Validated Stage 1 Science Maturity Readiness Review for Sea Ice Characterization

Presented by Jeff Key
Cryosphere Products Validation Team

September 4, 2014

Outline

- Algorithm Cal/Val Team Members
- Product Requirements
- Evaluation of algorithm performance to specification requirements
  - Evaluation of the effect of required algorithm inputs
  - Quality flag analysis/validation
  - Error Budget
- Documentation
- Identification of Processing Environment
- Users & User Feedback
- Conclusion
- Path Forward

Cryosphere Team Membership

EDR	Name	Organization
Lead	Jeff Key	NESDIS/STAR
Co-Lead	Pablo Clemente-Colón	NESDIS/STAR and NIC
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Maryland:		
Snow	Peter Romanov	CREST/CCNY
Snow	Igor Appel	IMSG
Colorado:		
Ice	Mark Tschudi	U. Colorado
Ice	Dan Baldwin	U. Colorado
Other:		
All	Paul Meade	DPE

Overview of Data Products

1. Sea ice characterization - *Provisional*
   - Currently this is an age category: no ice, new/young ice, other ice
2. Sea Ice concentration IP
   - Fractional coverage of ice in each pixel
3. Ice surface temperature (IST) – *Val 1*
   - Radiating temperature of the surface (ice with or without snow)
4. Snow cover

   4a. Binary snow cover – *Val 1*

   4b. Fractional snow cover – *Provisional*

Notes:

- Information on ice and snow cover is needed by other EDRs.
- AMSR2 on GCOM-W1 will be used to generate other snow and ice products: Ice Characterization, Snow Cover, Snow Depth, and Snow Water Equivalent (SWE).

SNPP Validation Stages Maturity Definition

Validated Stage 1:

Using a limited set of samples, the algorithm output is shown to meet the threshold performance attributes identified in the JPSS Level 1 Requirements Supplement with the exception of the S-NPP Performance Exclusions

Validated Stage 2:

Using a moderate set of samples, the algorithm output is shown to meet the threshold performance attributes identified in the JPSS Level 1 Requirements Supplement with the exception of the S-NPP Performance Exclusions

Validated Stage 3:

Using a large set of samples representing global conditions over four seasons, the algorithm output is shown to meet the threshold performance attributes identified in the JPSS Level 1 Requirements Supplement with the exception of the S-NPP Performance Exclusions

Sea Ice Characterization EDR L1RD Requirements

Sea Ice Characterization Requirements from L1RD version 2.9

Note that because the percentage of N/Y ice is, on the annual average, very small, the 70% probability of correct typing of both types together could be met by simply labeling all ice pixels as “Other Ice”!

	24 hours (monthly average)	
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

Evaluation of algorithm performance to specification requirements (3-5 slides)

- Findings/Issues from Provisional Review:
  - "VIIRS Sea Ice Characterization EDR has met the provisional maturity stage based on the definitions and the evidence shown
  - Some issues have been uncovered during validation and solutions are being evaluated." (Specific issues are too numerous to list here but are in the additional slides.)
- Improvements since Provisional
  - A number of improvements have been made to the VIIRS Cloud Mask (by the Cloud Team) and to snow/ice gridding, which have resulted in improvements to SIC.
  - However, no changes have been made to the SIC algorithm. In-depth testing and analysis has not resulted in any solutions.
- Cal/Val Activities for evaluating algorithm performance:
  - See the following slides…

Summary of VIIRS Sea Ice Characterization EDR

- The VIIRS Sea Characterization EDR (Ice Age) consists of ice classifications for *Ice Free*, *New/Young* and *Other Ice* at VIIRS moderate spatial resolution (750m @ nadir), for both day and night, over oceans poleward of 36^{o}N and 50^{o}S latitude.

- New or Young ice is discriminated from thicker ice (Other Ice) by a threshold ice thickness of 30 cm. Discrimination of New/Young ice from thicker ice is achieved by two algorithms:

  1. Energy (heat) balance based retrieval for night and high solar zenith angles
  2. Reflectance/ice thickness retrieval using modeled Sea Ice Reflectance LUT for daytime

- Heritage: No operational visible/IR heritage. AVHRR research heritage (Comiso and Massom 1994, Yu and Rothrock 1996 and Wang et al. 2010)

Summary of VIIRS Sea Characterization EDR (Ice Age) Algorithm Overview

Reflectance Threshold Branch (Day Region Algorithm)

- Input ice tie point reflectance (I1, I2), VCM IP, AOT IP
- Input granulated NCEP gridded precipitable water, total ozone fields
- Obtain snow depth for each ice thickness bin obtained from climatology modeled snow depth/ice thickness LUT
- Retrieve ice thickness from sea ice reflectance LUT using ice tie point reflectances, modeled snow depth, AOT, precip. water and solar and satellite view geometry
- Classify by comparing retrieved ice thickness to 30 cm ice thickness threshold

Energy Balance Branch (Terminator and Night Region Algorithm)

- Input Ice Temperature Tie Point IP
- Input granulated NCEP gridded surface fields (sfc.P, sfc air temp, specific hum. etc…)
- Compute snow depth for 30cm ice thickness threshold from heat/energy balance
- Classify by comparing computed and climatology LUT snow accumulation for a 30 cm ice thickness threshold

The Snow-Depth-Ice Thickness Climatology LUT contains:

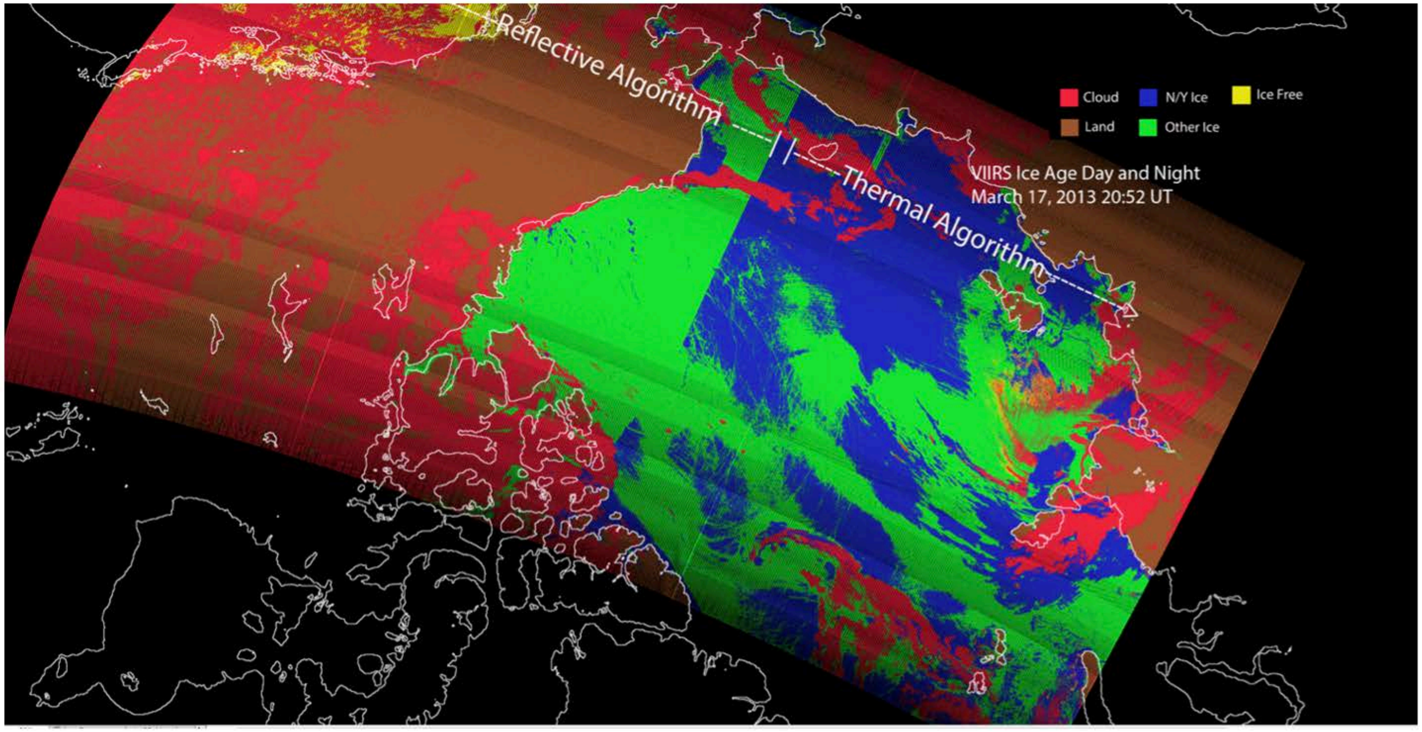
- predicted snow accumulation depths for modeled ice thickness threshold growth times based on monthly climatology surface air temperatures and precipitation rates

