VIIRS Sea Ice Characterization EDR

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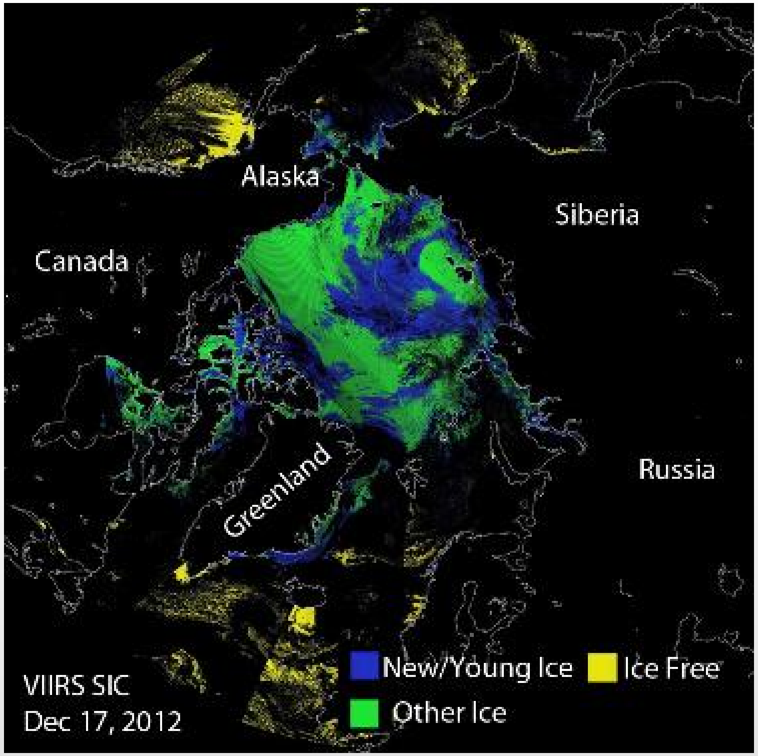
Summary of VIIRS Sea Ice Characterization (Ice Age) EDR



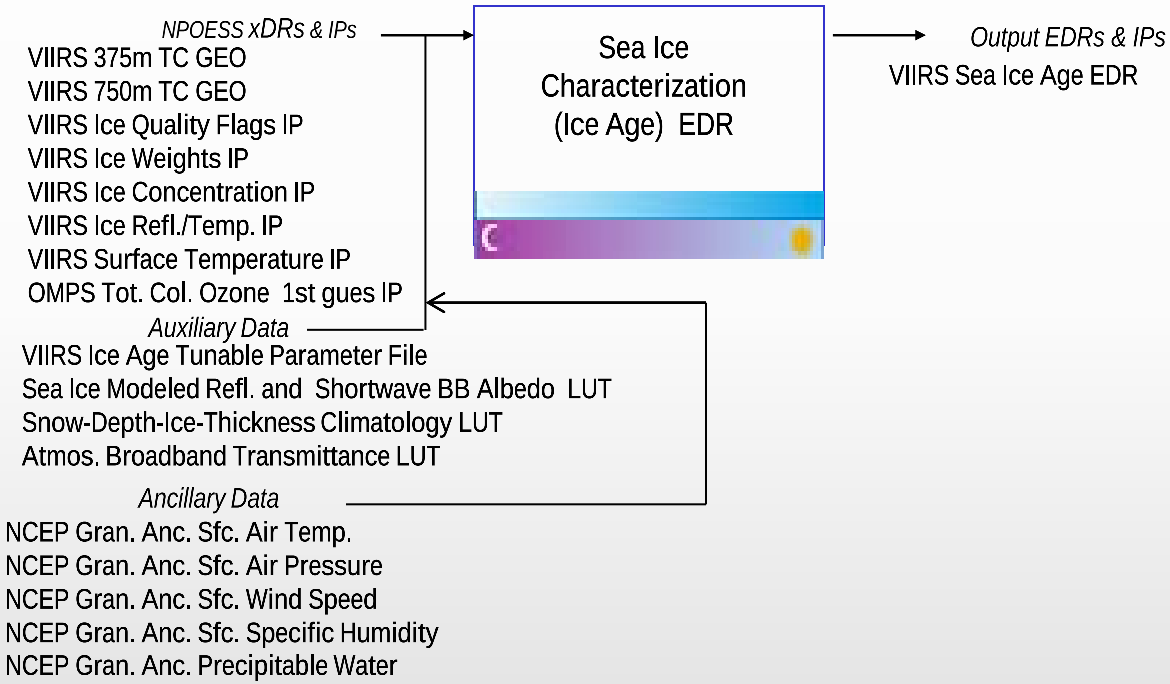
- The VIIRS Sea Ice Characterization (Ice Age) EDR consists of ice classifications for *Ice Free*, *New/Young* and *Other Ice* at VIIRS moderate spatial resolution (750 m @ nadir), for both day and night, over oceans poleward of 36ºN and 50ºS latitude.

- **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 the VIIRS Characterization EDR (Ice Age) Algorithm Inputs



Summary of VIIRS Sea Ice 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

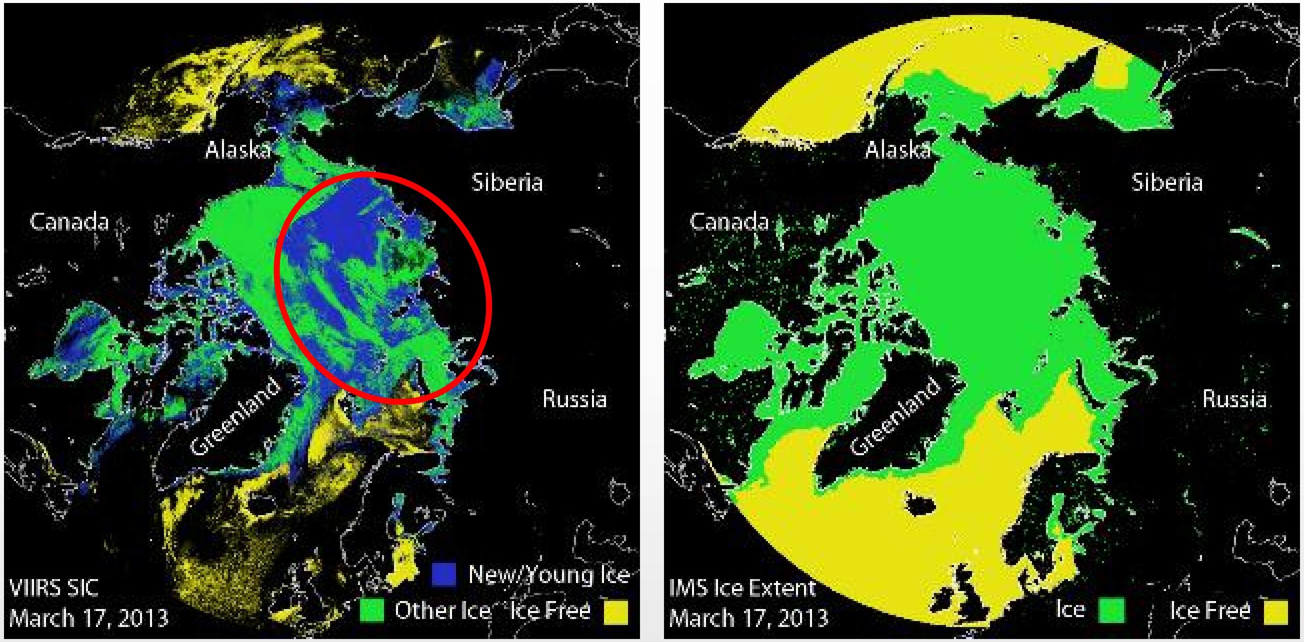
The Snow-Depth-Ice Thickness Climatology LUT contains:

