Cryosphere and Polar Winds EDRs

Jeff Key

Cryosphere Team Lead

March 30, 2016

Algorithm Cal/Val Team Members

EDR	Name	Organization
Lead; ice and winds	Jeff Key	NESDIS/STAR
Co-Lead; ice and snow	Pablo Clemente-Colón	NESDIS/STAR and NIC
Wisconsin:		
Ice conc., temp.	Yinghui Liu	CIMSS/U. Wisconsin
Ice thickness	Xuanji Wang	CIMSS/U. Wisconsin
Ice	Rich Dworak	CIMSS/U. Wisconsin
Winds	Dave Santek	CIMSS/U. Wisconsin
Maryland:		
Snow cover, fraction	Peter Romanov	CREST/CCNY
Colorado:		
Ice temp., conc.	Mark Tschudi	U. Colorado
Ice temp., conc.	Dan Baldwin	U. Colorado
Other:		
	Paul Meade	JMA (until recently)

Products

1. Sea ice characterization (IDPS); Sea Ice Age/Thickness (NDE)
   - Age category: no ice, new/young ice, other ice (IDPS); thickness (NDE)
2. Sea Ice Concentration (IDPS IP and NDE)
   - Fractional coverage of ice in each pixel
3. Ice Surface Temperature (IST) (IDPS and NDE)
   - Radiating temperature of the surface (ice with or without snow)
4. Snow Cover (binary) (IDPS and NDE)
5. Snow Fraction (IDPS and NDE)
6. Polar winds (NDE)
   - Tropospheric winds at various levels

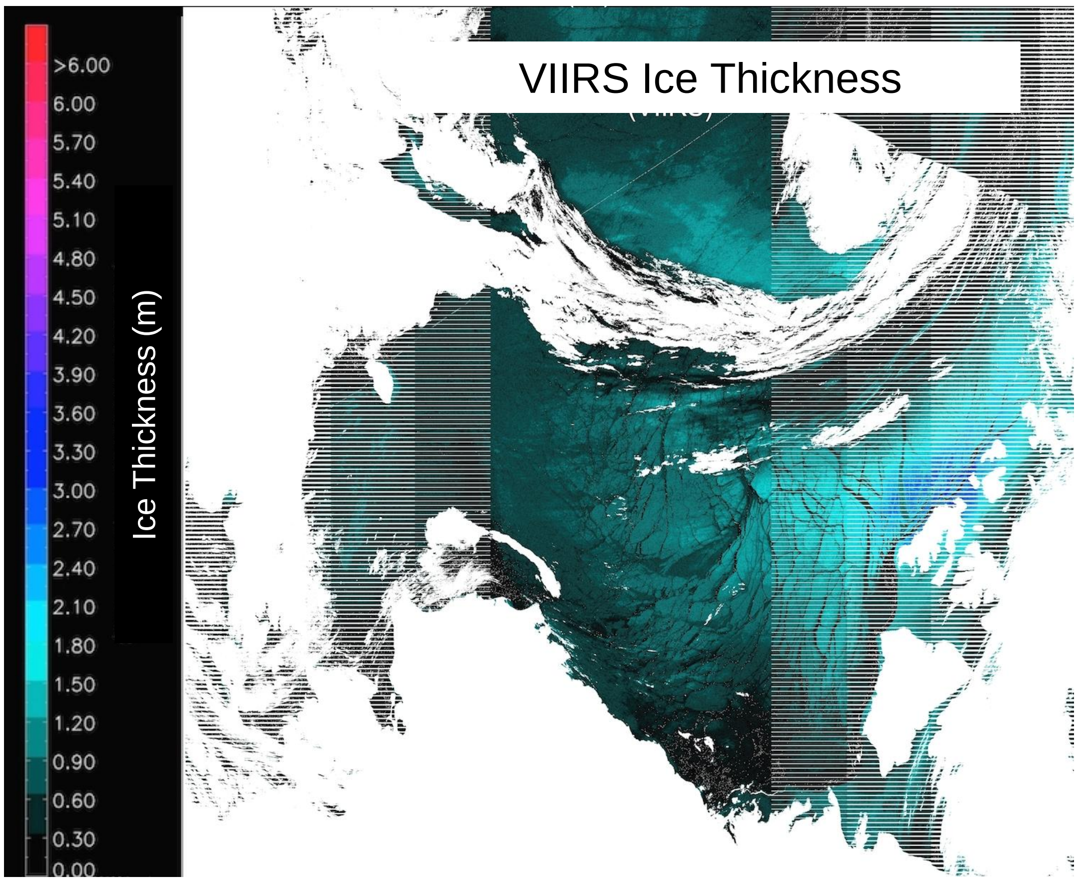
- AMSR2 on GCOM-W1 will have other NDE snow and ice products that will be operational in 2016:
  - Ice Characterization
  - Snow Cover
  - Snow Depth
  - Snow Water Equivalent (SWE)

