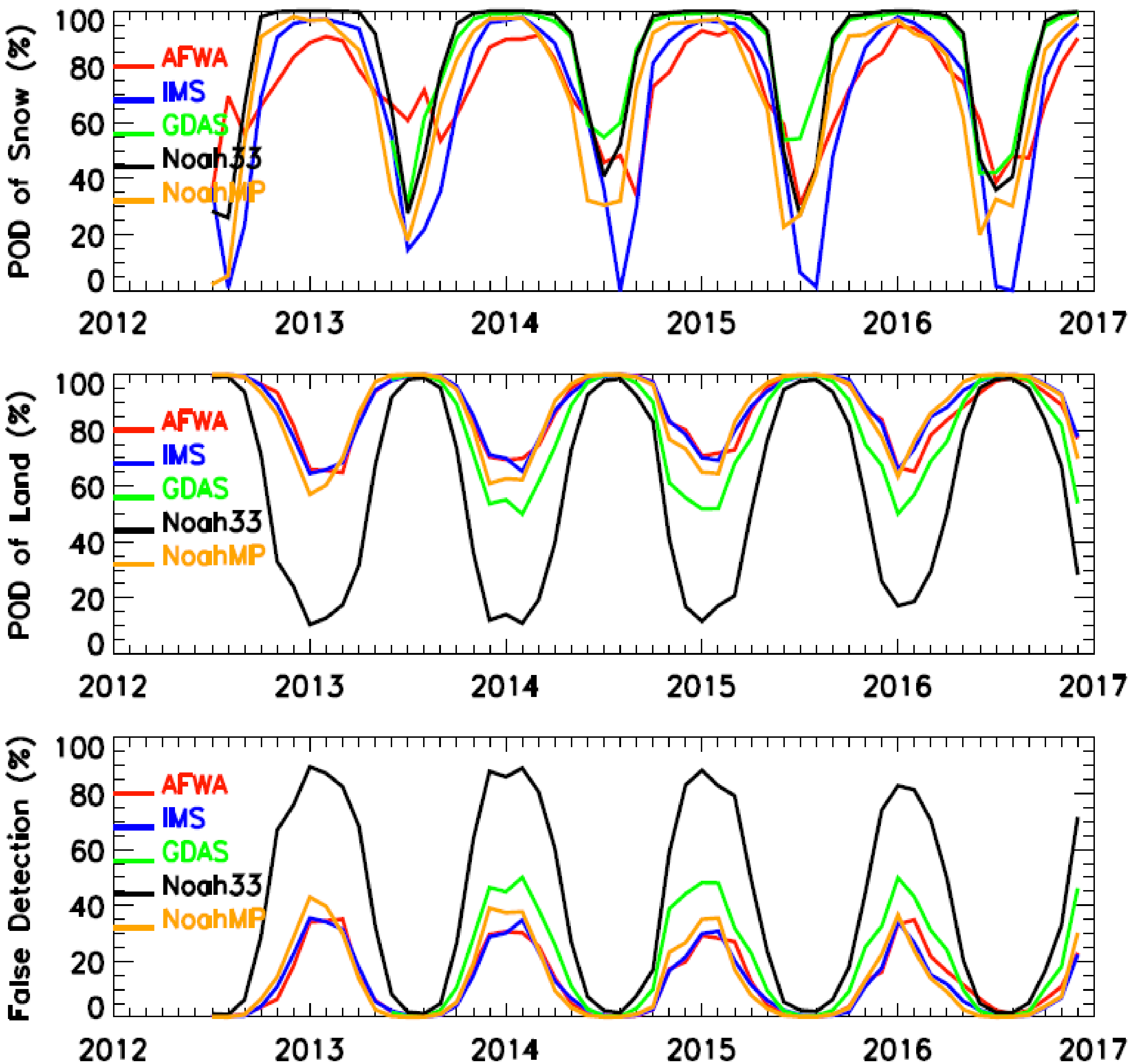


Comparison of POD between AFWA SNODEP and IMS Snow Cover



IMS snow cover product shows higher accuracy in snow cover detection than AFWA/SNODEP, especially over CONUS. Assimilation of IMS snow cover will be helpful in the regions with fast snow phase changes.

Snow Cover Mapping



GFS demonstrates a strong ability to simulate the presence of snow cover (98%) comparing to IMS (94%) and AFWA SNODEP (87%).

However, GFS shows larger false snow cover detection (>40%) in winter months than IMS and AFWA (<30%).

LIS/Noah Cycle with GFS forcing shows even higher *POD* in snow detection (99%), but false alarm ratio is as higher as 80% during winter months.