- 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

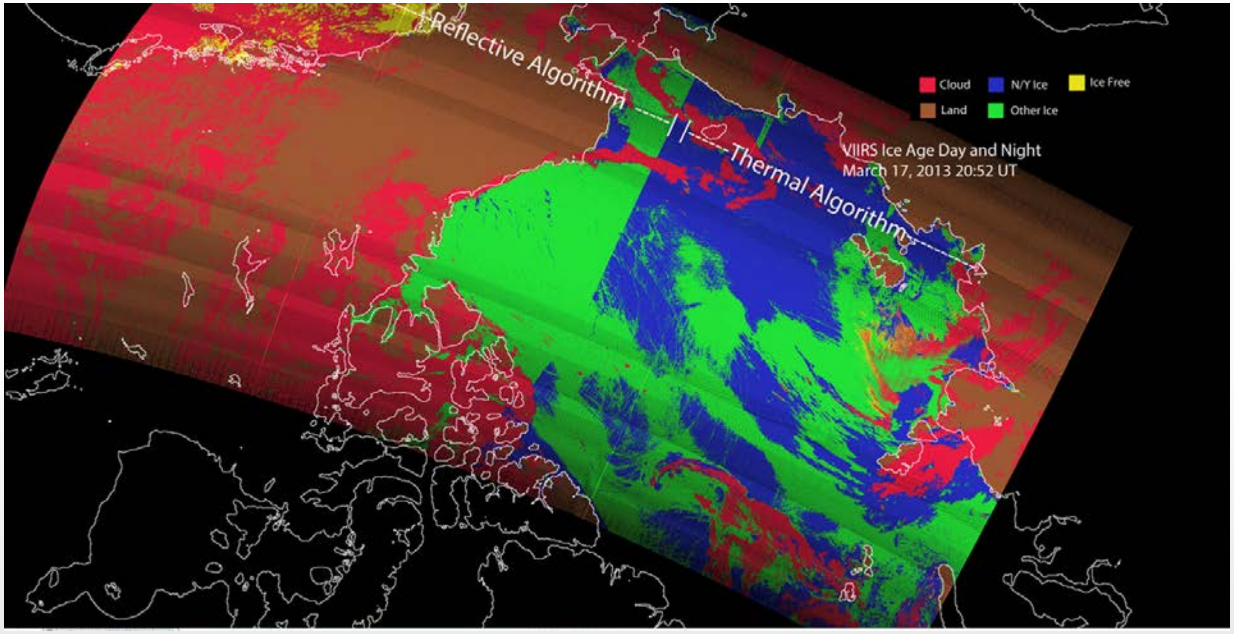
- Detailed analysis of 20 Arctic scenes including four seasons: April 5, 2012 – Dec 4, 2013
- Golden granule: March 17, 2013
  - Examined performance of daytime, nighttime and terminator (transition) areas
- Comparisons to other products:
  - VIIRS SDR reflectance
  - NOAA IMS ice extent
  - CU ice age
  - Airborne ice thickness
    - IceBridge ice thickness
    - Airborne EM & Lidar

VIIRS Sea Ice Characterization EDR
Extent of Misclassified New Young Ice on March 17, 2013



VIIRS Sea Ice Characterization (SIC) EDR (left) vs. NOAA IMS Ice Extent (right). Ice coverage is similar, but new/young ice is too extensive (as seen by manual interpretation).

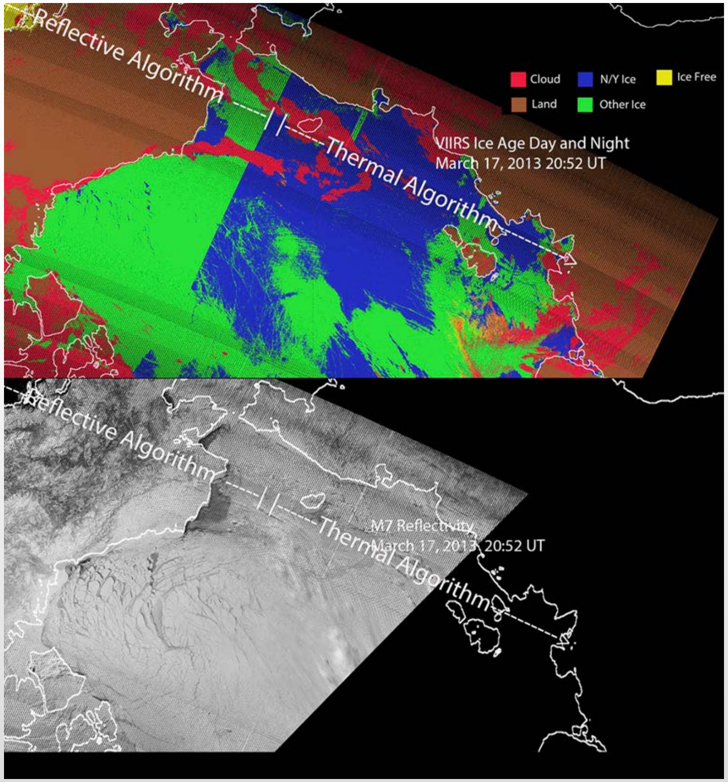
Sea Ice Characterization EDR – March 17, 2013
Misclassified Ice



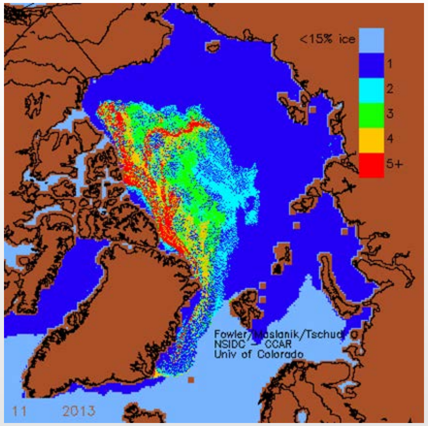
Dan Baldwin/CU, Mark Tschudi/CU

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)