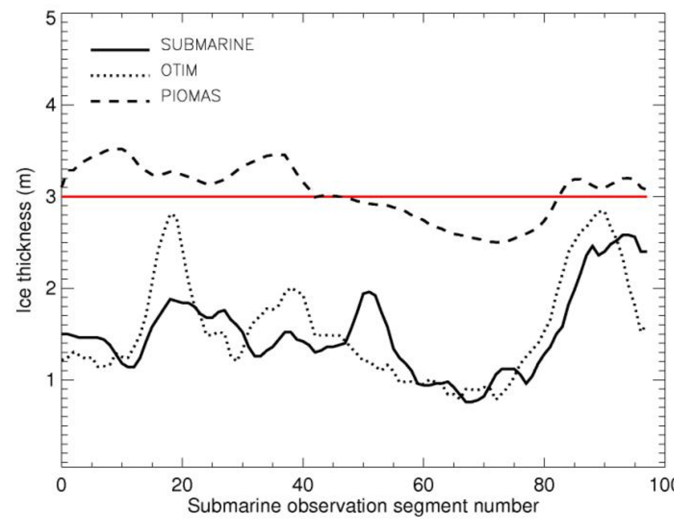
Users

- Communities, Applications
  - Navigation and Security
  - Emergency Management
  - Operational Weather Prediction
  - Hydrology
  - Climate Research
- U.S. Users
  - Operations:
    - National/Naval Ice Center (NIC)
    - NWS Ice Desk (Anchorage)
    - Naval Research Laboratory (NRL)
    - Naval Oceanographic Office
    - NCEP (anticipated)
  - Science:
    - NOAA, particularly STAR
    - Various universities
    - NASA: Goddard Space Flight Center, JPL
    - …and many others

Sea Ice Thickness

Sea Ice Age/Thickness is a 3-category product: new/young ice (< 30 cm thick), “other ice”, and ice-free. The new product for JPSS-1 will also provide a continuous ice thickness range from 0-3 m.

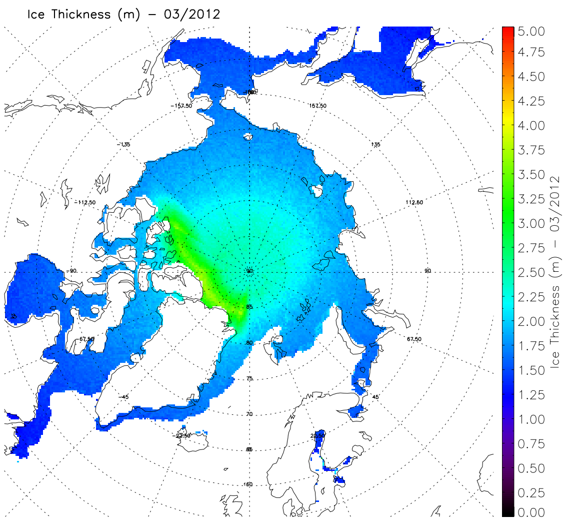




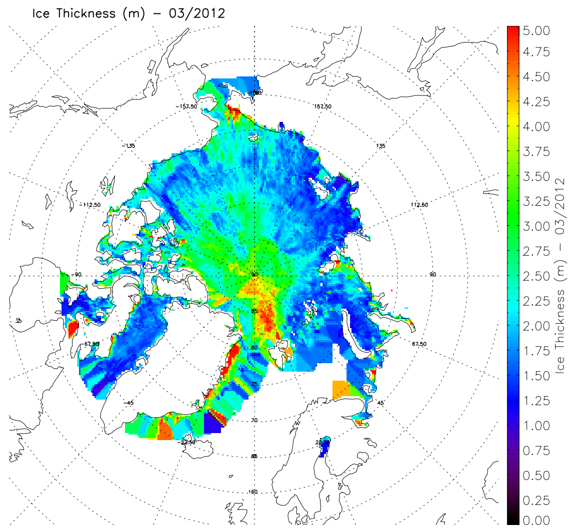
Validation with submarine sonar and modeled ice thicknesses.

Ice Thickness Intercomparison

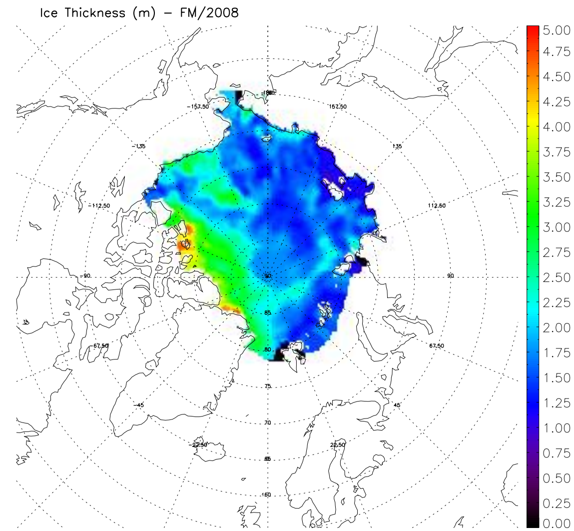
APP-x (VIIRS algorithm)