Performance Evaluation of the VIIRS Sea Ice Characterization EDR (Ice Age) Algorithm

- Detailed analysis of 20 Arctic scenes including four seasons: July 2012, March – May 2013, December 2013, and April 2014
- Golden granule: March 17, 2013
  - Examined performance of daytime, nighttime and terminator (transition) areas
- Comparisons to other products:
  - VIIRS SDR reflectance
  - NOAA IMS ice extent
  - CU ice age
  - One-dimensional Thermodynamic Ice Model (OTIM)
  - Airborne ice thickness
    - IceBridge ice thickness
    - Airborne EM & Lidar

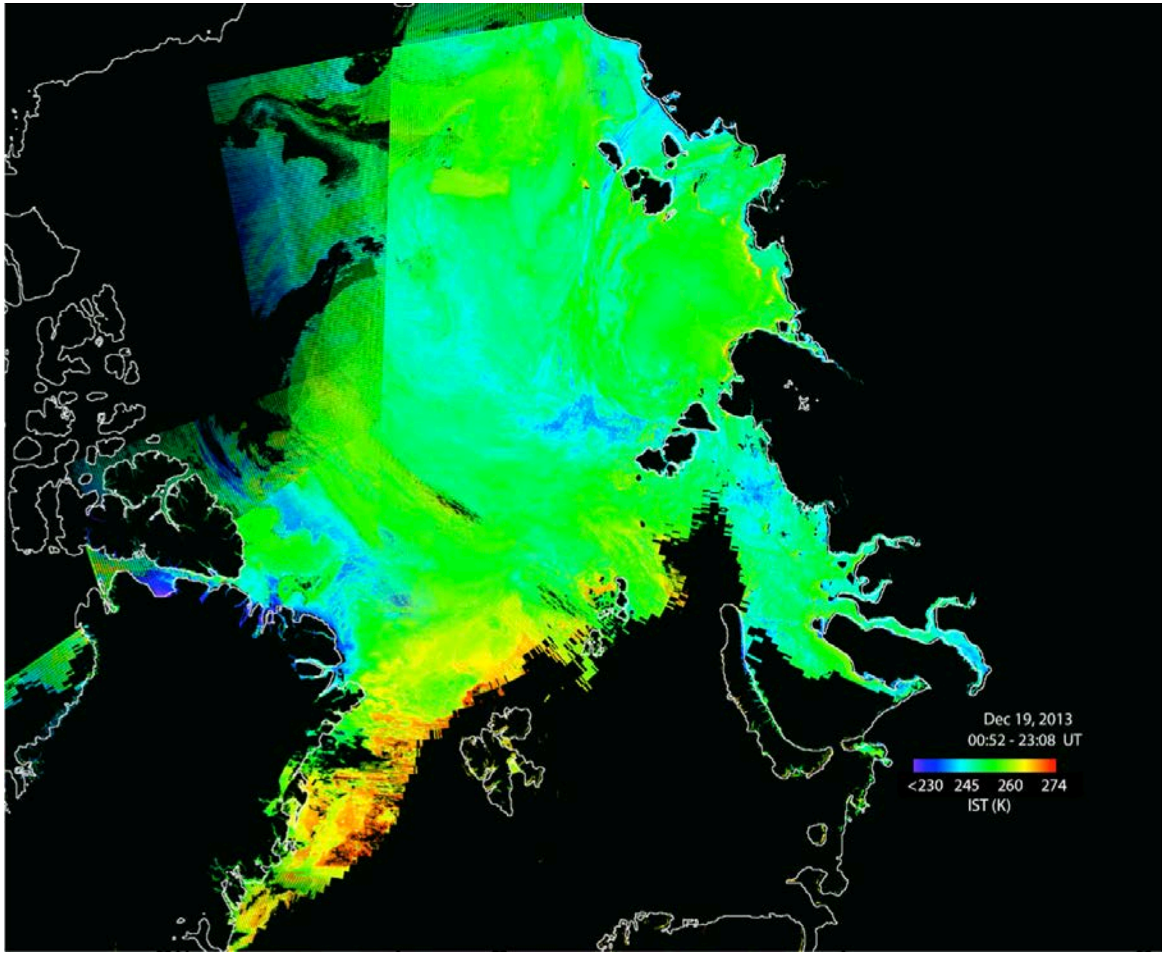
Assessment of the Sea Ice Characterization EDR

Summary: There are times when performance is good, and other times (too many) when performance is not good. Overall, it does not appear to be meeting the accuracy requirements. This is a complex algorithm where improvements would be required in a number of components.

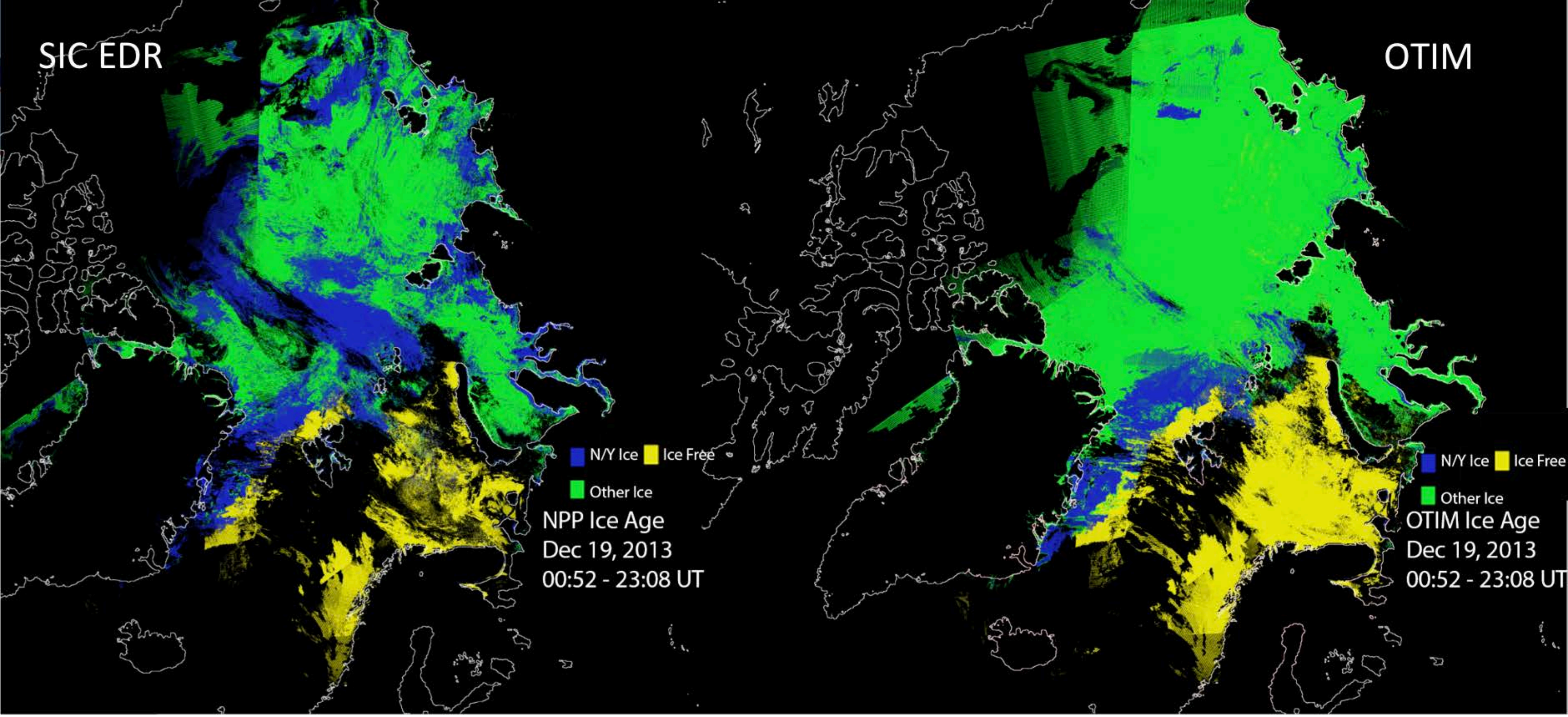


March 17, 2013 20:52 UTC scene (above) shows a broad region of Other Ice (green) misclassified as New Young ice (blue) in the terminator region **where the algorithm transitioned from the reflective algorithm (left half) to the thermal heat balance branch (right half)**