Details of Ice Misclassification - March 17, 2013

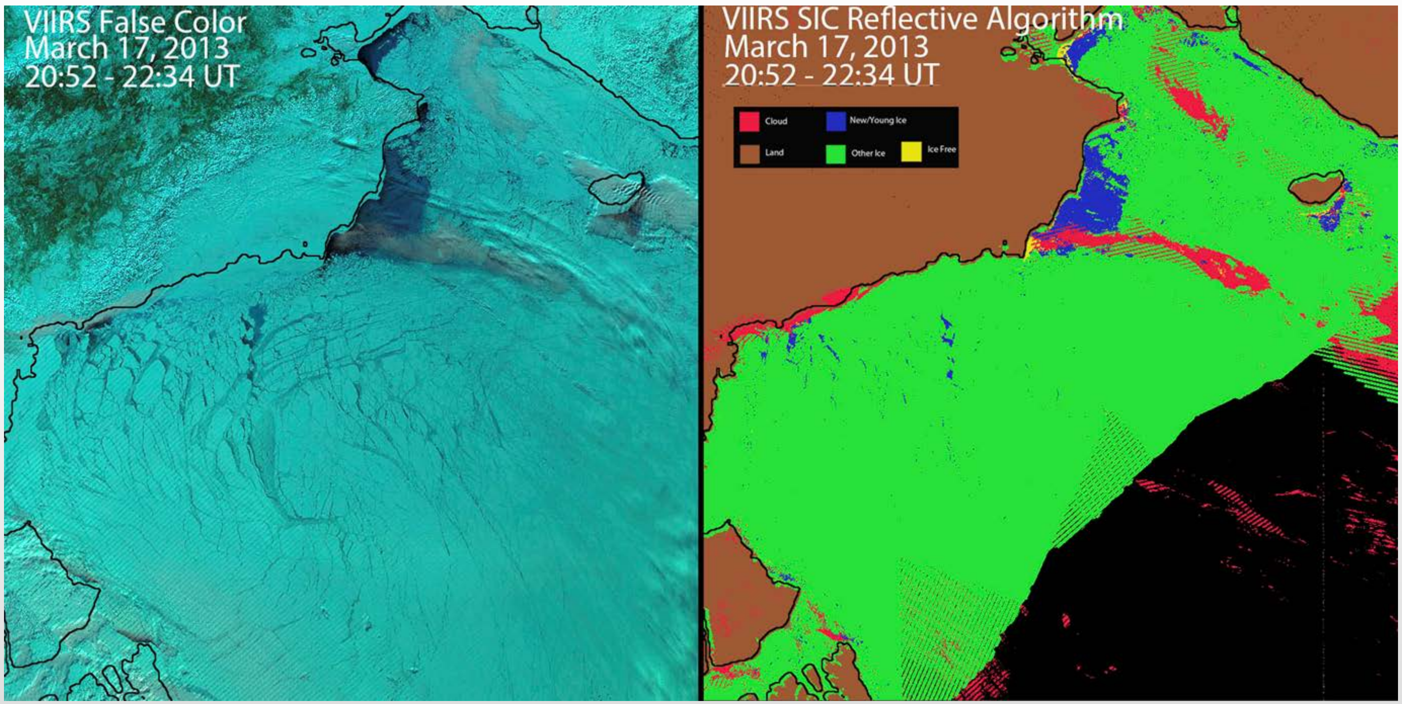


- In this case, the daytime (reflective) algorithm identifies other ice, but misses many leads likely containing N/Y ice
- Nighttime (thermal) algorithm overestimating N/Y ice
- Discontinuity at the transition zone



- CU's ice age product
- Dark blue is FYI, *not necessarily N/Y ice*
- Shows that multiyear ice exists in areas that Thermal Algorithm classifies as "new/young"

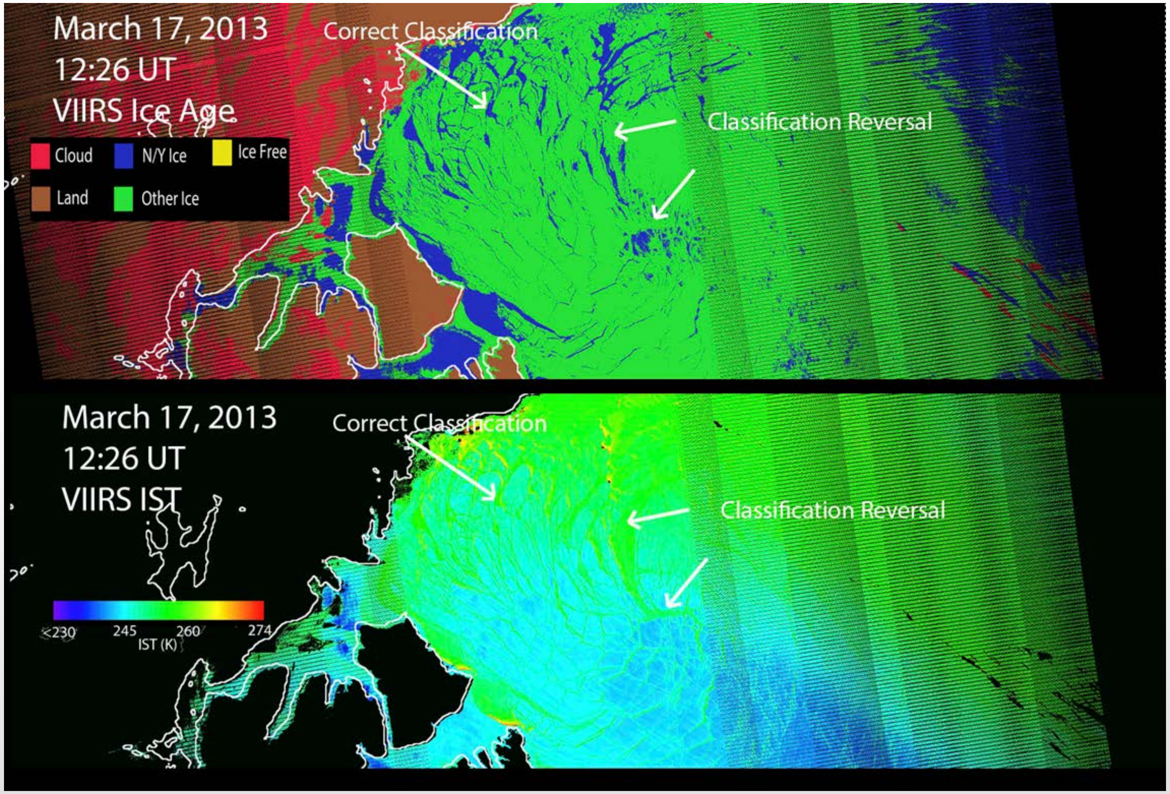
March 17, 2013 Day Reflectance Algorithm: Ice Age Compared with False Color VIIRS SDR Reflectance Image



Many leads, likely containing thin ice, seen in the VIIRS false color reflectance imagey (left) are not detected in the Ice Age EDR (right)

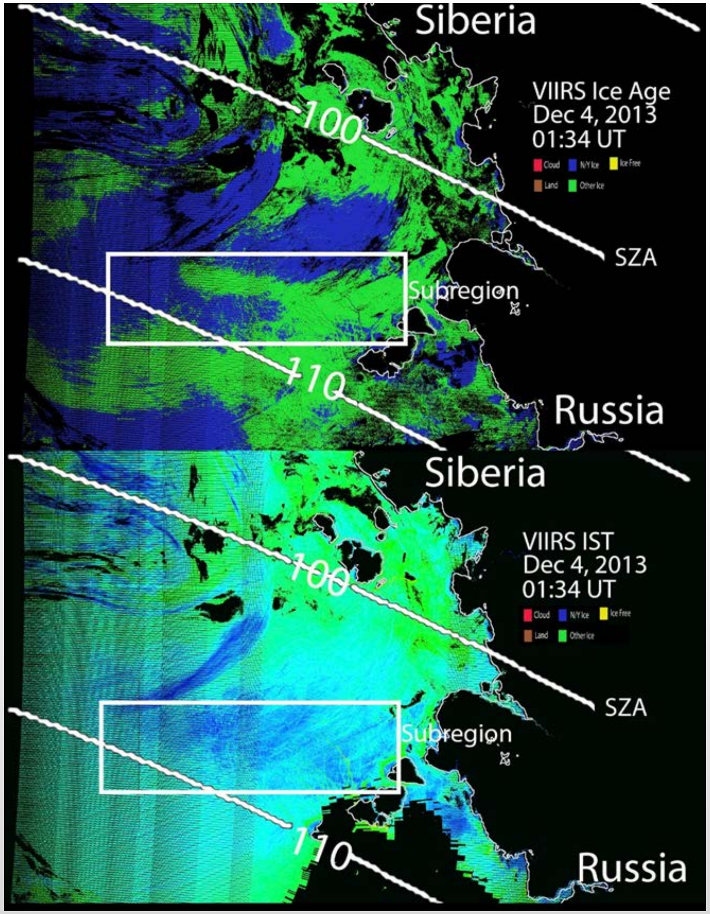
This may be due to use of ice tie point reflectance instead of the remotely sensed reflectance at each pixel