$$POD_S = \frac{SS}{NS + SS}$$

$$POD_N = \frac{NN}{NN + NS}$$

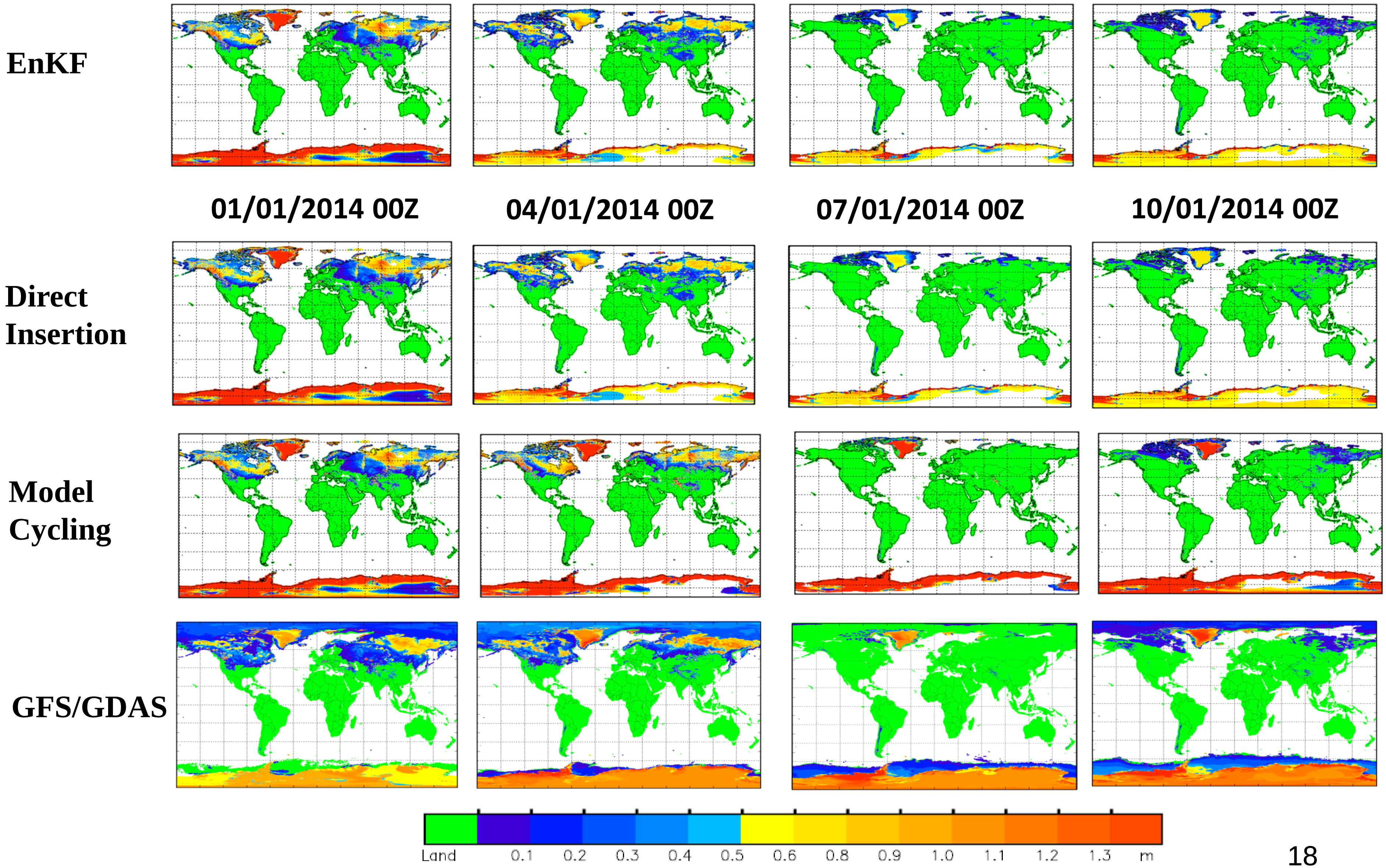
Snow Cover Mapping

	POD_S	FAR	Accuracy POD_{S+N}
IMS	93.85	8.29	91.91
AFWA	87.46	8.80	90.85
GFS/GDAS	98.35	14.47	86.69
Noah.3.3	99.50	32.10	71.01
Noah-MP3.6	93.71	9.03	91.24

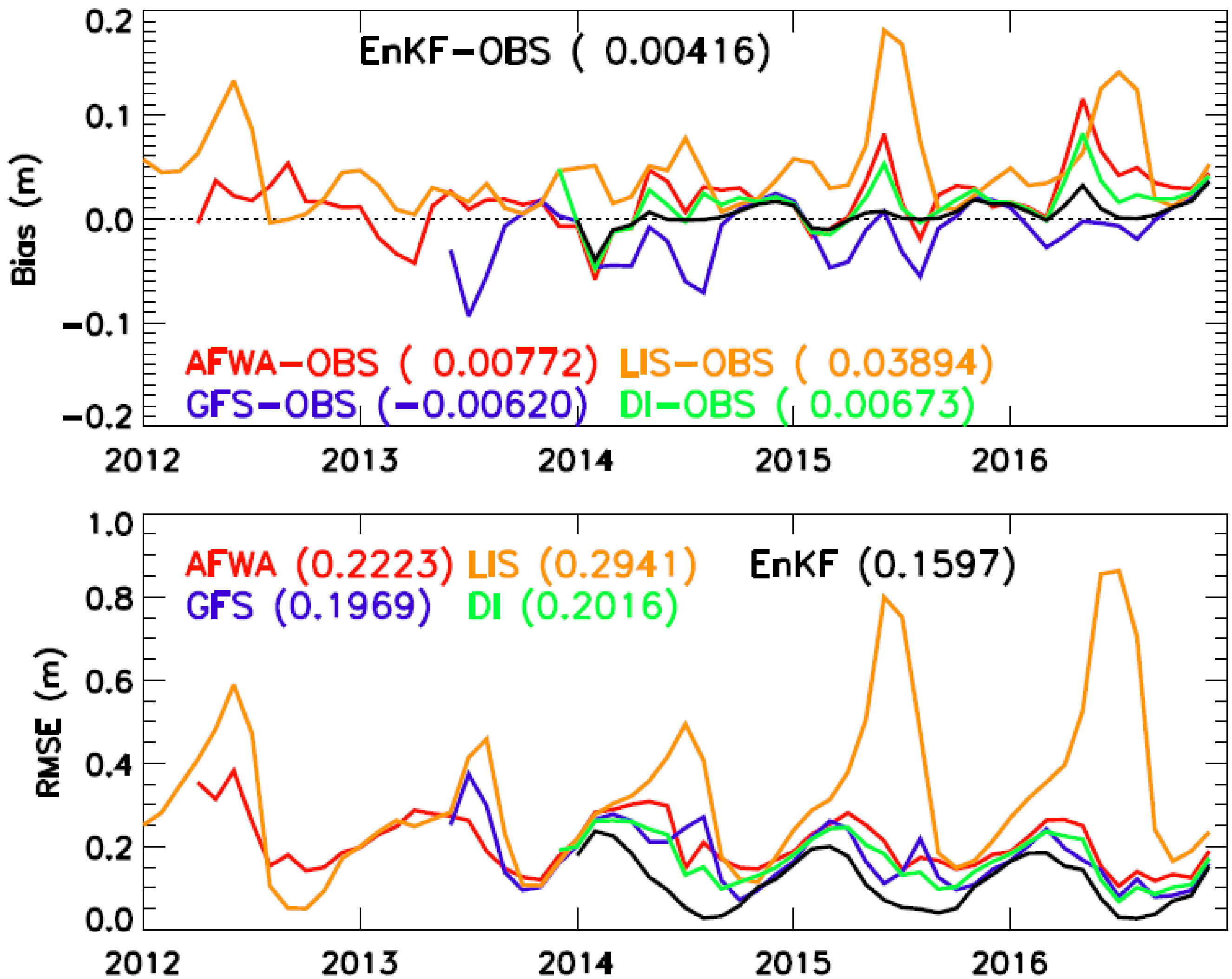
$$POD_S = \frac{SS}{NS + SS} \qquad FAR = \frac{SN}{SN + NN} \qquad POD_{S+N} = \frac{SS + NN}{NS + SS + SN + NN}$$

Noah.3.3 cycled with GFS forcing shows higher *POD* of snow (99.5%), but with large FAR (32%).
The general accuracy of *POD* of snow and land (POD_{S+N}) is higher from IMS, AFWA and Noah-MP cycle.