Case Study: December 2013

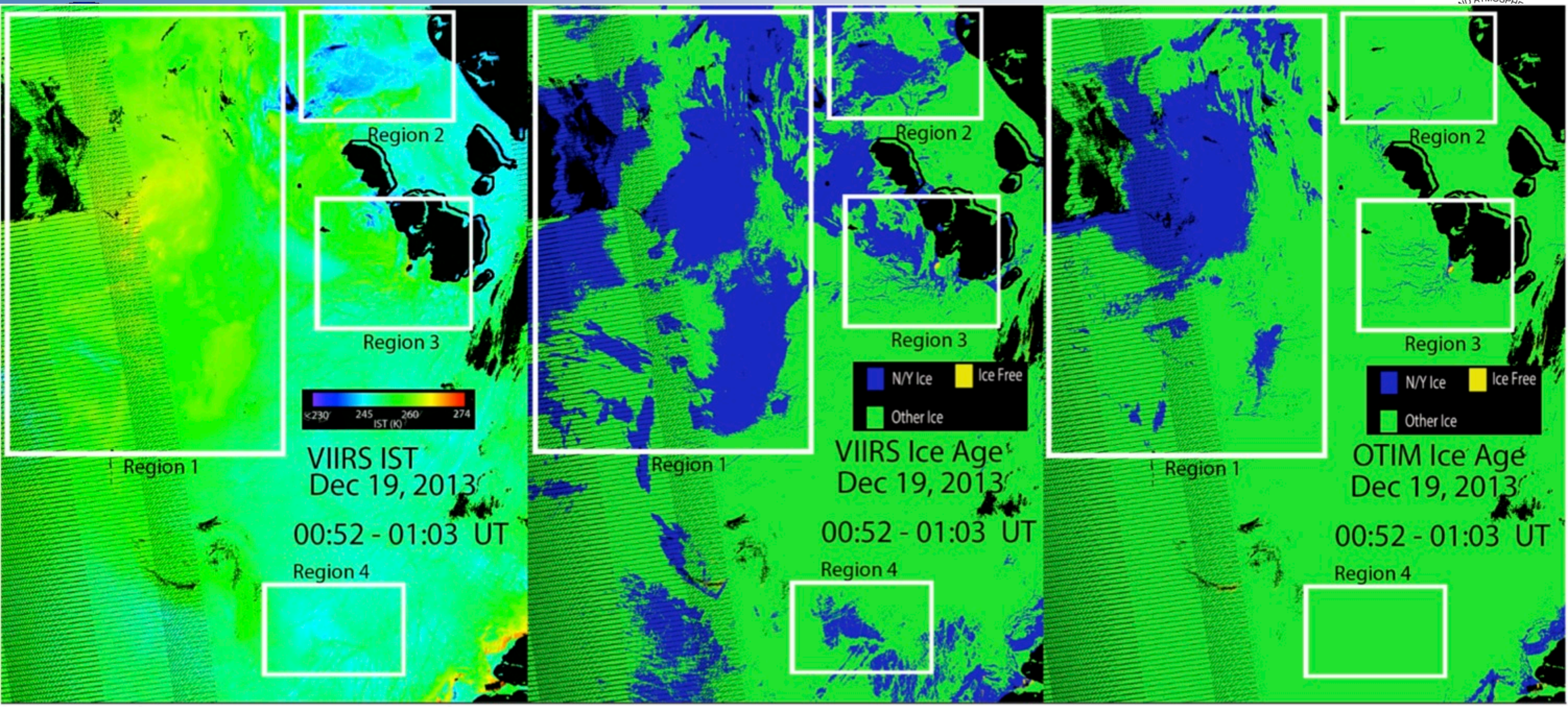


VIIRS Ice Surface Temperature composite on Dec 19, 2013. Note warmer temperatures in the Greenland Sea, extending north. We would expect thinner ice here (it's December, so no melting), hence "New/Young" ice should be most prevalent in this region.



The VIIRS Sea Ice Characterization EDR nighttime algorithm composite (left) and the OTIM* algorithm (right). Note that OTIM calculates sea ice thickness – here the thickness is binned into either “New/Young” (NY) ice for ice <= 30 cm, or “Other Ice” for thickness > 30 cm, to match the classification for Ice Age. Both the VIIRS and OTIM algorithms identify the thin ice near Greenland, but overall VIIRS appears to over-estimate NY ice, while OTIM appears to underestimate it.

*OTIM (One-dimensional Thermodynamic Ice Model) was developed for GOES-R ABI and will run in NDE on VIIRS data.

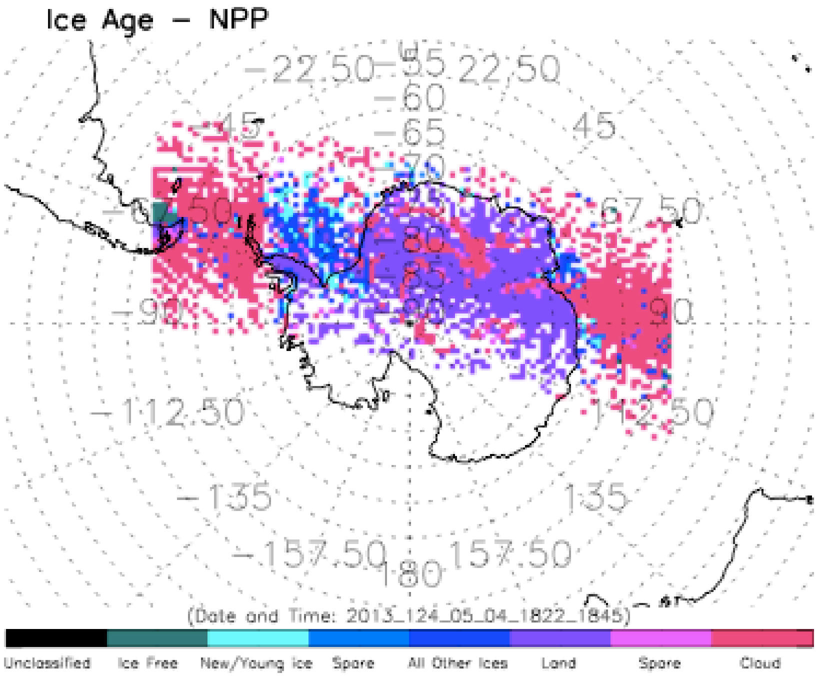


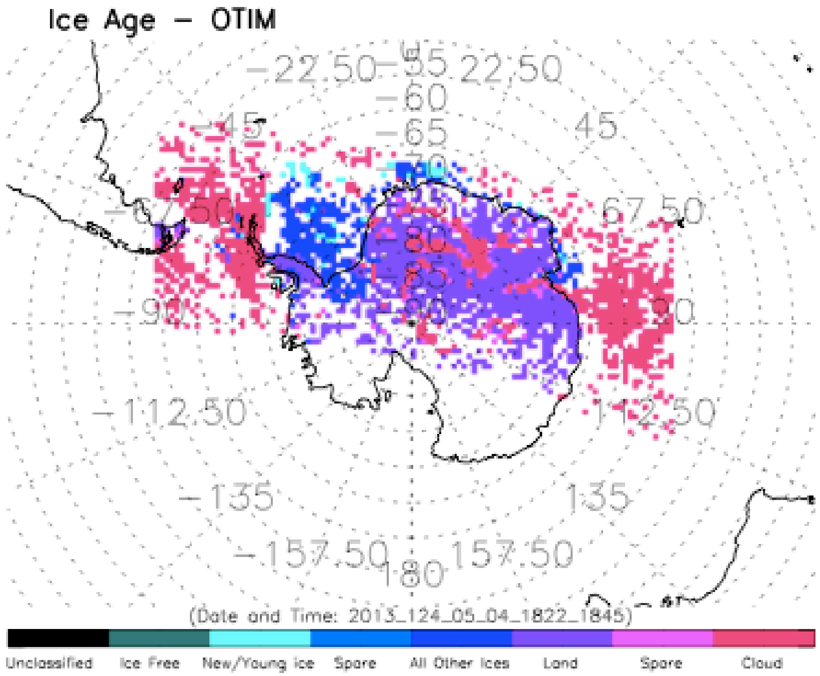
Now we zoom into the Laptev / East Siberian Seas for a single overpass.