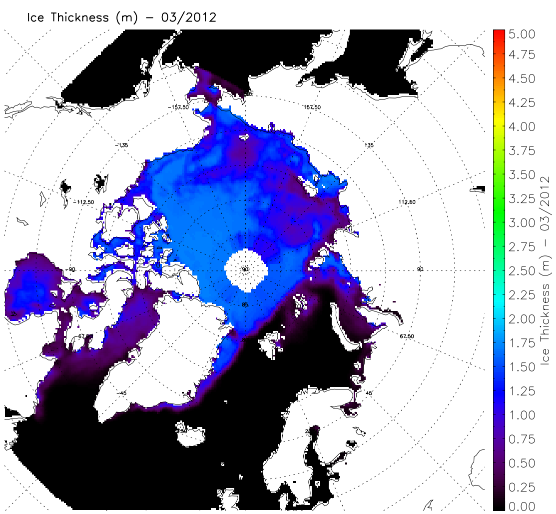
CryoSat-2



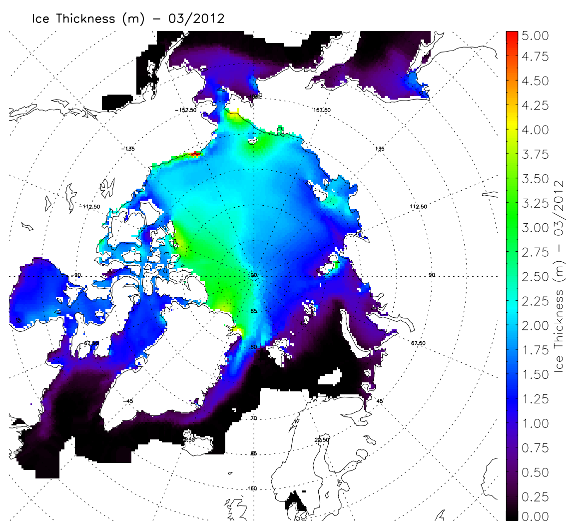
ICESat (different mo/yr)



SMOS



PIOMAS



Sea Ice Age/Thickness Algorithm

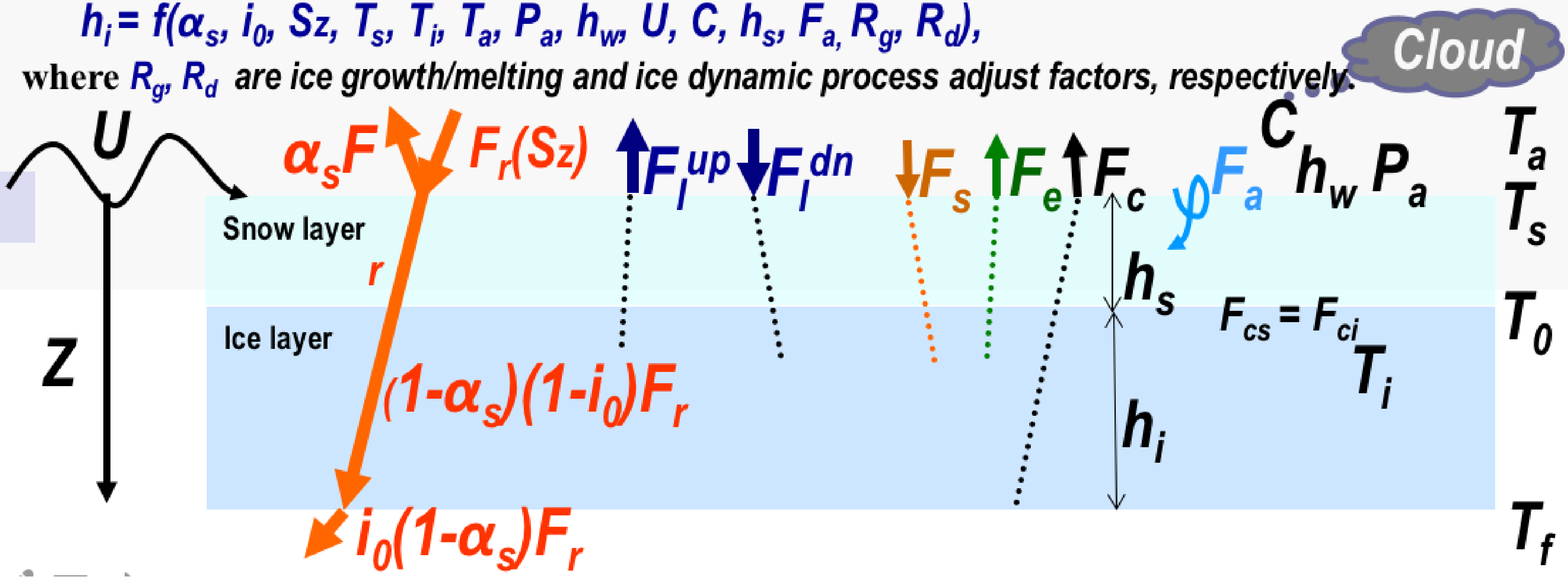
Based on the surface energy budget at thermo-equilibrium state, the fundamental equation is

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

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

$$h_i = f(\alpha_s, i_0, Sz, T_s, T_i, T_a, P_a, h_w, U, C, h_s, F_a, R_g, R_d),$$

where R_g, R_d *are ice growth/melting and ice dynamic process adjust factors, respectively.*