March 17, 2013 Nighttime Algorithm Ice Age Classification Reverse Classification

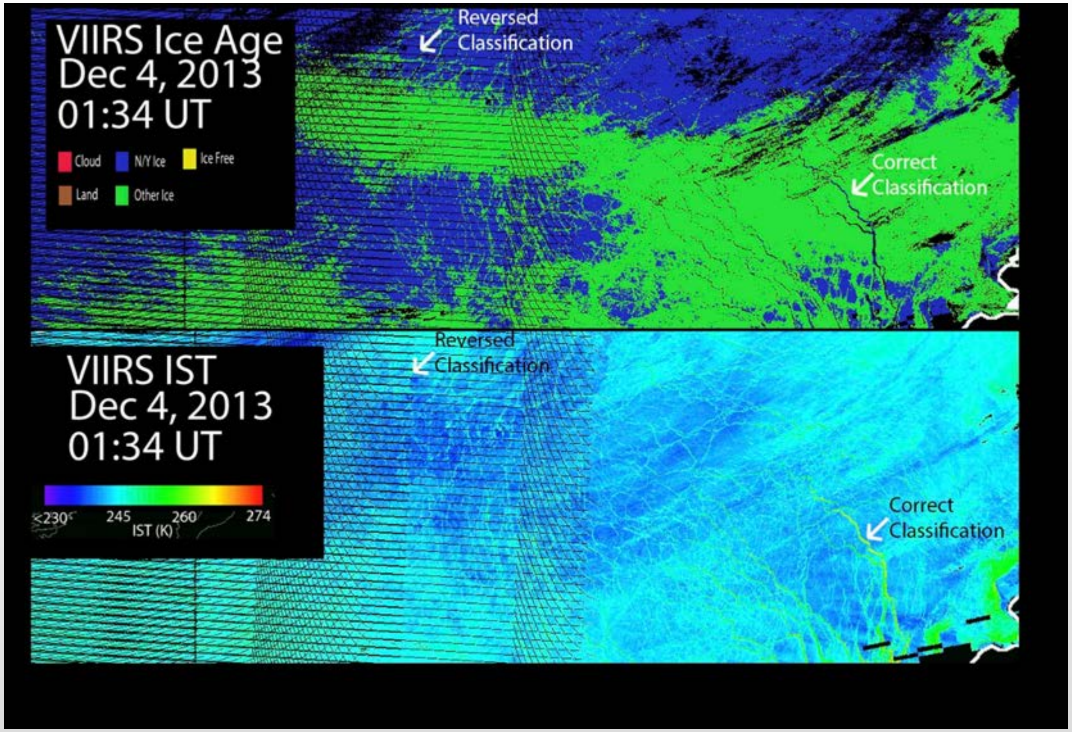


- Most ice classification is reasonable – many leads with thin ice are identified
- Misclassification suspected in area of warmer ice

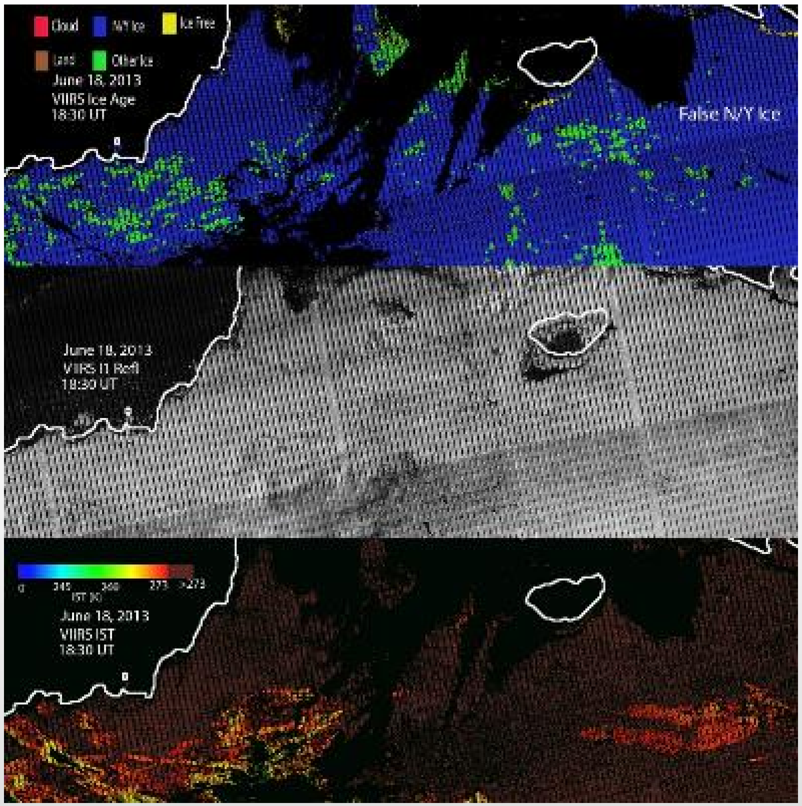
Classification Reversals Identified by Comparison to IST EDR for Dec. 4, 2013 Night Scene



- Occurs in several nighttime images
- Many other leads classified correctly, however