Region 1: VIIRS ice age nighttime algorithm appears to overestimate N/Y ice; OTIM classification appears to be more accurate
Region 2: VIIRS algorithm misclassifies cold pixels as N/Y ice, OTIM does not
Region 3: OTIM estimates much less N/Y ice than the VIIRS algorithm
Region 4: VIIRS algorithm misclassifies N/Y ice, OTIM appears to be more accurate

Ice Thickness and Age
IDPS and NDE (OTIM) Comparison

Sea ice age categories from VIIRS sea ice age classification (left) and OTIM ice thickness converted to the same categories (right) on May 4, 2013 over the Arctic.





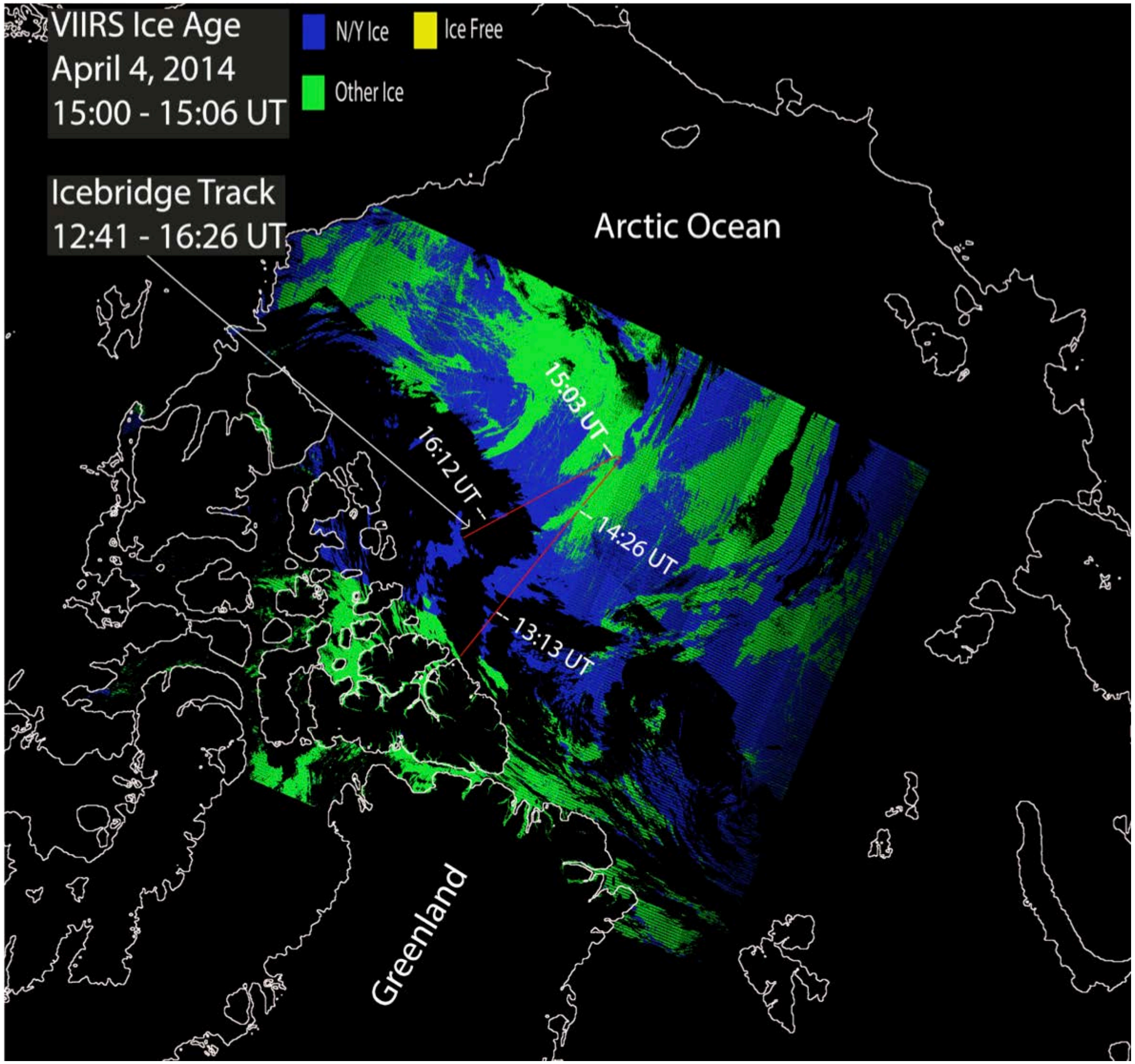
Ice Thickness and Age
IDPS and NDE (OTIM) Comparison

Statistics for figure on previous slide:

Percentage in each ice age category from VIIRS and OTIM for May 4, 2013 case.

Categories	VIIRS ice age	OTIM ice age	Difference (VIIRS-OTIM)
Day and night time:			
Ice free	13	24	-11
New/Young ice	52	9	43
Other ice	35	67	-32
Daytime:			
Ice free	27	50	-23
New/Young ice	53	3	50
Other ice	20	47	-27
Nighttime:			
Ice free	10	20	-10
New/Young ice	52	10	42
Other ice	38	70	-32

Validation with IceBridge



For some NASA IceBridge Arctic flights, sea ice thickness was estimated from lidar (ice freeboard) and radar (snow depth) (NSIDC: *Kurtz et al., 2012, updated 2014)*

- *IceBridge thickness compared to correct typing of SIC EDR New/Young Ice (<30cm) and Other Ice (>30cm)*
- *April 4, 2014 (shown at left):*
  - *2307 total pixels*
  - *19% N/Y pixels correct*
  - *2% N/Y incorrect*
  - *18% Other correct*
  - *60% Other incorrect*
- *March 17, 2014:*
  - *13535 total pixels*
  - *<1% N/Y correct*
  - *1% N/Y incorrect*
  - *96% Other correct*
  - *4% Other incorrect*