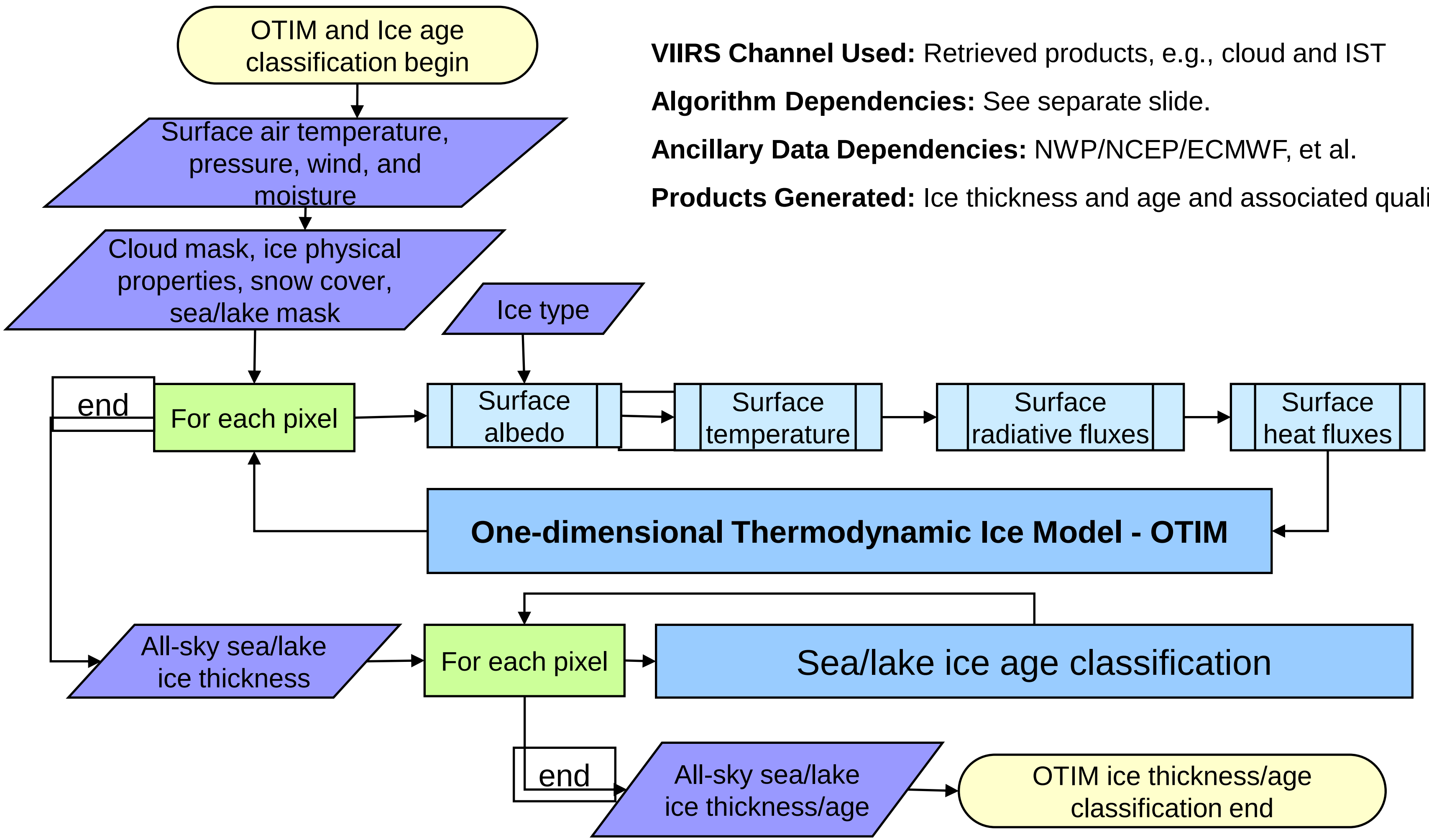
Sea Ice Age/Thickness Processing

VIIRS Channel Used: Retrieved products, e.g., cloud and IST

Algorithm Dependencies: See separate slide.

Ancillary Data Dependencies: NWP/NCEP/ECMWF, et al.

Products Generated: Ice thickness and age and associated quality flags.



Sea Ice Age/Thickness

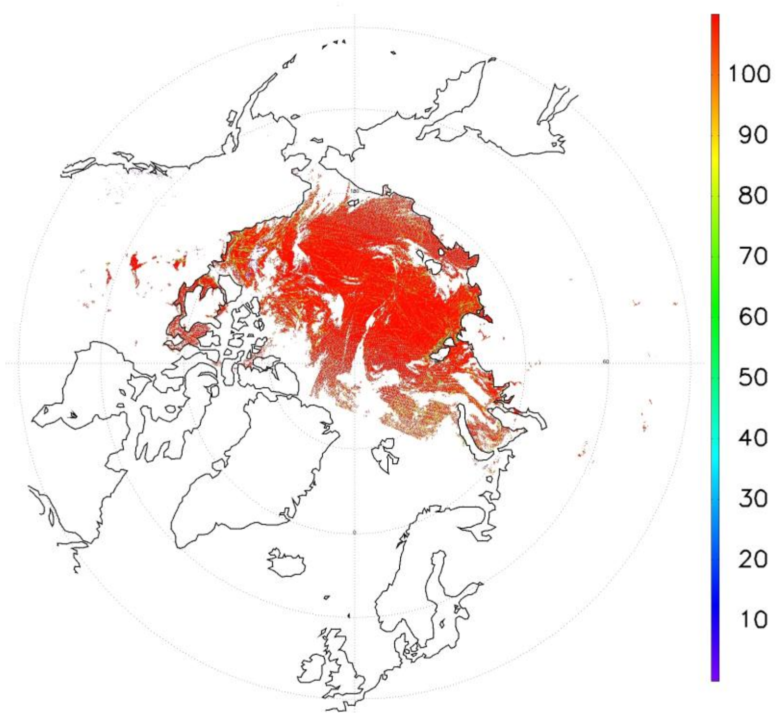
- Team members:
  - CIMSS
- Users:
  - National Ice Center (NIC)
  - NWS Ice Desk
  - Eventually modelers (operational and research)
- What instruments use this product?
  - VIIRS, MODIS, AVHRR, ABI, AHI (not yet)