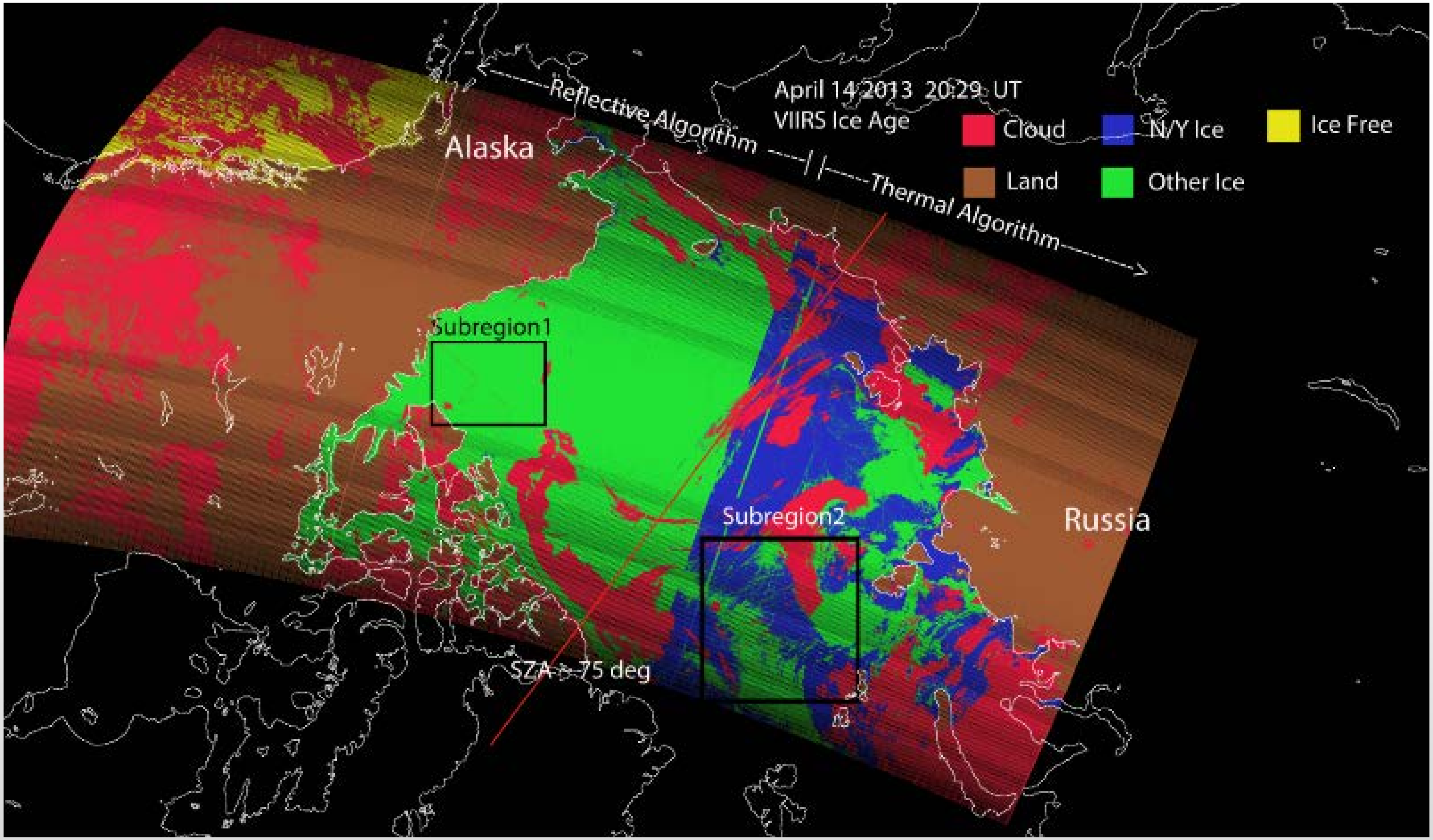


SIC EDR Daytime Misclassification Due to Melting Ice

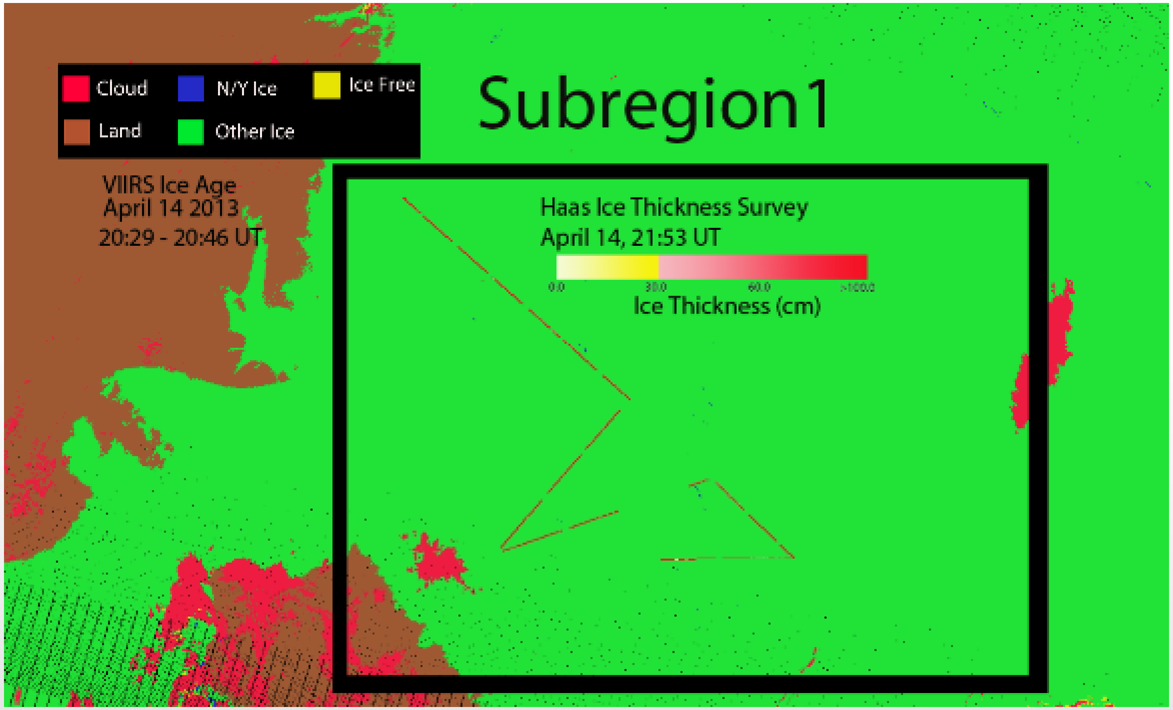


- Ice/snow melt (note IST is at melting temp) lowers reflectance
- Lower reflectance (<0.53) causes daytime algorithm to misclassify ice as N/Y, instead of other
- Melting ice may need to be included in the “other ice” category, as thickness may not be obtainable

Airborne Ice Thickness Data: Verification of Daytime Ice Age Classification for "Other Ice" in Subregion1



Airborne Ice Thickness Data:
Verification of Ice Age Classification for "Other Ice" in Subregion1



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

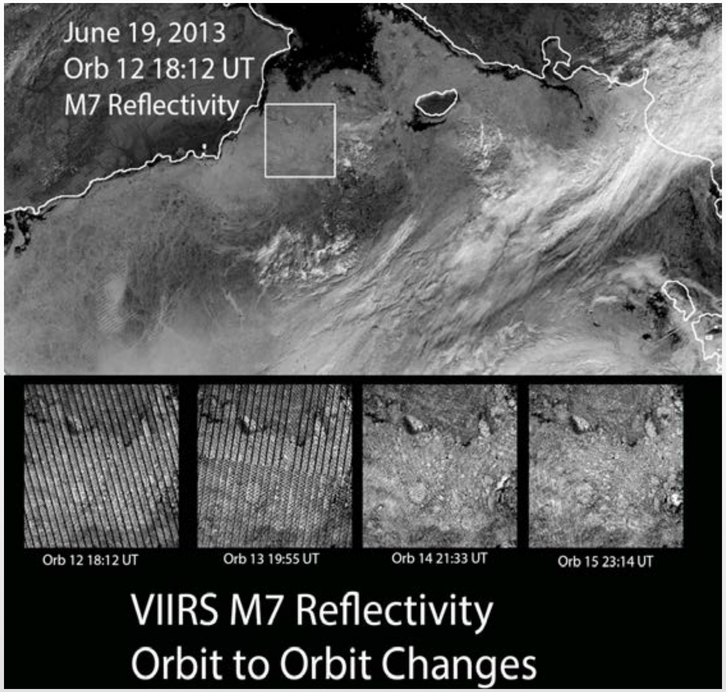
- **All ice for VIIRS SIC EDR is "other ice" (> 30 cm)**
- **1004 airborne data points: 99% > 30 cm (in agreement with VIIRS SIC EDR)**

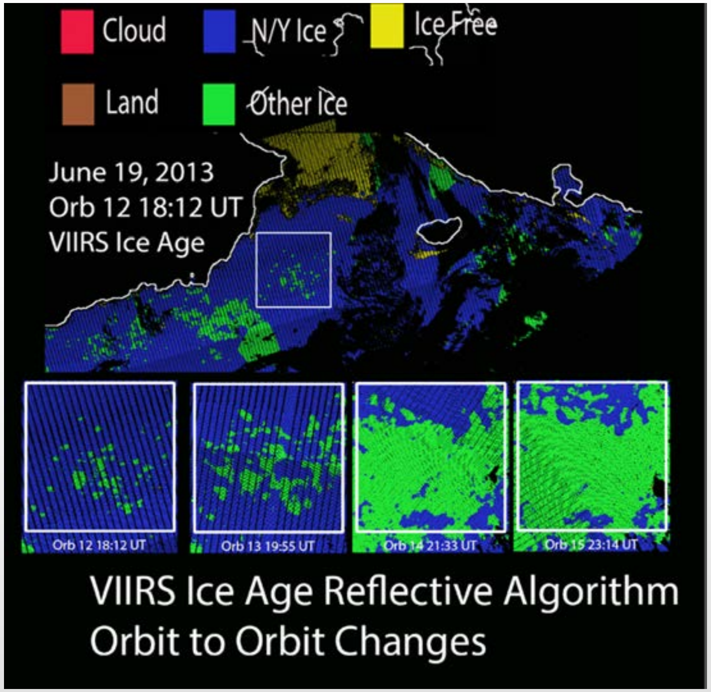
Airborne Ice Bridge Ice Thickness: Verification of Ice Age Classification for "Other Ice"