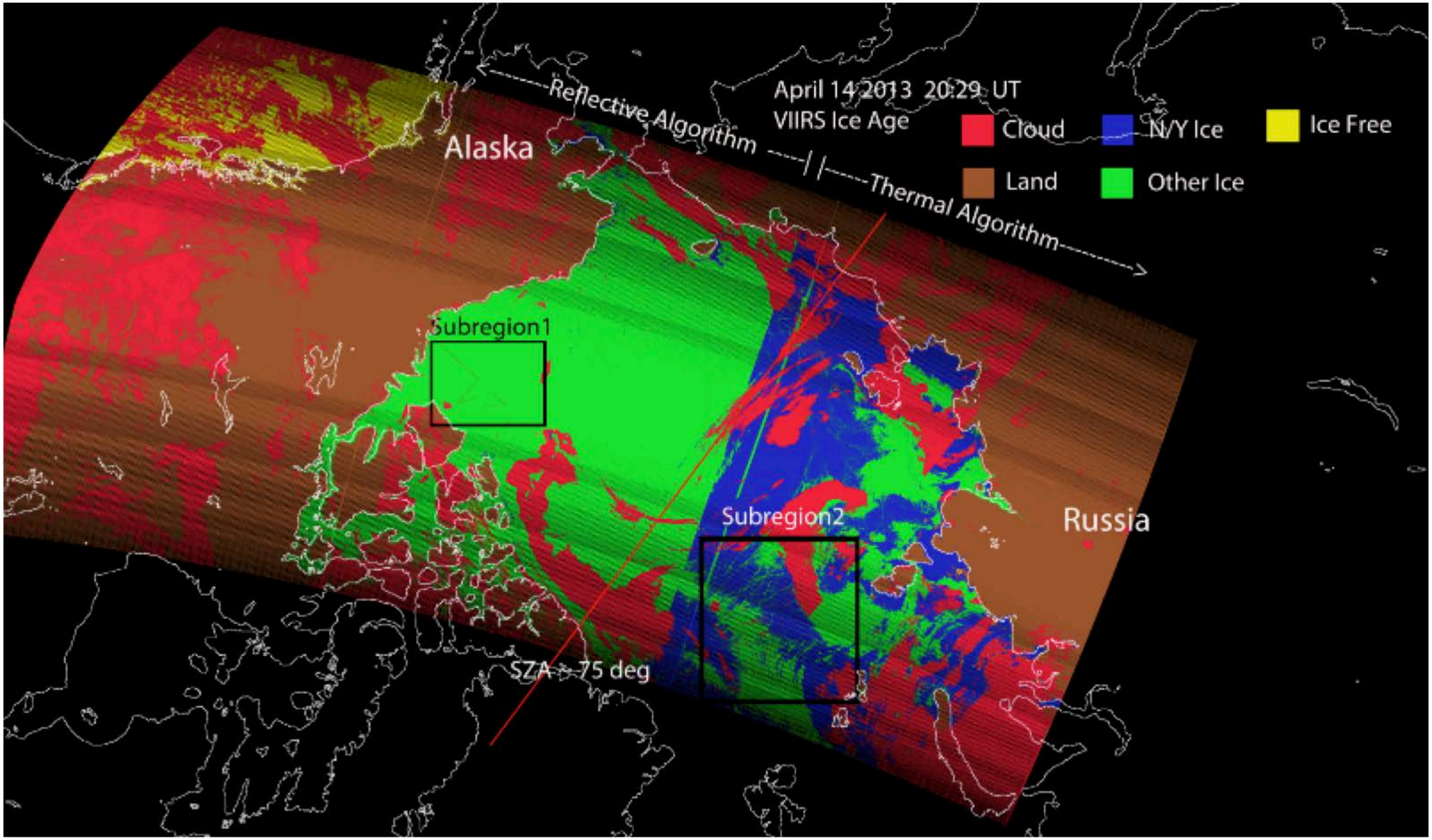
Validation with IceBridge

All ice is "Other" ice in this case

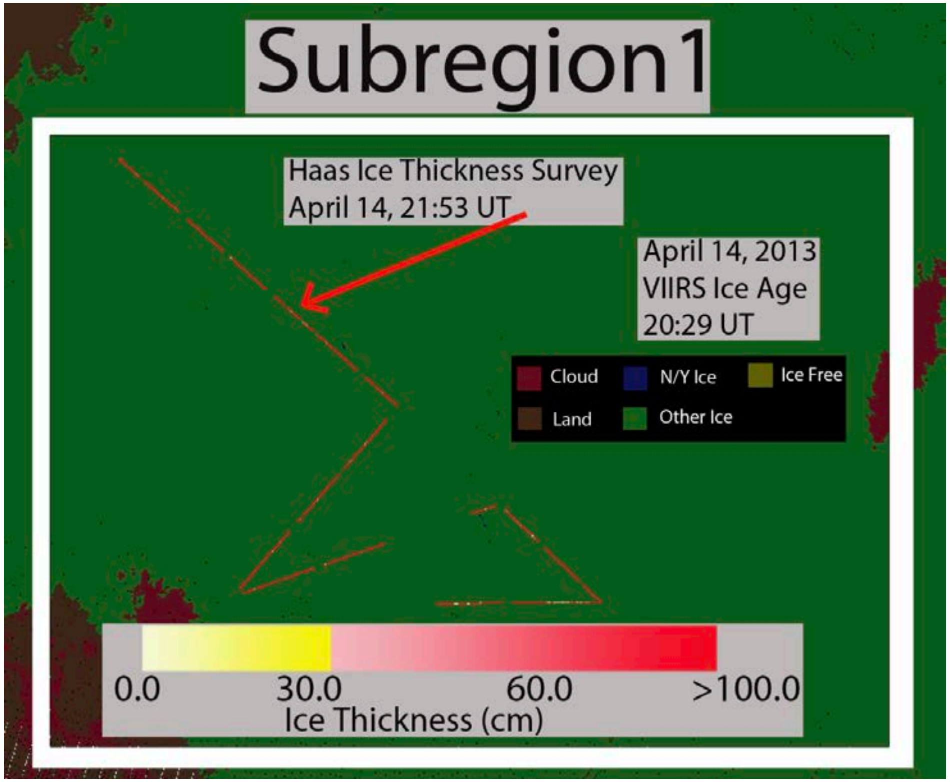
- SIC EDR, daytime algorithm
- Classification accuracy for 1155 pixels = 76%

IceBridge Ice Thickness
[*Kurtz et al,* 2012]

Validation with EM & Lidar



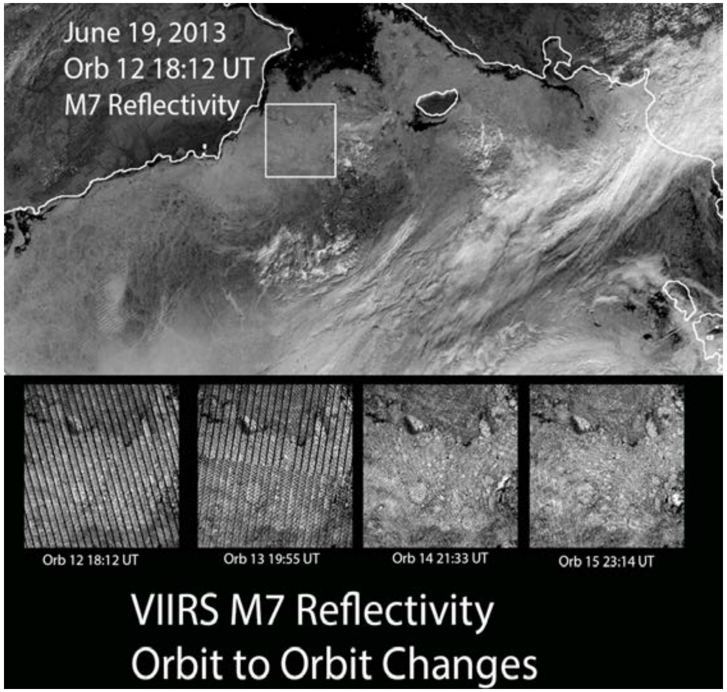
Validation with EM & Lidar

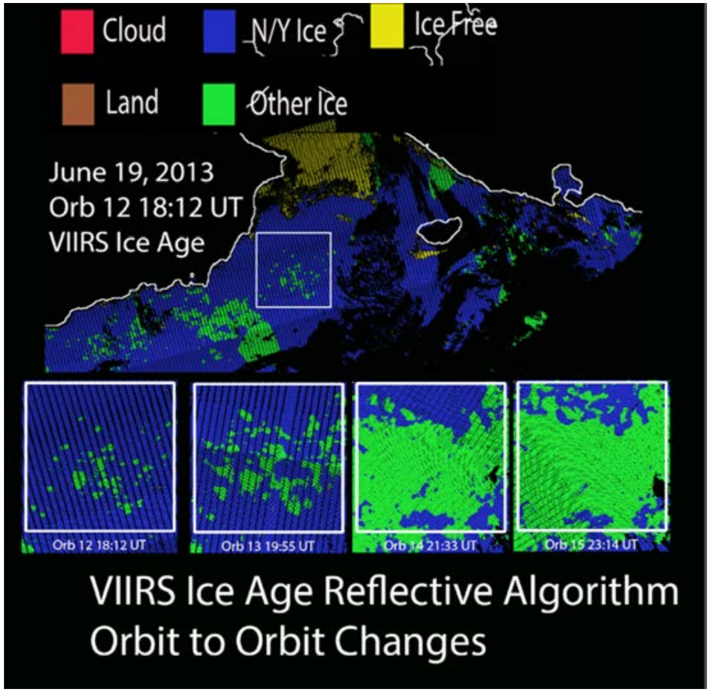


Thickness (cm) courtesy of C. Haas: Airborne EM & Lidar

- All ice for VIIRS SIC EDR is “other ice” (> 30 cm)
- 1004 airborne data points: 99% > 30 cm (in agreement with VIIRS SIC EDR)

Other issues: Orbit-to-Orbit Classification Variability

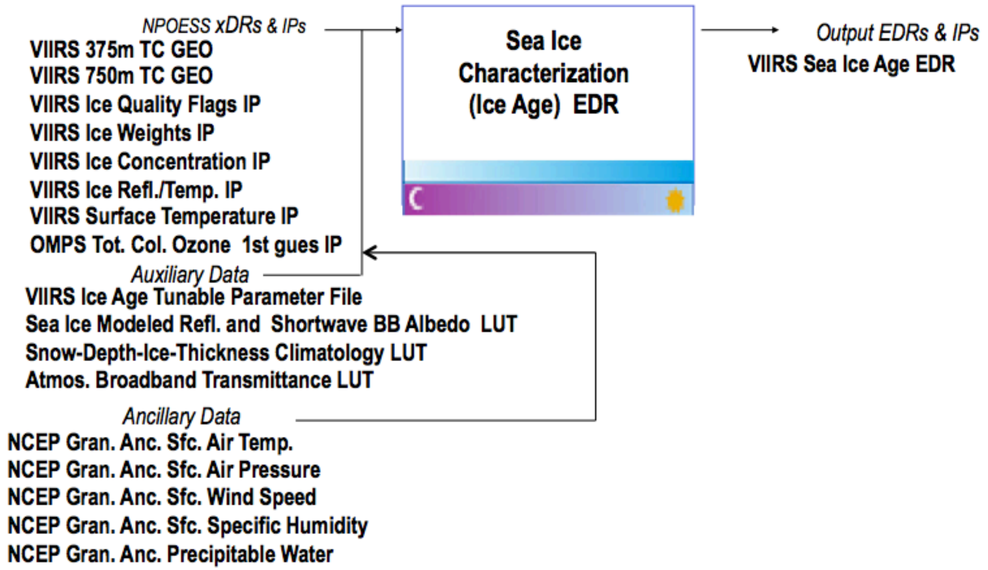




Note: This is with the daytime algorithm. The problem has been observed on multiple days.