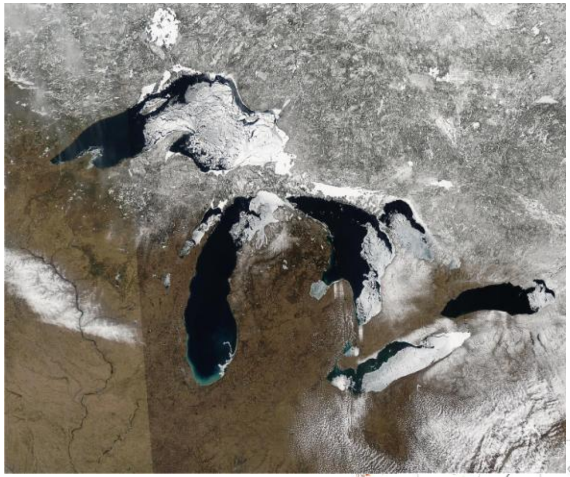
Path Forward: Ice Age/Thickness

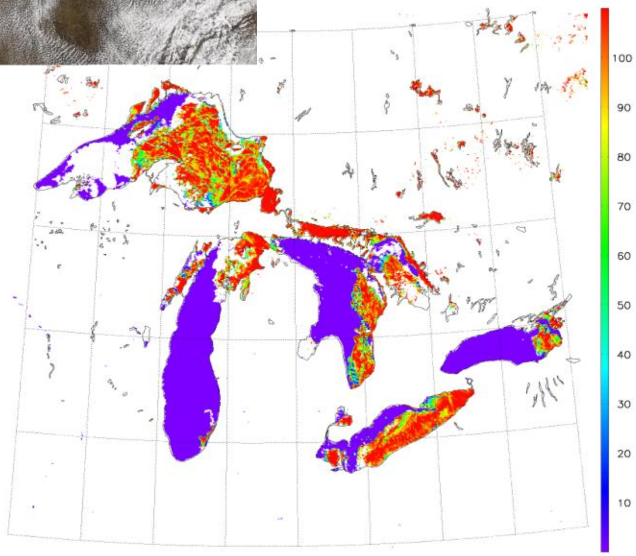
- Similarity to IDPS EDR:
  - Similar concept (nighttime) but very different overall.
  - Performance is much better.
- Status:
  - CDR and ARR complete. Scheduled for operations in 2016.
- Anticipated developments
  - Continue improving the daytime retrieval
  - Investigate the benefits of blending VIIRS and Cryosat-2 ice thickness
- Upcoming Deliveries/Reviews
  - None
- Risks
  - None

Ice Concentration

Sea ice concentration is the areal extent of ice, calculated as the fraction of each pixel covered in ice. The concentration of sea ice varies within the ice pack due to deformation, new ice development, melting, and motion.







Above: Ice concentration over the Arctic Ocean from VIIRS on February 20, 2015. Right: MODIS ice concentration on the Great Lakes, March 28, 2015.

Ice Concentration

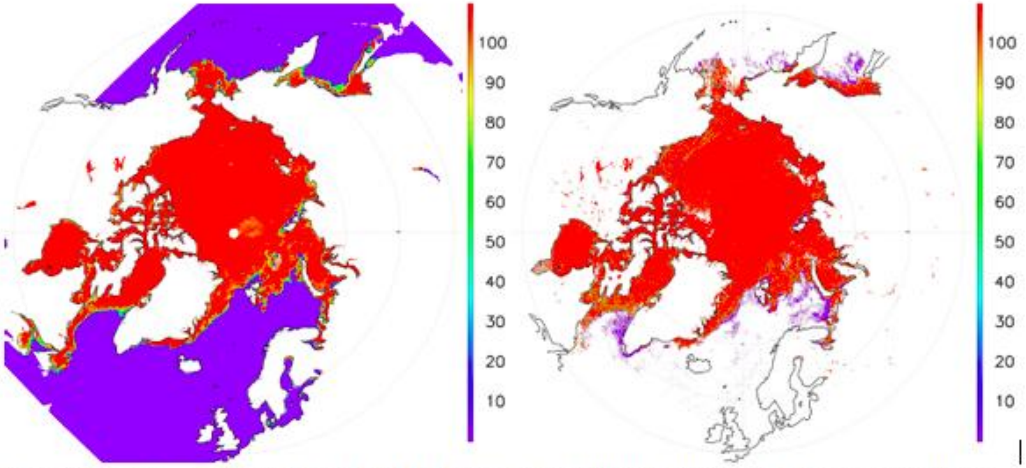


Figure 8: Ice concentration from SSMIS (left) and a daily ice concentration composite from VIIRS (right) over the Arctic on February 20, 2015.