Demonstration of LIS land data assimilation of AFWA Snow Depth

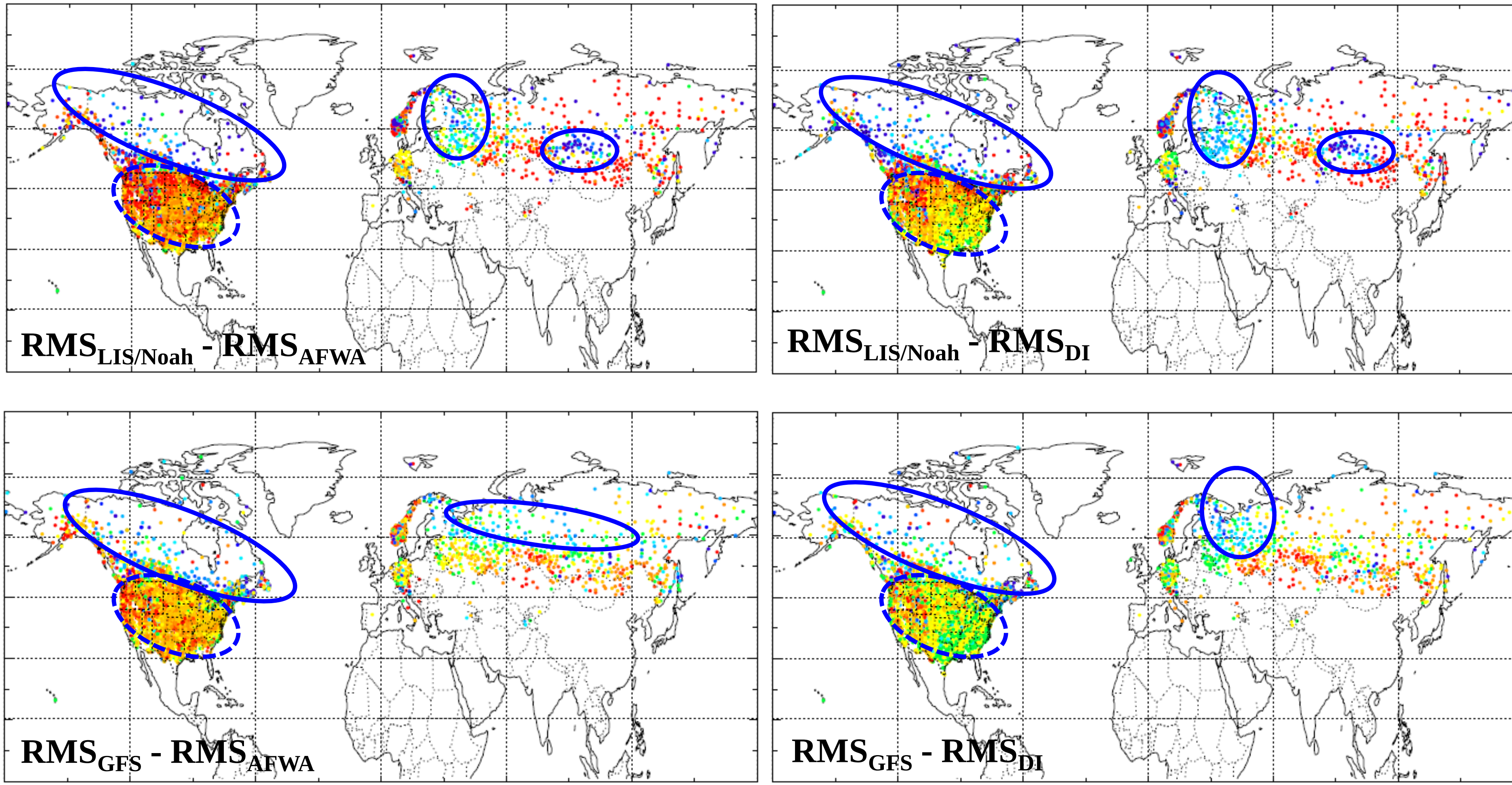


AFWA / Noah33 / GFS / DI / EnKF

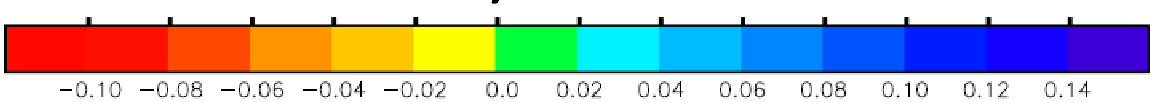


Temporally, **AFWA/SNODEP** shows positive bias, and **GFS/GDAS** shows negative bias.
DI (ingest AFWA/SNODEP into Noah) shows improved estimates in snowdepth with less bias and RMS errors.
EnKF DA results are much better than all the other products with bias and RMS significantly reduced.

AFWA SNODEP and DI



Statistics over January 2014 to December 2016

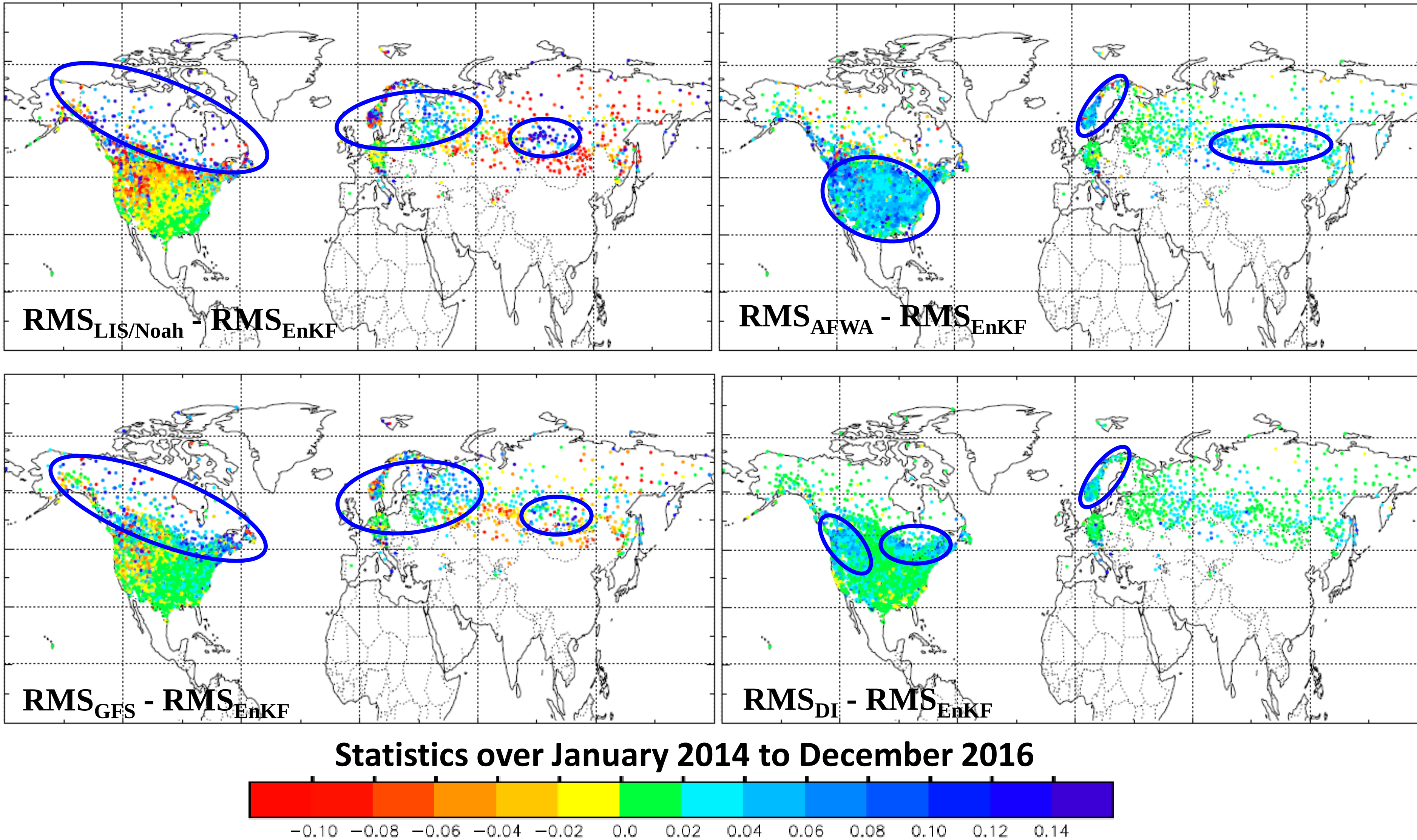


AFWA SNODEP is better in Canada and Europe, and **DI Assimilation** shows improvements in these regions.

AFWA SNODEP is worse over CONUS, while **DI Assimilation** of AFWA SNODEP shows improvements over CONUS.

High quality satellite data will be required to improve surface snow depth estimates.

EnKF vs Others



LIS EnKF DA results are better than all the other products including **model cycling**, **AFWA/SNODEP**, **GFS/GDAS**, and **DI**. Again, high quality satellite data result in big improvement in snow depth estimates.