Evaluation of the effect of required algorithm inputs

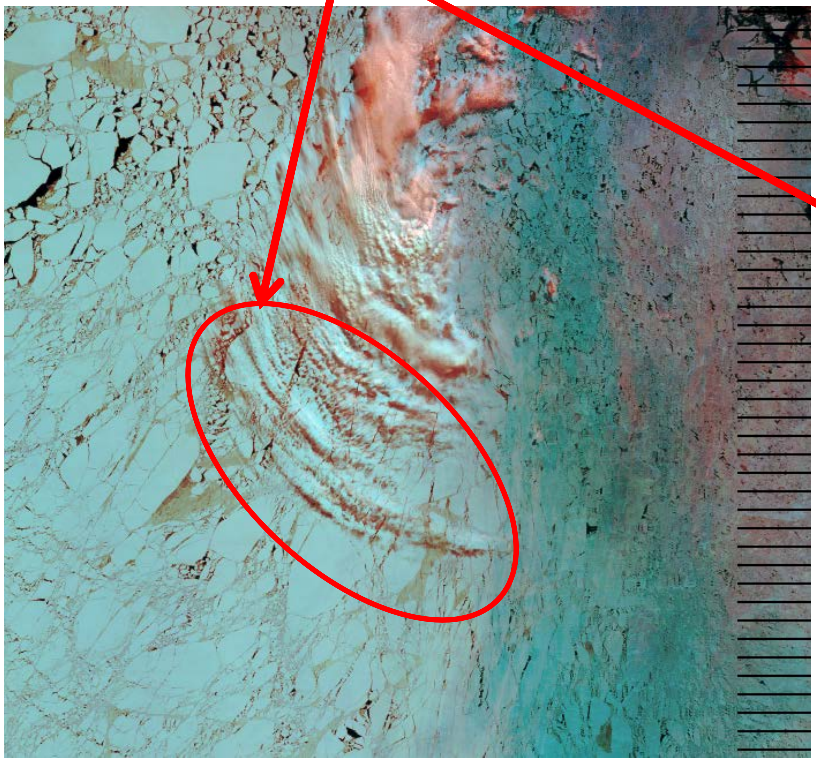
- Required Algorithm Inputs
  - Ice Reflectance/Temperature IP, Ice Quality Flags IP, AOT IP
  - Granulated ancillary surface wind speed, surface air pressure, surface air temperature and surface air specific humidity
  - Modeled Snow Depth/Sea Ice Climatology LUT, modeled sea ice reflectance LUT, sea ice spectral albedo and broadband albedo LUTs, atmospheric transmittance LUT Ancillary Data

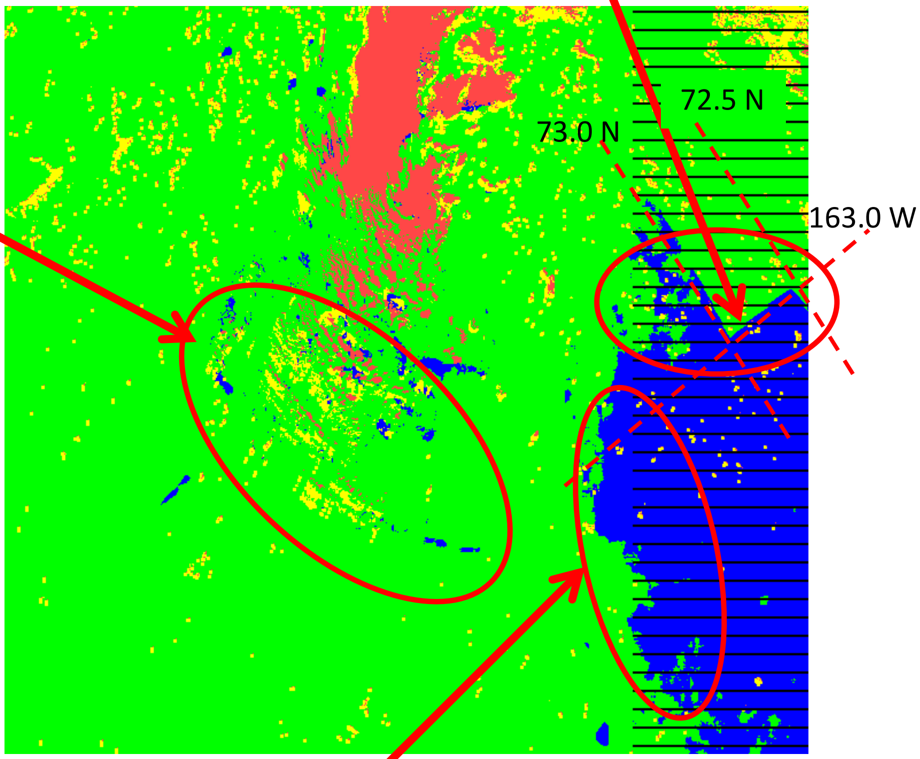


Impact of Errors in Inputs

Some misclassification evident due to VCM IP cloud leakage and cloud shadows

Discontinuities detected along lat/lon boundaries spaced 0.5 deg.





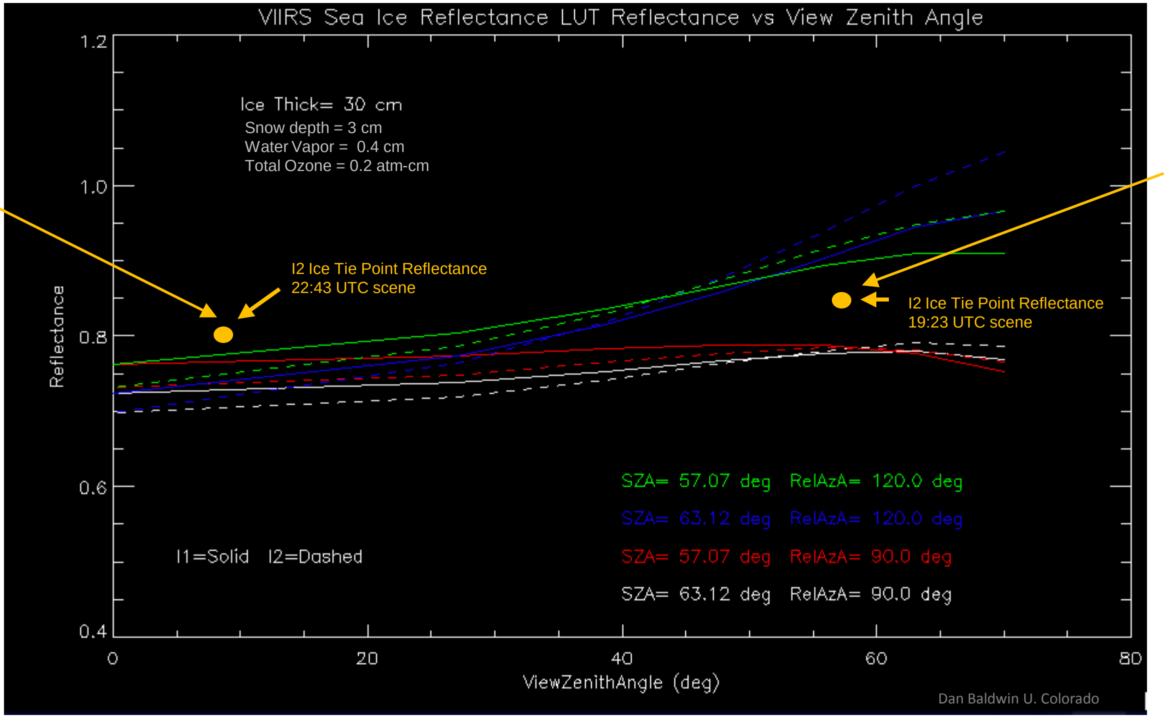
Large region misclassified where ice tie point reflectance values drop below ~ 0.53