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

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

Orbit to Orbit Classification Variability over Same Geographic Region



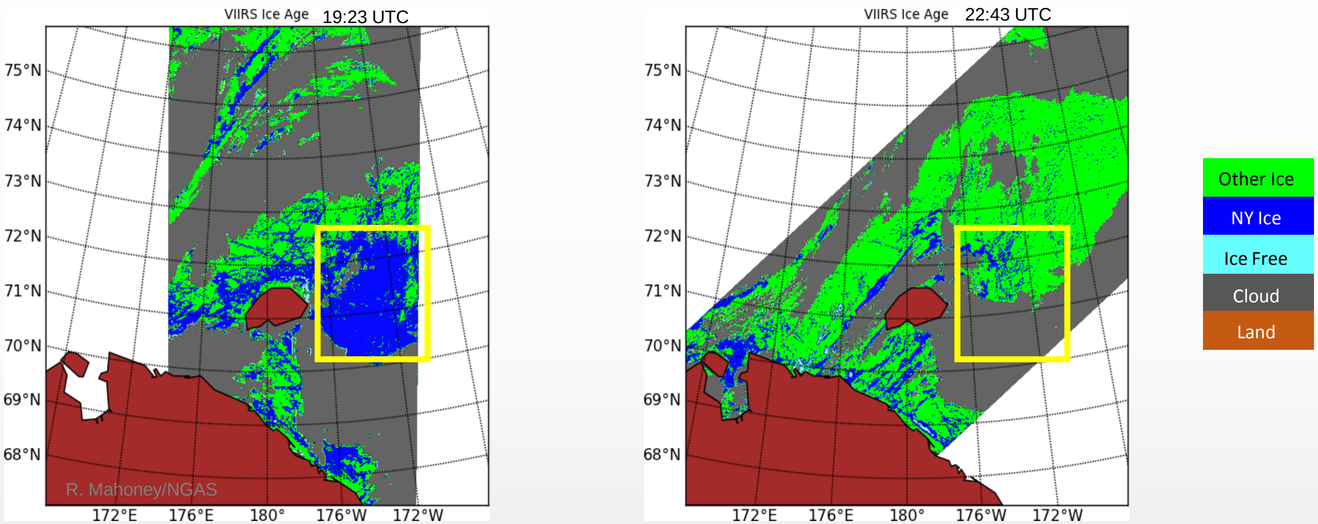


- daytime algorithm
- observed on multiple days

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

- Deep dive analysis performed for May 20, 2013 day scene ice for misclassification of thicker “Other Ice” as “New Young”
  - reflectance branch algorithm inputs and internal computed fields dumped from ADL were visually inspected:
    1. Modeled Sea Ice Reflectance from LUT
    2. Climatology Modeled Snow Accumulation/Ice Thickness LUT snow depths
    3. Ancillary input fields, internally computed ice thicknesses
    4. Ice tie point reflectance

Detailed Analysis for Orbit to Orbit Misclassification of NY/Other Ice (May 20, 2013 19:23 and 22:43 UTC orbits)



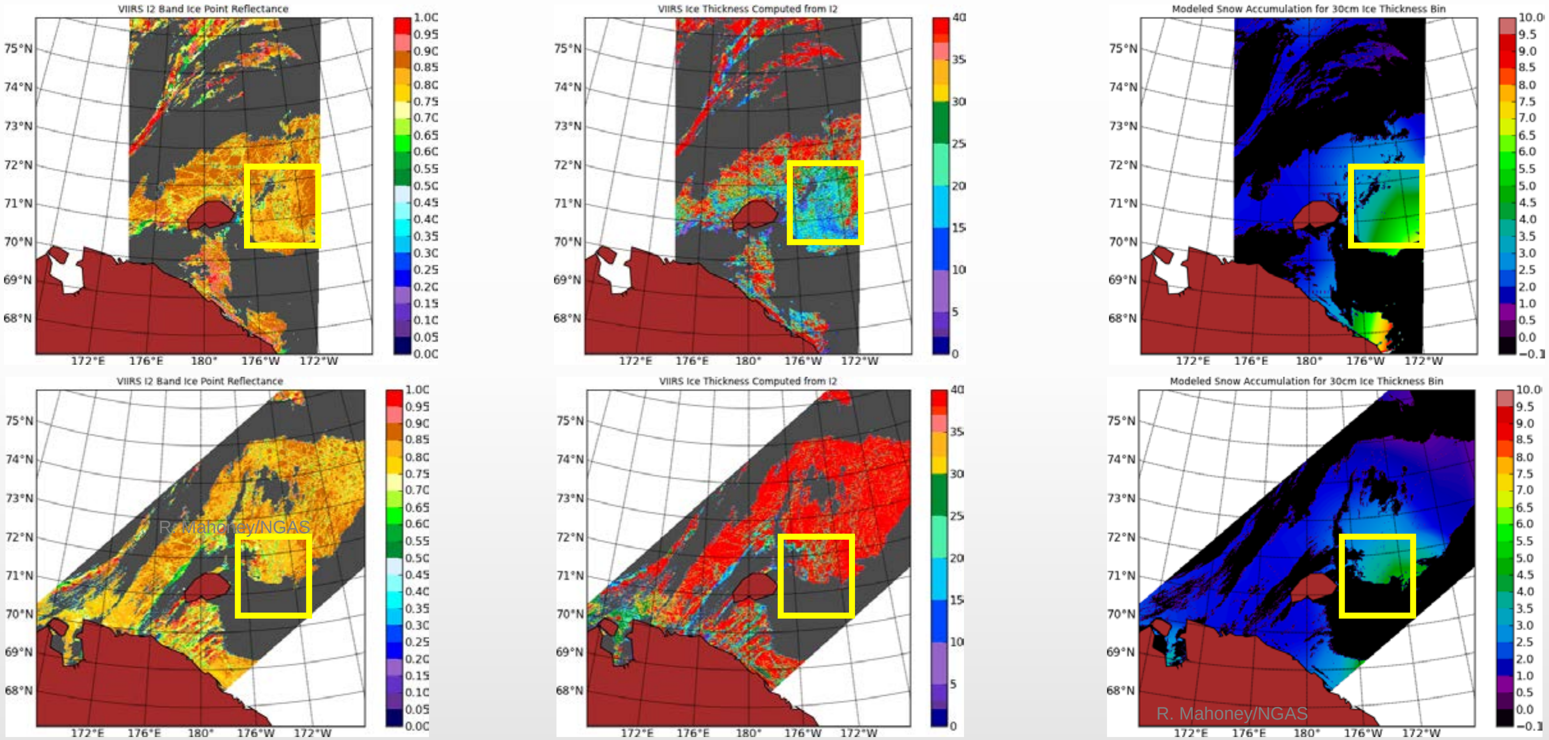
Region near Wrangle Island showed significant amounts of sea ice that were correctly classified as thicker "Other Ice" in 22:43 UTC orbit scene (right) being misclassified as NY in the 19:23 UTC orbit scene (left). The yellow boxed region shows a broad region of misclassified NY ice in the 19:23 scene.

SDR RGBs, ice tie point reflectance,   modeled sea ice reflectance, modeled snow accumulation depth, internally computed ice thickness and other inputs were examined and compared in order to determine the cause for the misclassification

Ice Tie Point Refl. (I2), Internally Computed Ice Thickness, and Climatology Modeled Snow Accumulation

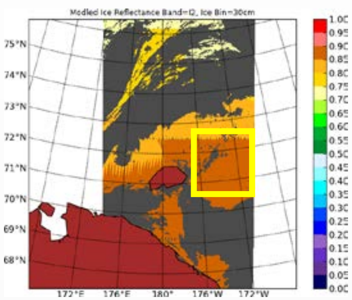
19:23 UTC

22:43 UTC

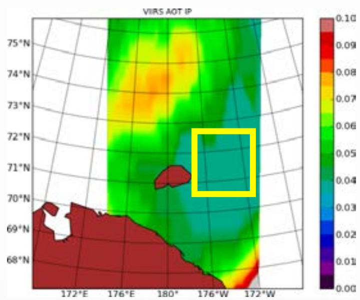


Values of the **I2 ice tie point reflectance** (left), **and modeled snow depth** (right) examined for the misclassification region (box) have **similar values for both orbits**. However, computed ice thicknesses (center) are different. Lower values of ice thickness in the 19:23 UTC orbit have a pattern similar to that of the higher values of modeled snow depth in the boxed region (upper right).