Summary

- For NWP and seasonal forecasting, assimilation of AFWA SNODEP snowdepth demonstrated the improved estimates of surface states.

- Noah-MP is improved with explicit canopy, CO_2-based photosynthesis, dynamic vegetation, groundwater, multi-layer snowpack, and refined soil processes. Noah-MP is good at mapping snow.

- Large errors of snow depth modeling result from forcing including cold bias and overestimates of snowfall. EnKF is working relatively well with considering the errors from forcing fields.


THANK YOU!

Naval Oceanographic Office

Cryosphere Session

STAR JPSS 2017 Annual Science Team Meeting
14 – 18 August 2017 NCWCP College Park, MD

NAVOCEANO	Bruce McKenzie, Melissa Dykman, Danielle Carpenter
NRL-DC	Li Li, William Johnston
NRL-SSC	Pam Posey, Rick Allard

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Outline

- Naval Research Lab-Stennis Space Center (NRL-SSC)
  - Arctic Cap Nowcast/Forecast System (ACNFS)
  - Global Ocean Forecast System (GOFS)
  - Assimilating Ice
- NRL- Washington, DC (NRL-DC)
  - VIIRS Ice concentration
  - Blended AMSR2/VIIRS
- NAVOCEANO
  - Operational Sea Ice for assimilation
- Questions and contacts

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Arctic Cap Nowcast/Forecast System (ACNFS)

- *ACNFS* ***consists of 3 components:***

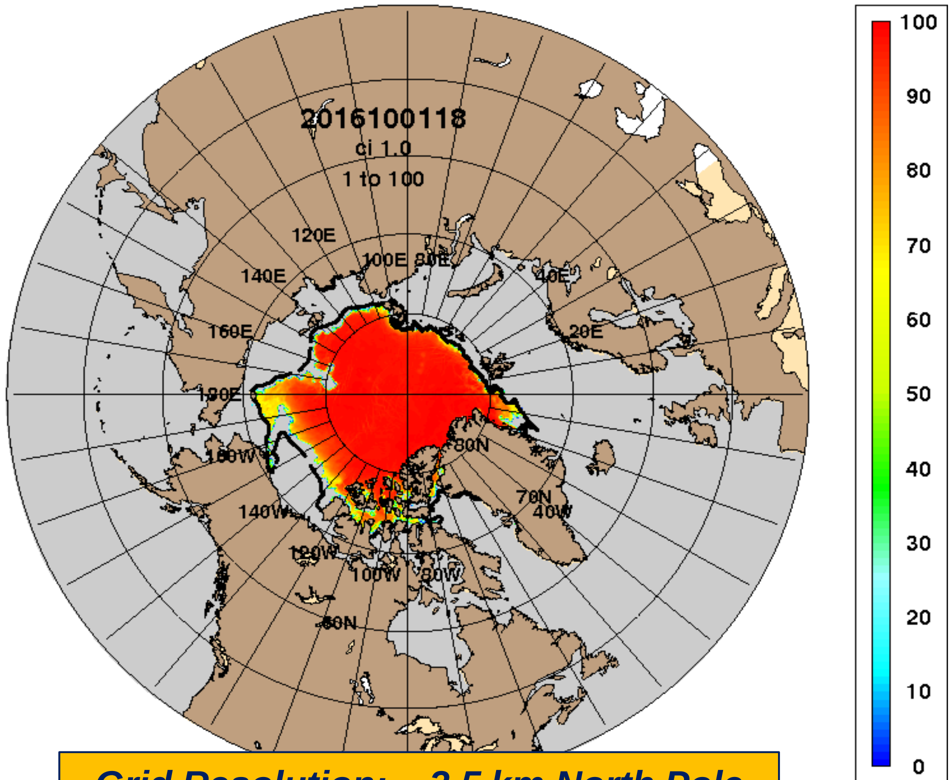
  ***Ice Model**: Community Ice CodE (CICE) v4*

  ***Ocean Model**: HYbrid Coordinate Ocean Model (HYCOM)*

  ***Data assimilation**: Navy Coupled Ocean Data Assimilation (NCODA)*
- ***Prescribed atmospheric forcing from NAVy's Global Environmental Model (NAVGEM)***
- ***Declared operational Sept 2013***
- ***Runs daily at the Naval Oceanographic Office (NAVOCEANO)***
- ***ACNFS produces nowcast/7-day forecasts of ice concentration, ice thickness, ice drift, SST, SSS, and ocean currents for the Northern Hemisphere***
- ***Products pushed daily to the U.S. National Ice Center (NIC) and NOAA***

Daily graphics can be found: www7320.nrlssc.navy.mil/hycomARC

ARCc0.08-04.6 Ice Concentration (%): 20160929



Grid Resolution: ~3.5 km North Pole Black line is the independent ice edge location (NIC). Animation spans Sept – Oct 2016

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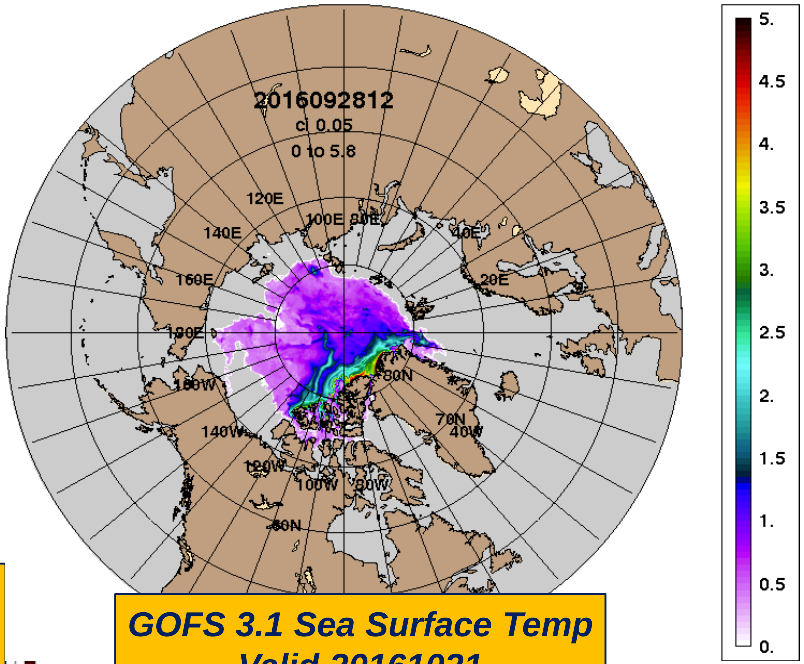
Global Ocean Forecast System (GOFS) 3.1

- ***Similar to ACNFS, GOFS 3.1 produces ice forecasts in the Northern Hemisphere and also has the added capability of forecasting ice conditions in the southern hemisphere.***
- ***OPTEST is underway, scheduled to be completed by end of summer 2017***
- ***Once declared operational, GOFS 3.1 will replace ACNFS***