Several discontinuities that align along 0.5 steps of latitude and longitude are evident as shown along the black dashed lines. The reflectance based day algorithm has dependencies on the coarse resolution NCEP ancillary fields for precipitable water and total column ozone. In addition the algorithm also has a dependency on the climatological snow depth/ice thickness LUT (modeled using 2.5 deg. surface air and precipitation rate climatology data) . The 0.5 deg are strongly suggestive of sensitivity to the NCEP precipitable water field. (Data from June 8, 2012)

Daytime Ice Age Dependency Reflectance LUT

Examination of the Modeled Sea Ice TOA Reflectance LUT:

I2 ice tie point reflectance for 22:43 UTC orbit for low value of sensor zenith is above that of the corresponding modeled Sea Ice Reflectance LUT.



I2 ice tie point reflectance for 19:23 UTC orbit for high value of sensor zenith is below that of the corresponding modeled Sea Ice Reflectance LUT.

VIIRS I1 (640 nm) and I2 (865 nm) band reflectances extracted from the Modeled Sea Ice Reflectance LUT are shown as function of satellite view zenith angle for two solar zenith angle and relative azimuth bins that bound the scene conditions. The fact that the I2 band modeled reflectances are greater than that of the I1 band reflectances is unexpected since the spectral albedo of snow decreases with increasing wavelength beyond about 0.5 µm.

Evaluation of Cloud and Ice Quality Flags

SIC EDR is compared to MODIS over sea ice during the melt period, when only "other ice" is expected.

Beaufort Sea, July 23, 2012

NOTE BOTTOM ROW

ALLCLD=No Cloud Cover Quality Flag Filter
ALLQUAL=No Ice Quality Flag Filter
CNFCLR=Only Pixels with Confidently Clear Cloud Cover Flag
GOOD=Only pixels with Good Ice Quality Flag

	ALLCLD ALLQUAL #1	ALLCLD GOOD #2	CNFCLR ALLQUAL #3	CNFCLR GOOD #4
MODIS Ice Pix	63252	27889	40190	27889
VIIRS Ice Pix	45136	32458	33368	32458
VIIRS New/Young Ice Pix	42708 (94.6%)	31867 (98.2%)	32485 (97.4%)	31867 (98.2%)
VIIRS Other Ice Pix	2428 (5.4%)	591 (1.8%)	883 (2.6%)	591 (1.8%)
Ice Agree	30695 (48.5%)	27608 (99.0%)	27902 (69.4%)	27608 (99.0%)
MODIS Ice Free Pix	83064	59067	62080	59067
VIIRS Ice Free Pix	109187	61632	80778	61632
Ice Free Agree	74192 (89.3%)	58511 (99.1%)	61479 (99.0%)	58511 (99.1%)
MODIS ICE VIIRS Cloud	15599	N/A	N/A	N/A
MODIS Ice VIIRS Free	16958	281	12288	281
Ice Type Classification Accuracy*	5.4%	1.8%	2.6%	1.8%

** note: all pixels with good ice quality are confidently clear, so columns 2 & 4 are identical.*

Error Budget

Attribute Analyzed	L1RD Threshold	Analysis/Validation Result	Error Summary
SIC uncertainty (probability of correct typing)	70%	Comparison with MODIS ice extent: 2-5% correct typing	Beaufort Sea Melt season – depressed reflectance due to melt affects daytime algorithm
SIC uncertainty (probability of correct typing)	70%	Comparison with Airborne Lidar & EM: 99% correct	Beaufort Sea Spring - Almost all ice was measured thicker than 30cm and classified as "other"
SIC uncertainty (probability of correct typing)	70%	Comparison with IceBridge derived thickness: 4/14/14: 37% correct 3/17/14: 97% correct	Beaufort Sea: April 4 had 20% ice <30cm, March 17 had almost no ice < 30 cm
SUMMARY: SIC probability of correct typing	70%	2 – 99%, with case study results uniformly distributed in this range	(1) Validation data are limited. (2) Lowest accuracies occur during melt.

Evaluation Summary

- The Sea Ice Characterization EDR does meet the requirement for some sample, but does not meet the requirement overall.
- Misclassification of ice age was observed to occur for the following categories of conditions:
  - Day regions:
    - Bias towards misclassification of Other Ice as NY in regions with 1) large values of climatological snow depth, 2) high satellite view zenith angle and regions with 3) low reflectance due to melting ice and 4) cloud shadows
  - Night regions
    - Reversals of ice age classification
  - Terminator regions
    - Frequent, broad misclassification of Other Ice as NY and reversals of classification
    - Ice classification discontinuities are most evident and frequent where the algorithm transitions from the day reflectance based algorithm to the night energy balance based algorithm

Potential Solutions for Known Issues

Issue	Description	Proposed Solution
Day Region Ice Age Misclassifications	Daytime algorithm shows a bias towards N/Y ice for higher scattering angles	Update Modeled TOA Sea Ice Reflectance LUT to eliminate bias (reconstruct LUT based on CASIO/DISORT Snow/Ice BRDFs and coupled sea/ice/atmosphere RTM)
Night Region Ice Age Classification Reversals	Nighttime algorithm shows numerous classification reversals	Investigate tie point calculation in area of misclassification; investigate energy balance
Terminator Region Ice Age Misclassifications	Frequent misclassification of ice for broad regions, major discontinuities where algorithm transitions from day reflectance based to night energy balance algorithm, frequent reversal of ice classification	Update night algorithm to use a local sliding IST window; investigate energy balance and solar flux term
Climatology Modeled Snow Accumulation/Ice Thickness LUT	Snow depth thresholds based on the monthly, climatology based snow/depth ice thickness LUT are problematic	Investigate use of ancillary precipitation to derive snow depth and compute an ice thickness based on that snow depth. Dependence on the problematic SnowDepth/IceThickness Climatology LUT can then be eliminated.
False ice is frequently observed near cloud edges	False ice is frequently observed near cloud edges due to undetected clouds	Implement additional quality checks for extended cloud adjacency and partly cloudy conditions within the ice tie point search window in the Sea Ice Concentration IP

Known Issues and Potential Solutions, cont.

Issue	Description	Proposed Solution
Ice Age Misclassification due to low opacity clouds	Ice misclassifications occur due to low opacity clouds or ice fog, particularly during nighttime	Continued improvement of VCM to facilitate cloud vs. ice detection
Ice Age Misclassification due to melting ice	Lower reflectance of melting sea ice appears to cause the SIC EDR to indicate New/Young Ice, although this type of ice cannot be present this time of year.	Define and utilize melt season period where New/Young ice cannot exist. Could do this by date/latitude or possibly with IST or NCEP air temp input. During this time, ALL ice would be classified as "other ice."
Ice Age Misclassification due Cloud Shadows	Lower reflectance of cloud shadow regions cause SIC EDR to indicate New/Young even though surrounding ice is Other Ice	Continued improvement of VCM to extend cloud shadow algorithm and flagging. Add logic to Ice Age algorithm to check VCM cloud shadow flag cloud and set quality flag to indicate degraded Ice Age retrieval quality

While there are potential solutions to the issues that have been identified, there is no guarantee of the outcome should they be implemented. Furthermore, the loss of NGAS support has severely limited our ability to perform the necessary work.