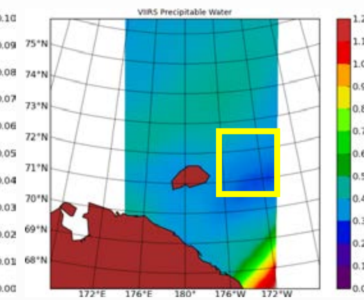
VIIRS I2 Modeled TOA Sea Ice Reflectance and Inputs to Extract the Modeled Reflectance from the LUT



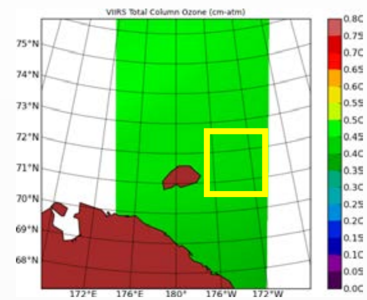
reflectance ~ 0.85-0.90



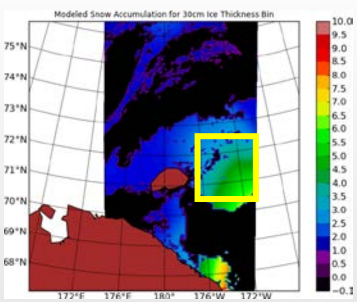
aot ~ 0.03



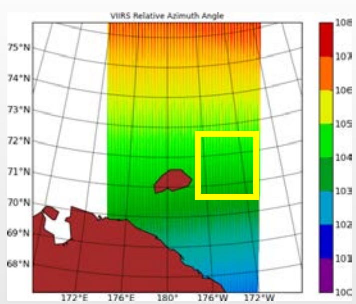
wv ~ 0.3-0.4 cm



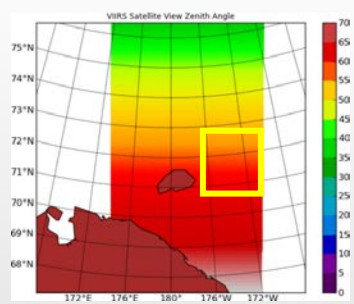
o3 ~ 0.4 atm-cm



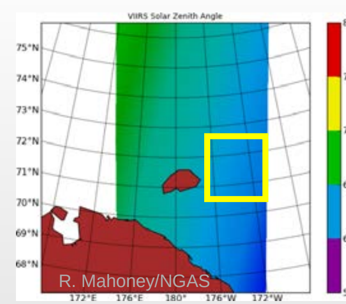
climatology modeled snow accumulation ~ 3-4 cm



relative azimuth angle ~ 105°



satellite view zenith angle ~ 56°

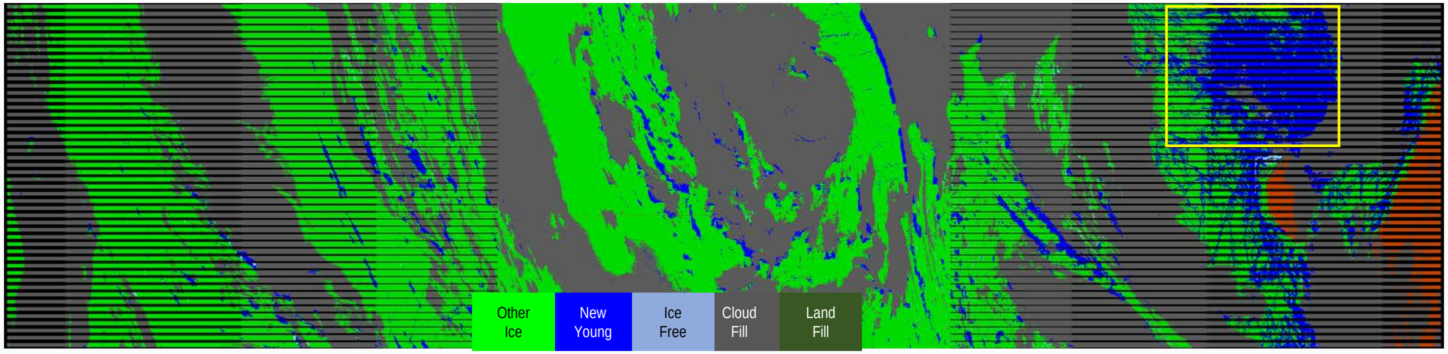


solar zenith angle ~ 62°

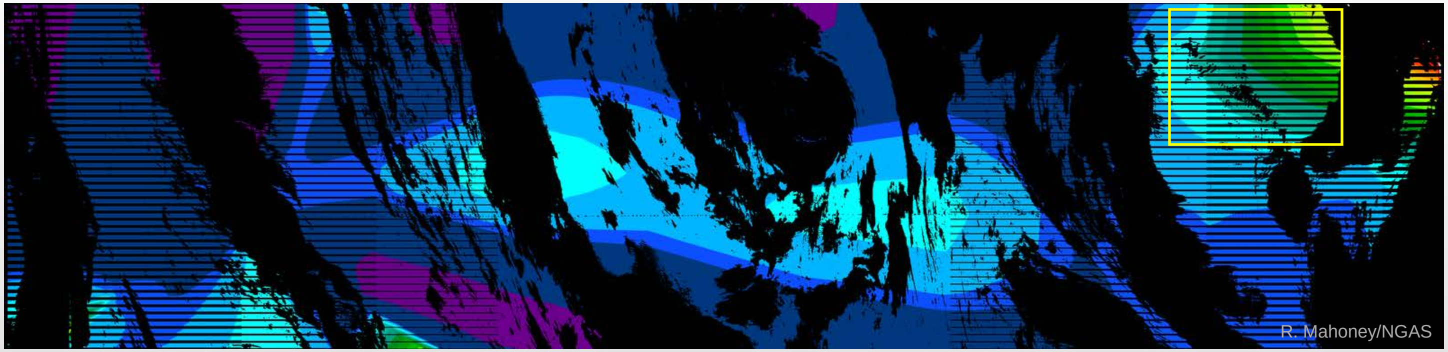
Modeled Sea Ice reflectance for I2 are between 0.85 and 0.9 in the boxed region. The input **parameter in the 19:23 UTC orbit that has the most difference** from that of the corresponding 22:43 UTC orbit (not shown here) is **the satellite view zenith angle**.

Ice Age EDR Compared with Input Modeled Snow Accumulation/Ice Thickness LUT Snow Depth

Sea Ice Age EDR



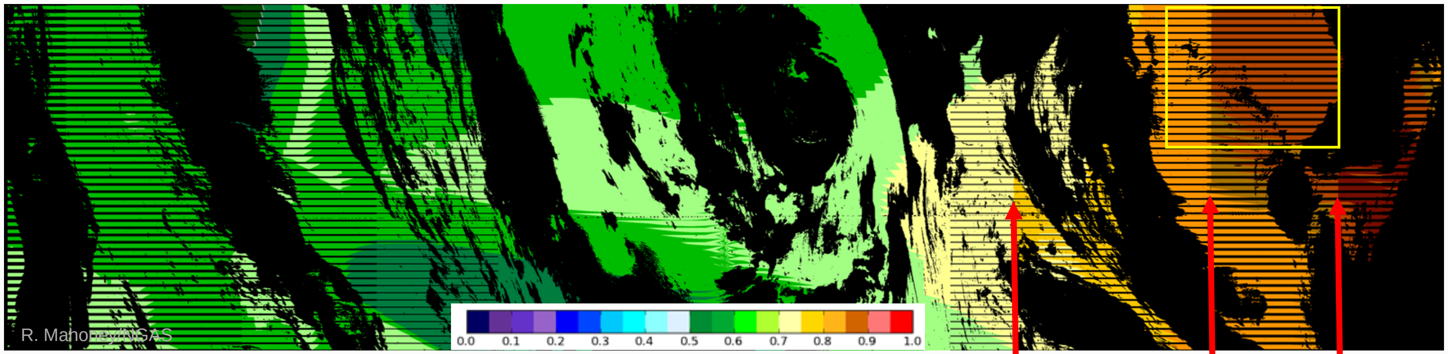
Modeled Climatology Snow Depth (30 cm ice thickness bin)