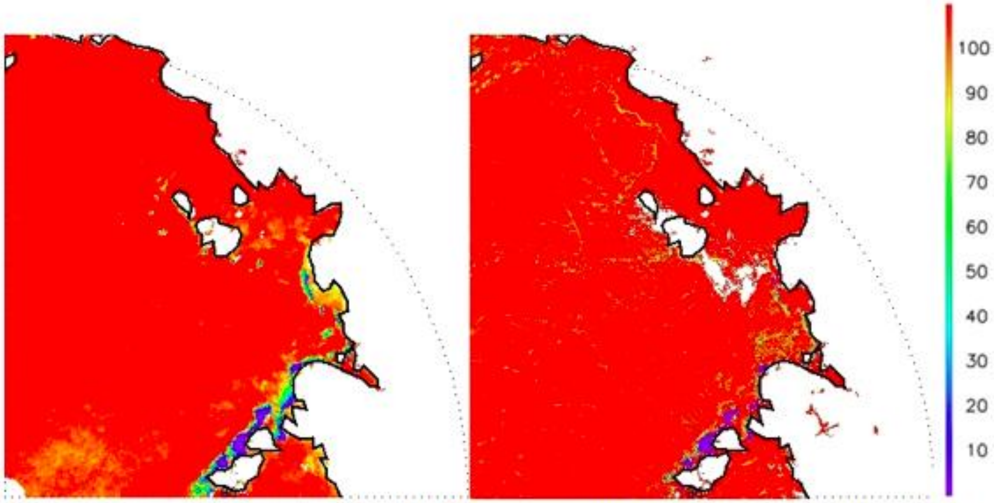


Figure 9: Ice concentration from SSMIS (left), and from VIIRS daily composite over portion of the Arctic (longitude: 90 – 180, latitude: 70 – 90) on February 20, 2015. The North Pole is in the lower left corner.

Ice Concentration Algorithm

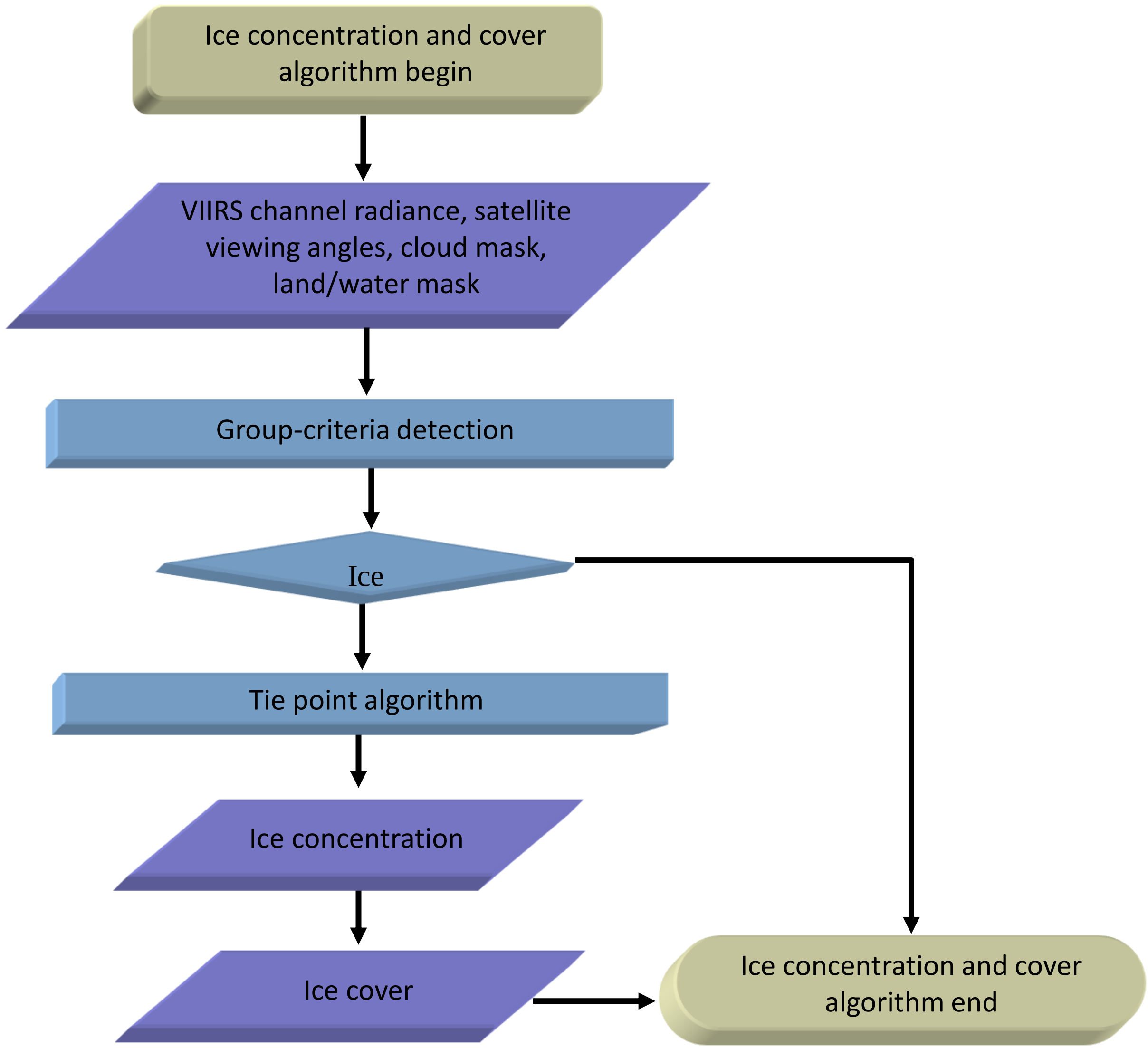
Use threshold tests to detect possible ice cover: Daytime and Nighttime