Documentation

- Status of documentation:
  - Current or updated ATBD: *Up to date*
  - Current or updated OAD: *Up to date*
  - README file for CLASS: *Up to date*

Identification of Processing Environment

- IDPS or NDE build (version) number and effective date:
  - Validation results were from July 2012 through April 2014.
  - Mx6.6 (Feb 28, 2012) through 8.3 (March 18, 2014). Most validation results based on the EDR from builds 6.7 and 8.0.
  - Effective date: N/A; the product is not recommended for Validated Stage 1 maturity
- Algorithm version: 1.O.000.001 - 1.O.000.003
- LUTS:
  - VIIRS-SNOWDEPTH-THICKNESS-LUT: 1-D-NPP-1 (12/02/2009)
  - VIIRS-ATMOS-BROAD-TRANSMIT-LUT: 1-D-NPP-1 (11/10/2001) (This is the Broadband Albedo LUT)
  - ICE-REFLECTANCE-LUT: 1-D-NPP-1 (12/02/2009)
- Description of environment used to achieve val stage 1
  - The SIC EDR was obtained from CLASS.
  - Build dates are listed above.

User Feedback

From 2014 STAR JPSS Annual Meeting.

- Main users
  - NIC, National/Naval Ice Center
  - Naval Research Laboratory and NAVO
  - NWS, including the Alaska Ice Desk and NCEP/EMC
- Summary from the NIC: The VIIRS Ice Age Product will be used by NIC on a limited basis to map ice extent, but has no utility for ice age identification. Needs algorithm improvement to be apply Ice Age product in operational ice charting or NWP assimilation. (Same sentiment from the NWS Alaska Ice Desk)
- EMC: No plans to use this product.
- Other comments:
  - Continuity: VIIRS, AMSR2, and ATMS products provide continuity with products from heritage imagers such as AVHRR, MODIS, and OLS for some products.
  - What more can we get? Freshwater ice concentration and thickness.

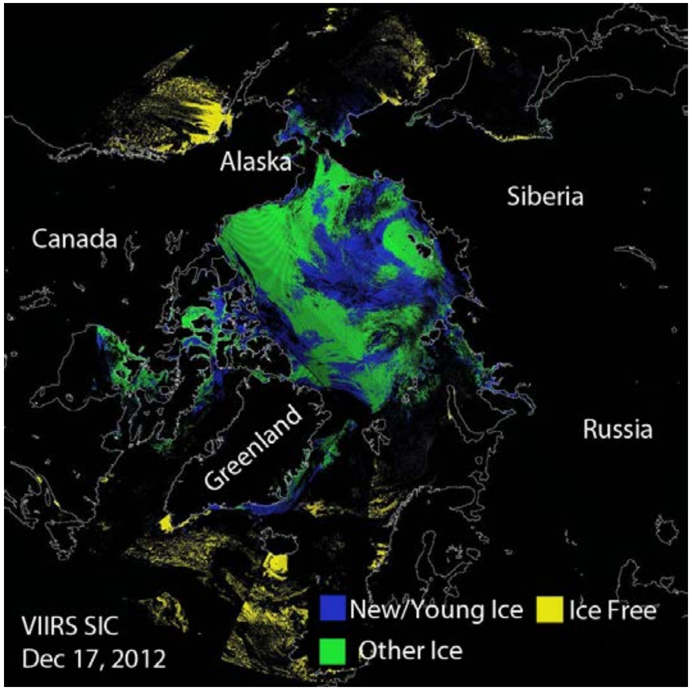
Conclusion

The Sea Ice Characterization EDR does meet the threshold attributes for a limited set of samples, but does not meet the requirements overall, particularly if the 70% probability of correct typing applies to each ice class.

Solutions are elusive. One alternate algorithm has been investigated.

Therefore, the Team defers to the AERB regarding the product maturity level.

Regardless of the maturity level, the Team recommends that the NDE ice thickness product ultimately replace the SIC EDR as its operational ice characterization (age or thickness) product.



Plans, Milestones

	Suomi NPP	JPSS J1
FY15	• Validated Stage n (various) maturity reviews • Continued validation of all products • Improve or recommend replacement of Sea Ice Characterization algorithm • Recommendations on snow/ice gridding	JPSS Risk Reduction Projects: • Run GOES-R algorithms on VIIRS products • Minor algorithm improvements
FY16	• Algorithm maintenance and minor improvements	• Hold algorithm preliminary design reviews • Define validation plan
FY17	• Long-term validation of VIIRS snow and ice products	• Hold algorithm critical design reviews • Begin transitioning to JPSS • Redefine products if needed • Generate LUTs for J1 VIIRS sensor
FY18	• Long-term validation of VIIRS snow and ice products	• J1 launch • Beta maturity status

Caveats for Operational VIIRS Sea Ice Characterization EDR - from Provisional Review

- Known problems and proposed technical solutions
  - In general, significant discontinuities in ice classification between New Young and Other Ice have been observed in the granule level mapped composite data.
    - Proposed solution: Investigate and mitigate sensitivity of retrievals to NCEP ancillary data inputs. Mitigation strategies include use of parameterizations or climatology
  - Ice classification discontinuities are very evident near the terminator region where the algorithm transitions from the day reflectance based algorithm to the night energy balance based algorithm
    - Proposed solution: Nighttime algorithm could be revised to utilize a local sliding IST window. For example, if the IST for the pixel is greater than the mean plus a threshold of the IST in the moving window, then it would be re-classified as new/young ice.)
    - Proposed solution: Investigate whether there is a problem with the solar energy flux term used by the heat balance for solar zenith angles between 80° and 90° and correct the implementation if necessary.
  - The snow depth thresholds based on the snow accumulation depth/ice thickness climatology LUT are problematic
    - Proposed solution: LUT generation logic requires modification to correct climatologically unrealistic values of snow accumulation depth identified the current LUT
    - Proposed solution: Investigate use of ancillary precipitation to derive snow depth and compute an ice thickness based on that snow depth. Dependence on the problematic SnowDepth/IceThickness Climatology LUT can then be eliminated.

Caveats for Operational VIIRS Sea Ice Characterization EDR (additional issues) - from Provisional Review

- False ice is frequently observed near cloud edges
  - Proposed solution: Implement additional quality checks for extended cloud adjacency and partly cloudy conditions within the ice tie point search window in the Sea Ice Concentration IP and pass quality flag to Sea Ice Characterization EDR
- Ice misclassifications occur due to low opacity clouds or ice fog, particularly during nighttime
  - Proposed solution: Assistance from VCM to improve cloud vs. ice detection
- Thin ice in small leads are evident in SDR imagery are sometimes not detected and are classified as thicker “Other ice”
  - Proposed solution: Investigate using VIIRS SDR reflectance and Surface Temperature IP value at each pixel for retrievals instead of the ice tie point
  - Proposed solution: Add an ice temperature threshold hold test to the day reflectance algorithm as a consistency check for the day, reflectance based retrievals
- Lower reflectance of melting sea ice appears to cause the SIC EDR to indicate New/Young Ice, although this type of ice cannot be present this time of year.
  - Proposed solutions: Define and utilize melt season period where New/Young ice cannot exist. Could do this by date/latitude or possibly with IST or NCEP air temp input. During this time, ALL ice would be classified as “other ice”
  - Investigate reflectance and temperature thresholds used in the algorithm
  - Investigate and mitigate sensitivity of retrievals to NCEP ancillary data inputs
  - Change the category “New/Young Ice” to “Thin Ice”. Thin ice can occur, through melt, in the warm season.

Backup: JPSS-1 Product Maturity Definition

JPSS/GOES-R Data Product Validation Maturity Stages – COMMON DEFINITIONS (Nominal Mission)
1. <u>Beta</u> o Product is minimally validated, and may still contain significant identified and unidentified errors. o Information/data from validation efforts can be used to make initial qualitative or very limited quantitative assessments regarding product fitness-for-purpose. o Documentation of product performance and identified product performance anomalies, including recommended remediation strategies, exists.
2. <u>Provisional</u> o Product performance has been demonstrated through analysis of a large, but still limited (i.e., not necessarily globally or seasonally representative) number of independent measurements obtained from selected locations, time periods, or field campaign efforts. o Product analyses are sufficient for qualitative, and limited quantitative, determination of product fitness-for-purpose. o Documentation of product performance, testing involving product fixes, identified product performance anomalies, including recommended remediation strategies, exists. o Product is recommended for operational use (user decision) and in scientific publications.
3. <u>Validated</u> o Product performance has been demonstrated over a large and wide range of representative conditions (i.e., global, seasonal). o Comprehensive documentation of product performance exists that includes all known product anomalies and their recommended remediation strategies for a full range of retrieval conditions and severity level. o Product analyses are sufficient for full qualitative and quantitative determination of product fitness-for-purpose. o Product is ready for operational use based on documented validation findings and user feedback. o Product validation, quality assurance, and algorithm stewardship continue through the lifetime of the instrument.