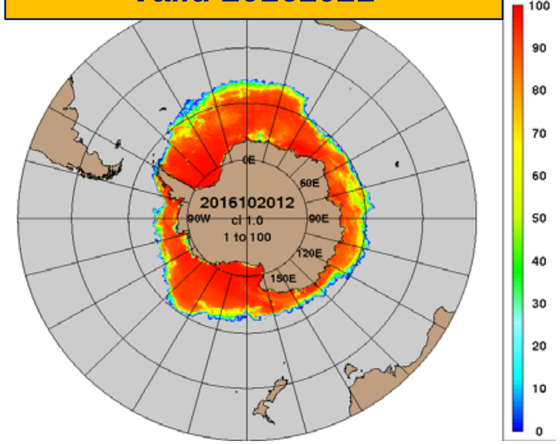
Daily graphics available:

http://www7320.nrlssc.navy.mil/GLBhycomcice1-12

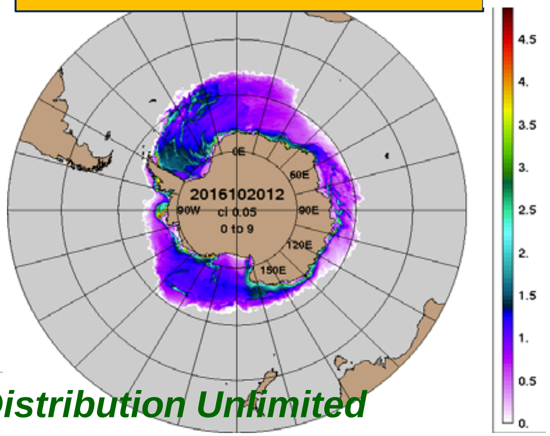
GLBb0.08-92.7 Ice Thickness (m): 20160929



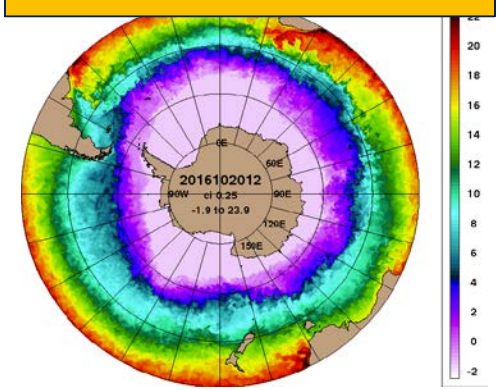
GOFS 3.1 Ice Concentration Valid 20161021



GOFS 3.1 Ice Thickness Valid 20161021



GOFS 3.1 Sea Surface Temp Valid 20161021



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Assimilating ice observations

- *Since the late 1990's, DMSP SSMI and then SSMIS ice concentration (~25km) have been assimilated in the Navy's ice forecast systems*
- *Since Feb 2015, implemented AMSR2 ice concentration into operational ACNFS and pre-operational GOFS 3.1*
- *NRL will be implementing VIIRS ice concentration into GOFS 3.1 by the end of calendar year 2017*
  - *Performed sensitivity tests assimilating new data source VIIRS ice concentration (NOAA – U of Wisconsin) in ACNFS for May – Sept 2016*

IMPORTANT:
For operational systems, observations must be available in near real-time (within 12 hrs).

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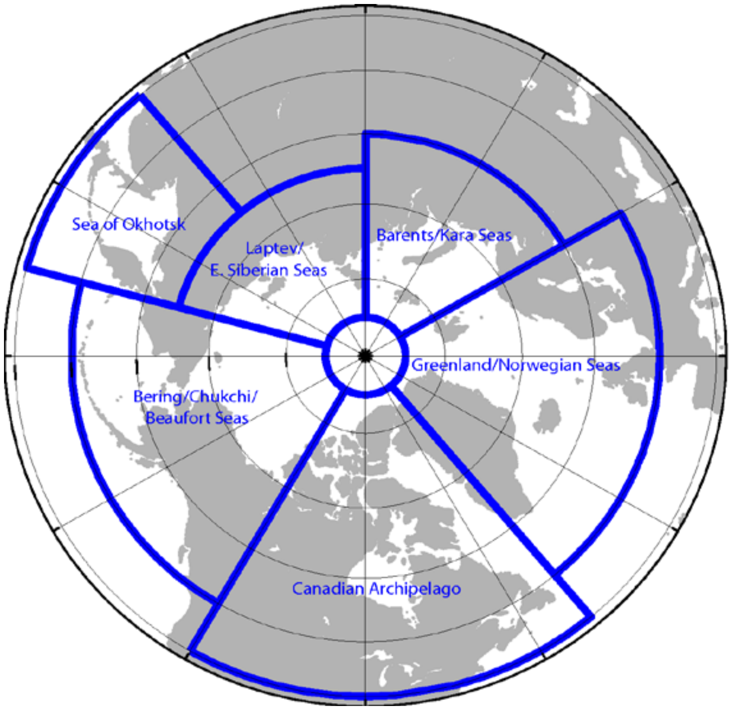
Ongoing Efforts:

Arctic ice validation analysis regions defined by the regional seas



Mean ice edge errors (km) between the observed ice edge and 6 hr ACNFS for the time period of May – Sept 2016

Region	Op ACNFS SSMI/AMSR2	ACNFS SSMI/AMSR2/VIIRS
Arctic	41 km	27 km
Greenland	38 km	26 km
Barents	34 km	24 km
Sea of O	31 km	23 km
Can Arch	54 km	31 km
Total improvement		34%

Improvement of 34% over current operational capability along the ice edge location