Use a tie-point algorithm to derive reflectance (temperature) for pure ice pixel, and then calculate ice concentration

- Reflectance (temperature) of pure ice and pure water are tied to points in a frequency histogram, and the ice fraction in a pixel (ice concentration) is determined by linearly interpolating between these tie points

Ice pixels with retrieved ice concentration larger than 15% are identified as ice. Ice pixels with retrieved ice concentration smaller than 15% are not identified as ice

Ice Concentration Processing



Ice Concentration

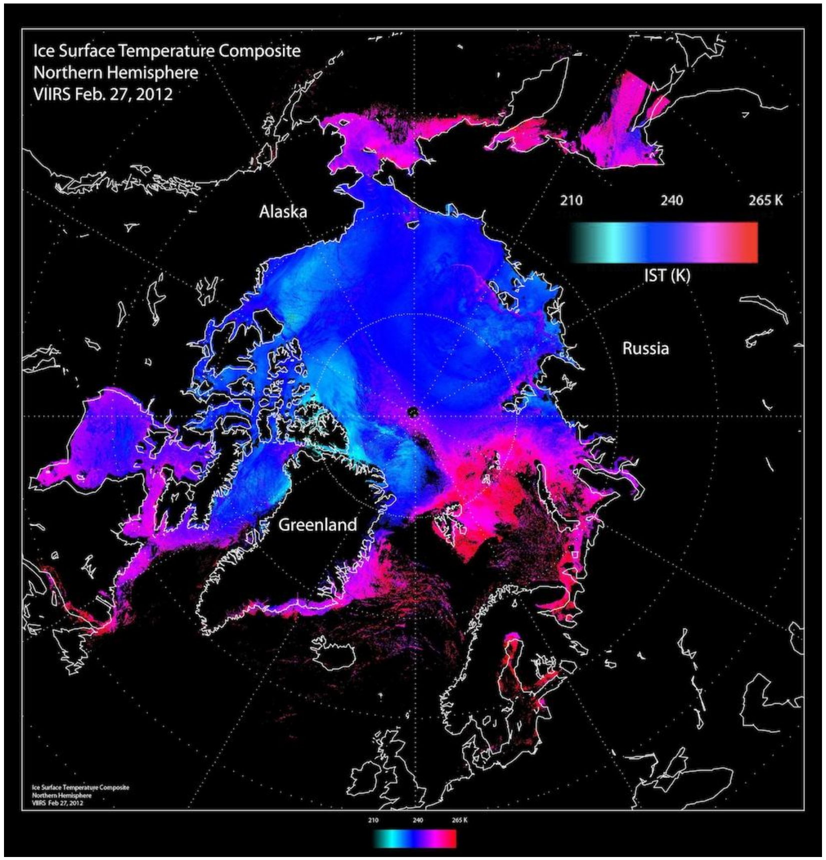
- Team members:
  - CIMSS, CIRES
- Users:
  - National Ice Center (NIC)
  - NWS Ice Desk
  - Naval Oceanographic Center
  - NCEP (anticipated)
- What instruments use this product?
  - VIIRS, MODIS, AVHRR, ABI, AHI

Path Forward: Ice Concentration

- Similarity to IDPS IP:
  - Similar algorithm. Differences in details.
  - Works for freshwater ice as well as sea ice.
  - Performance is similar overall; better in some conditions.
- Status:
  - CDR and ARR complete. Scheduled for operations in 2016.
- Anticipated developments
  - Tune tie point algorithm details
- Upcoming Deliveries/Reviews
  - None
- Risks
  - None

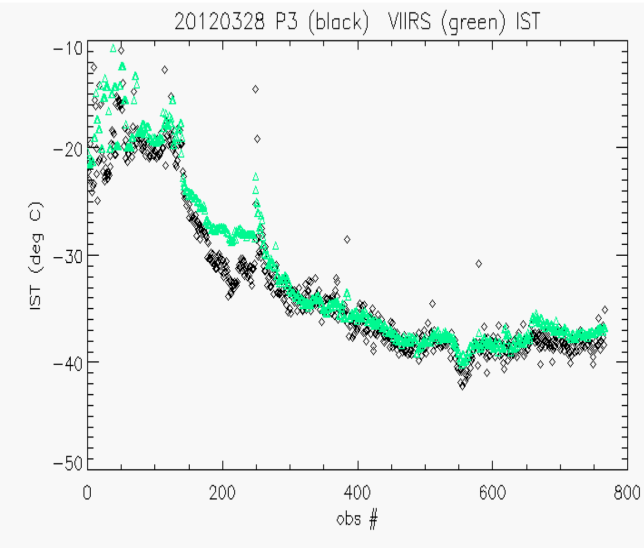
Ice Surface Temperature

The Ice Surface Temperature (IST) is the surface skin, or radiating, temperature of sea ice.