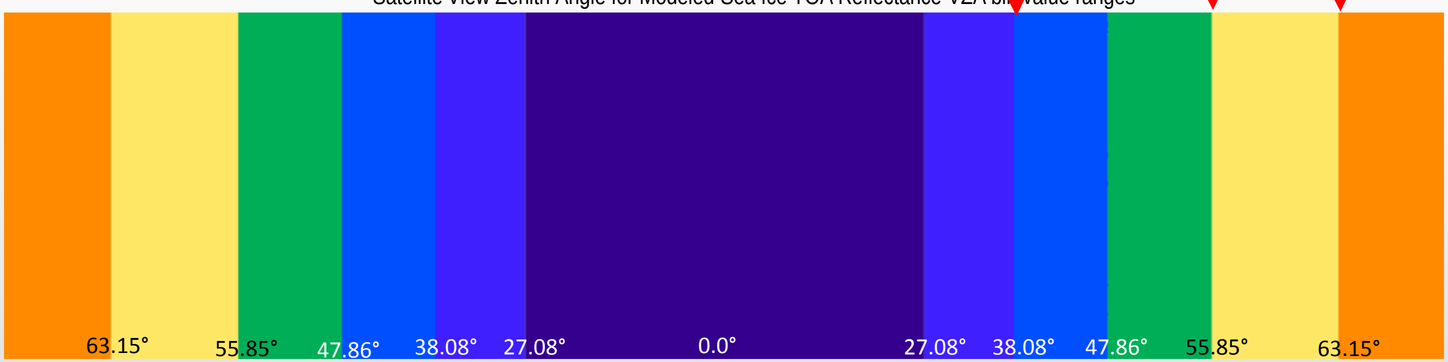
Misclassified New Young ice in the 19:23 UTC Sea Ice Age EDR orbit (upper figure, box region) correlates with the pattern high values of climatology modeled snow accumulation depth (lower figure, boxed region).

Granule Comparison of Modeled TOA Reflectance to Sat. View Zenith Angle May 20, 2013 19:23 UTC

I2 Modeled Sea Ice Reflectance (30 cm ice thickness bin)



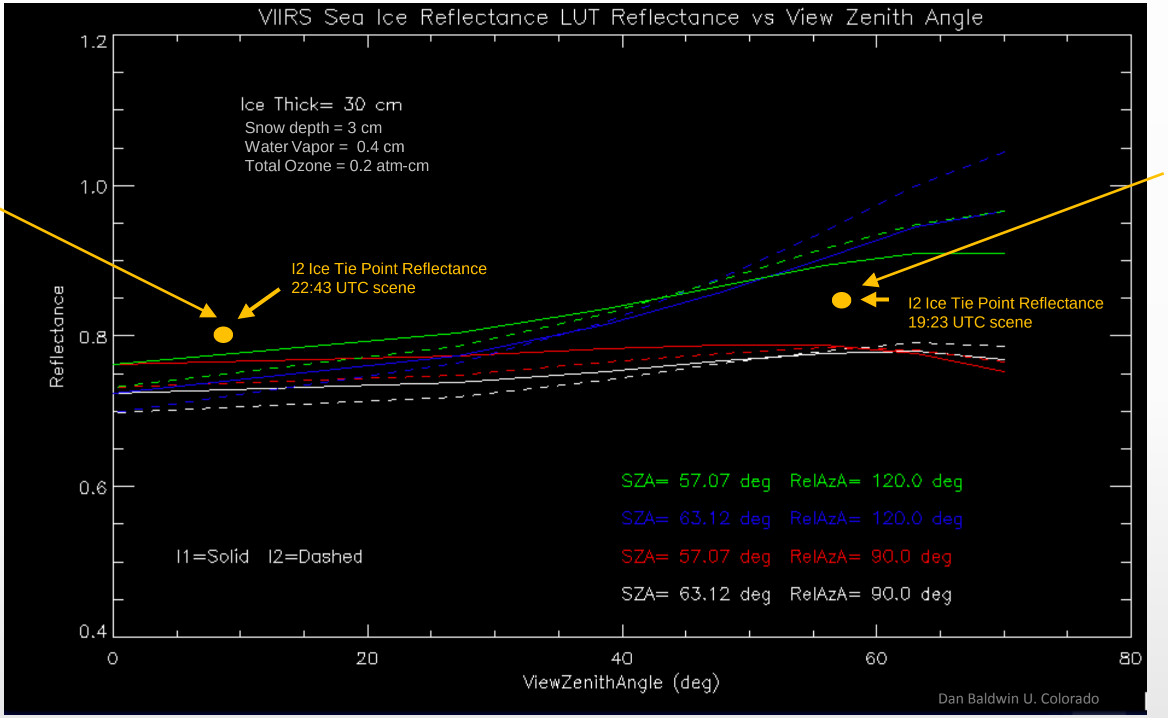
Satellite View Zenith Angle for Modeled Sea Ice TOA Reflectance VZA bin value ranges



Abrupt increases in the Modeled TOA Sea Ice Reflectance with increased view zenith angle (upper figure) correlate to the values (lower figure) of the modeled sea ice reflectance LUT's view zenith angle bin boundaries.

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.

Summary

- Evaluation of Sea Ice Characterization EDR (Ice Age) performance based on visual comparison of a set of golden granules consisting of day, terminator and night scenes indicates that the Sea Ice Age EDR has considerable performance challenges but particularly for terminator scenes

- 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 climatology 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

- Detailed analysis performed for May 20, 2013 day, orbit to orbit variations over Wrangle Island
  - Ice misclassified as NY due to high Modeled TOA Sea Ice Reflectance LUT values corresponding to regions with large climatology modeled snow depths and satellite view zenith angles
  - Detailed analysis for night and terminator scenes has not been performed yet

VIIRS Sea Ice Characterization EDR Known Issues & Proposed Solutions

- In general, significant discontinuities in ice classification between New Young and Other Ice have been observed in the granule level mapped composite data.

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

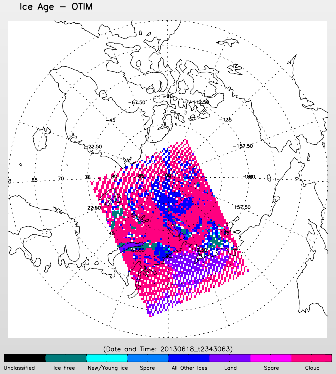
VIIRS Sea Ice Characterization EDR Known Issues & Proposed Solutions (continued)

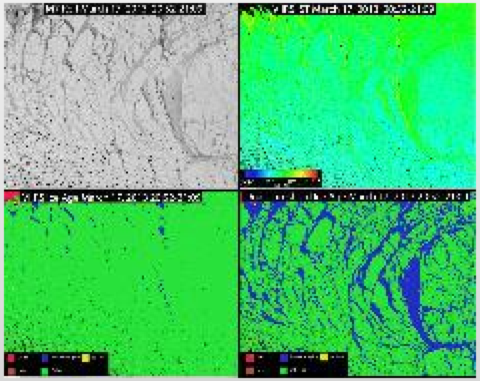
Issue	Description	Proposed Solution
Ice Age Misclassification due to low opacity clouds	Ice misclassifications occur due to low opacity clouds or ice fog, particularly during nighttime	Continued improvement of VCM to facilitate cloud vs. ice detection
Ice Age Misclassification due to melting ice	Lower 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

VIIRS Sea Ice Characterization EDR Known Issues & Proposed Solutions – Alternate Algorithms

- Alternate Algorithms to Replace Current day and/or Night Ice Age Algorithms
  - It is not known if the proposed solutions above will be sufficient. It is therefore be necessary to identify and test alternate algorithms
    1. OTIM
       - One-dimensional Thermodynamic Ice Model (OTIM) of Wang et al. (2010) - Night Regions
    2. Temperature/Reflectance threshold algorithm – Day, Terminator and Night Regions
       - A simpler approach using a temperature/reflectance threshold (daytime) is also being investigated. This technique could also be implemented using without use of reflectance (nighttime).

OTIM Ice Model





Threshold algorithm