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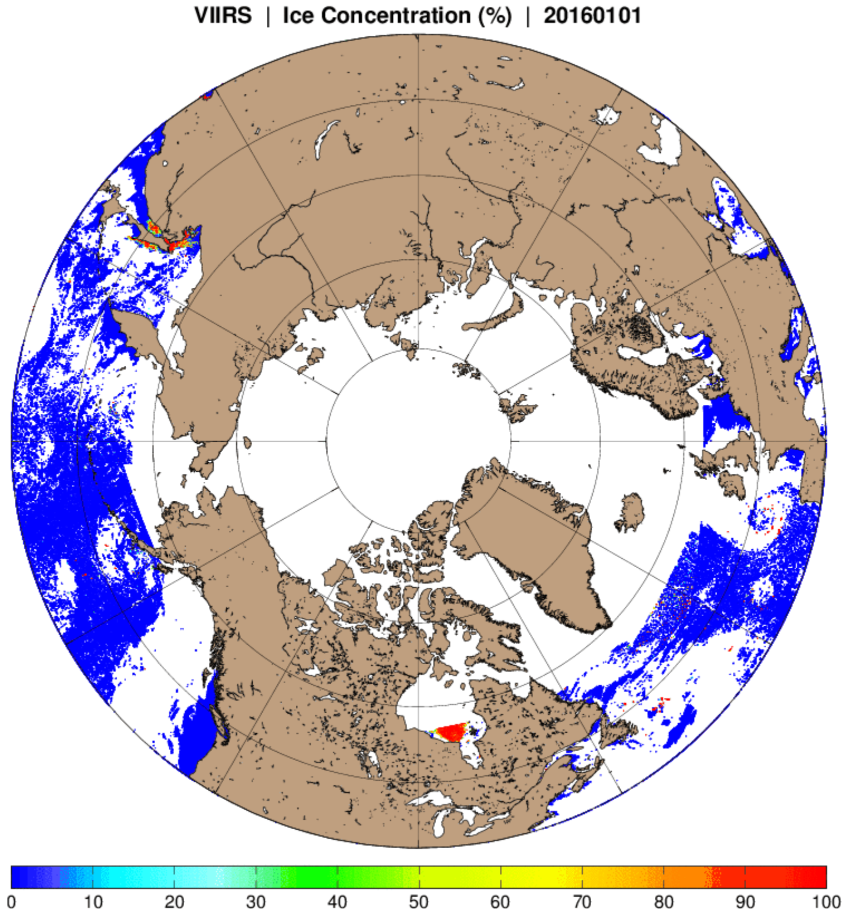
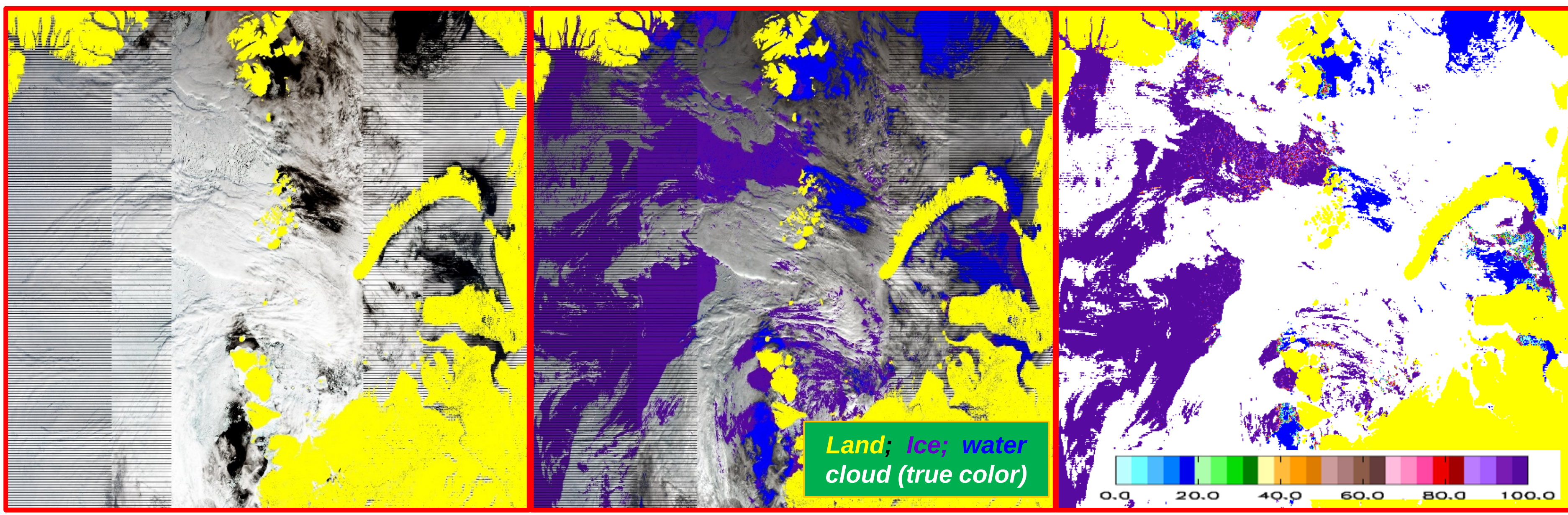
VIIRS Operational Satellite Sea Ice Concentration Algorithm

- *Adopted from the AMSR-E/MODIS algorithm to blend AMSR2/VIIRS sea ice data for data assimilation.*
- *VIIRS standalone algorithm doesn't require inputs data from AMSR2 and other VIIRS EDRs*
  - *Inputs: VIIRS visible & near IR data*
  - *Outputs: surface/cloud classification and sea ice concentration*
- *Daytime retrievals only*
- *Good coverage of Marginal Ice Zone*
- *Less affected by summer melt*



VIIRS Algorithm Procedure

1) *Surface classification at 375m resolution water/sea ice/snow-on-ice/cloud/land*
2) *Ice concentration is then calculated at a degraded 4km resolution to match the Arctic ice model resolution*
3) *Retrieval is performed on swath data then projected to the 4km EASE grid*



True Color | Surface Classification | Sea Ice Concentration

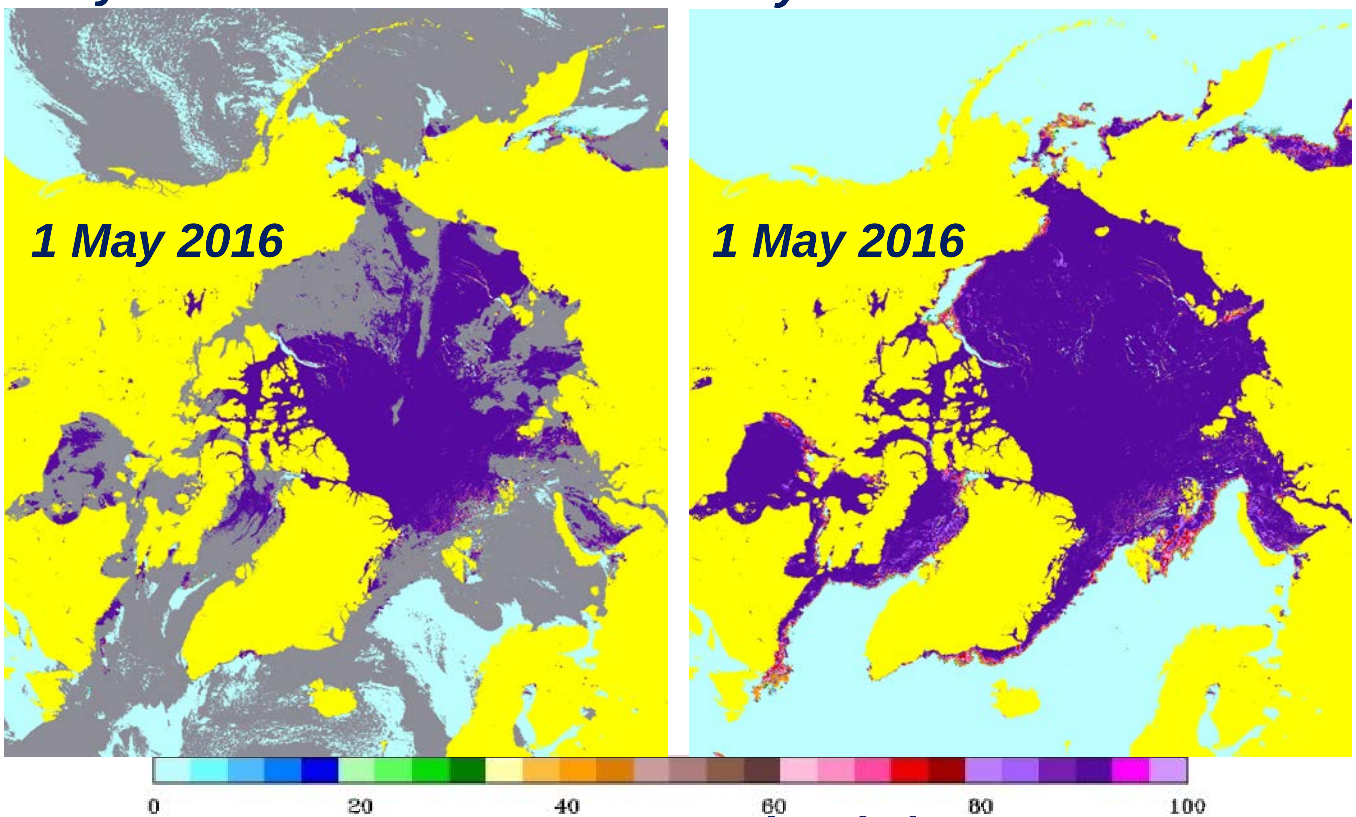
Blended AMSR2 and VIIRS Daily Sea Ice Concentration (SIC) Data

Combined AMSR2/VIIRS information provide the best resolution, accuracy and data coverage available.

Cloud & No Data

Clear Sky & No Ice

Daily VIIRS SIC | ***Daily AMSR2/VIIRS SIC data***



Ice Concentration (%)

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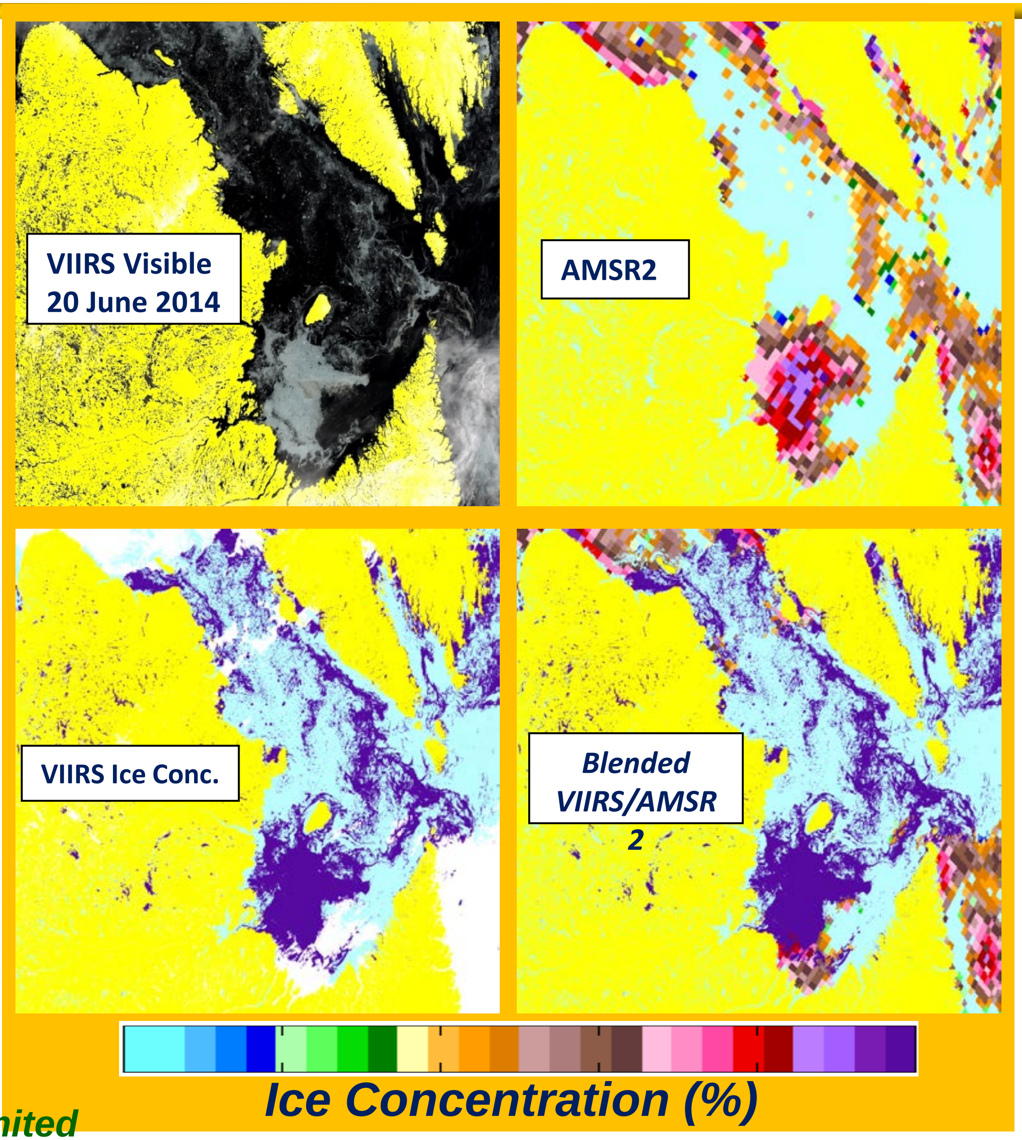
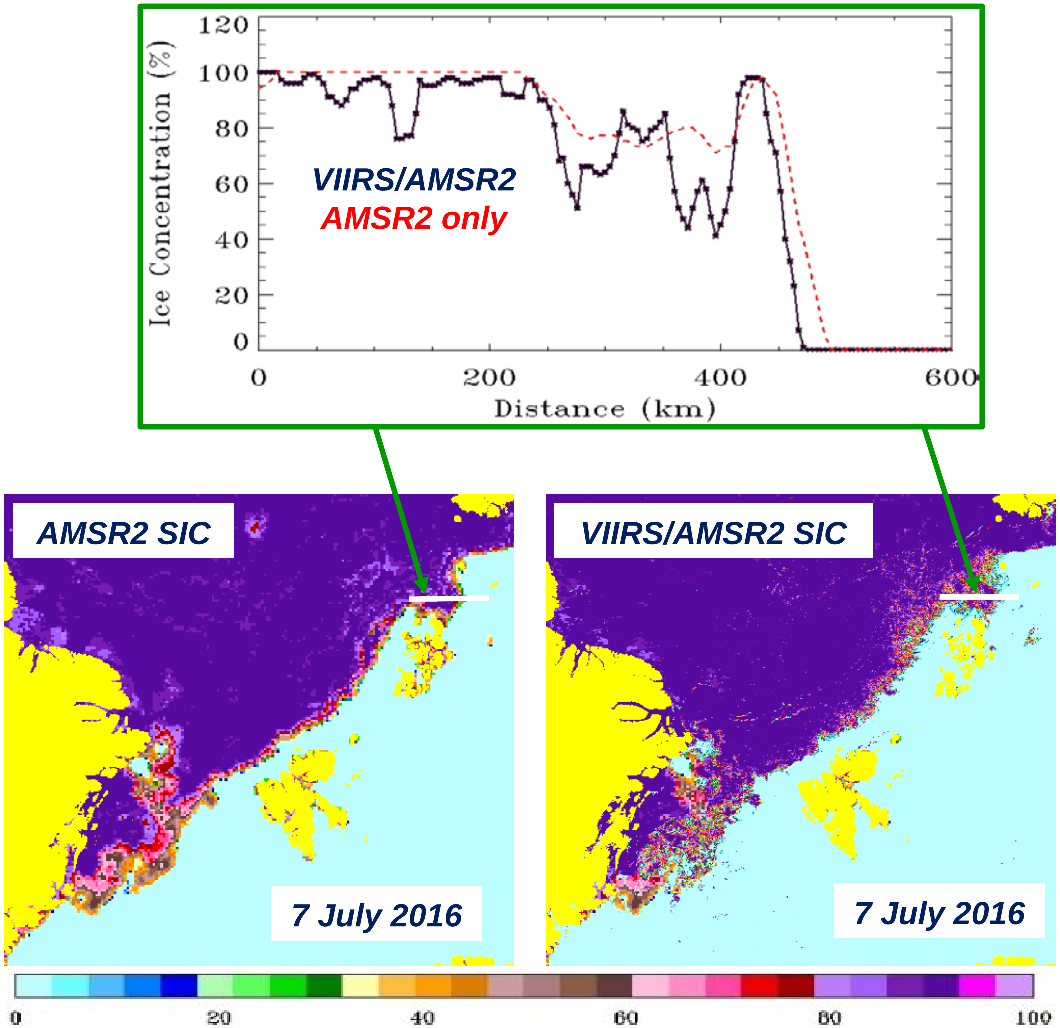
Blended AMSR2 and VIIRS Sea Ice Concentration Data in MIZ

- ***Better accuracy for the low ice concentration conditions in the MIZ for clear sky region***
- ***Better ice edge information than AMSR2 alone due to the improvements in data resolution***



Assimilation of the NPP VIIRS Sea Ice Concentration (SIC) Data for Arctic forecasts

Sea ice concentration observations



Mean ice edge errors (km) between the observed and forecasts

Region	Assimilation without VIIRS data	Assimilation including VIIRS data
Pan-Arctic	45.8	33.4
Greenland	43.8	34.6
Barents	37.7	25.3
Laptev	64.8	51.6
Sea of Okhotsk	40.1	35.8
Bering/Beaufort	43.0	35.6
Canadian Arch	57.6	33.3

- ***Average errors for the time period of Jan – Dec 2016.***
- ***Adding VIIRS SIC products into the operational sea ice forecast reduces ice edge error by an average of 25%***

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NAVOCEANO Operational Sea Ice data for ACNFS/GOFS Assimilation

Current

- JAXA AMSR2 Ice Concentration
- FNMOC SSMIS Ice Concentration
- NIC 4km IMS

FY18

- NAVO NPP VIIRS Ice Concentration
- NAVO AMSR2 Ice Concentration
- FNMOC SSMIS Ice Concentration
- NIC 4km IMS

FY19

- NAVO NPP VIIRS Ice Concentration
- NAVO J-1 VIIRS Ice Concentration
- NAVO AMSR2 Ice Concentration
- FNMOC SSMIS Ice Concentration
- NIC 4km IMS
- NIC Ice concentration
- Ice Thickness

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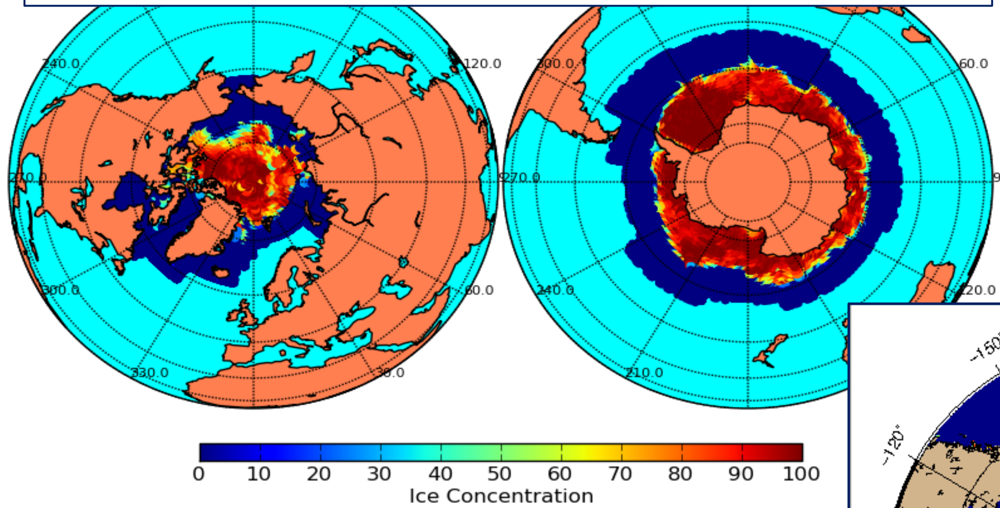
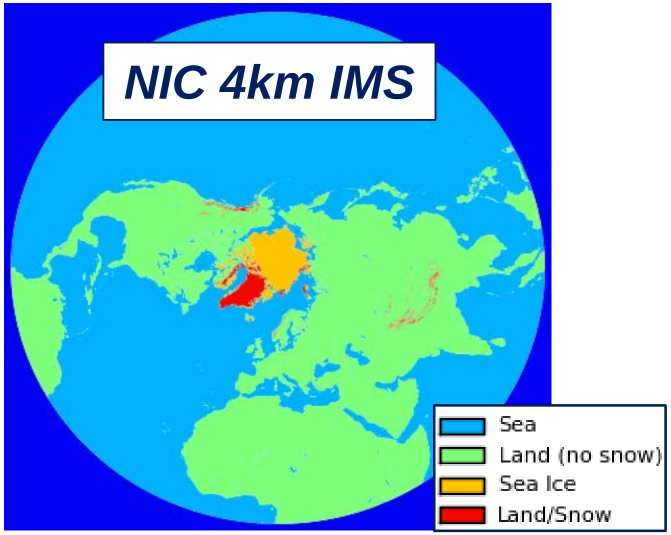
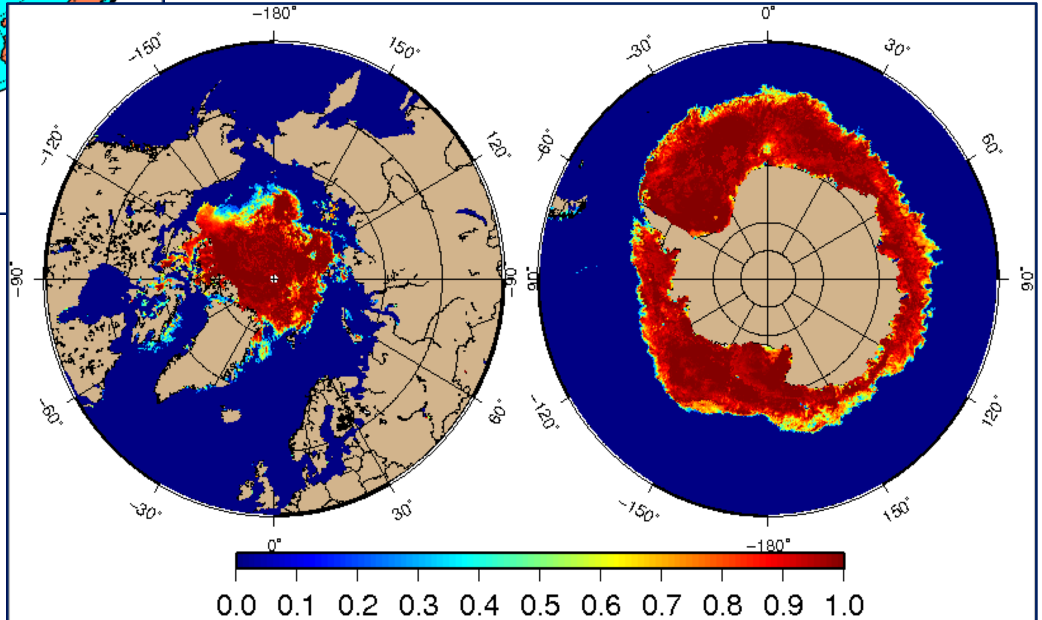
NAVOCEANO Operational Sea Ice data for ACNFS/GOFS Assimilation

FNMOC SSMIS F16/18 Ice Concentration



NIC 4km IMS





JAXA AMSR2 Ice Fraction

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Questions ?

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NRL-DC Li.Li@nrl.navy.mil
NRL-SSC Pamela.Posey@nrlssc.navy.mil

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