Composite of VIIRS Ice Surface Temperature on 27 Feb 2012.

IceBridge KT19 vs VIIRS IST, 2012

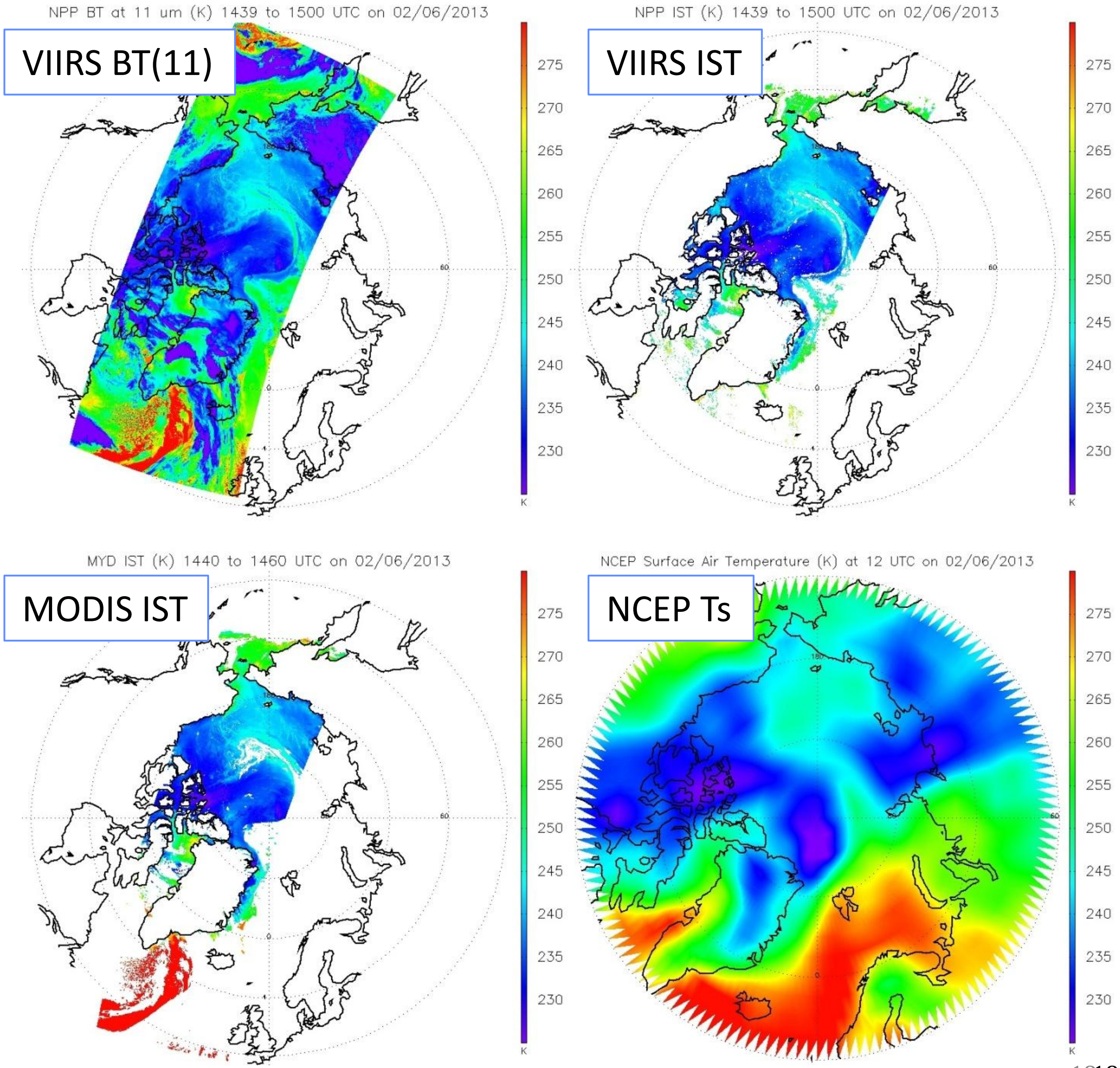


DATE	BIAS	RMS
3/14	0.56	0.08
3/15	-0.84	0.63
3/16	1.01	0.71
3/21	-0.55	0.41
3/22	-0.21	0.14
3/27	0.12	0.21
3/28	1.12	0.53
3/29	0.46	0.10
4/02	0.66	0.19

BIAS = VIIRS - KT19

Ice Surface Temperature

Comparisons are routinely done between MODIS IST and NCEP surface temperatures.



Ice Surface Temperature Algorithm

Ice/snow surface temperature is retrieved by the following equation (Key et al. 1997).

$$T_s = a + b\,T11 + cT12 + d\,[(T11\text{-}T12)(\sec\theta - 1)]$$

T_s = the estimated surface temperature (K)

T11 = the brightness temperatures (K) at 11 um

T12 = the brightness temperatures (K) at 12 um

θ = sensor scan angle

a, b, c, d = coefficients, derived for the following temperature ranges: T11 < 240K, 240K < T11 < 260K, T11 > 260K.

Ice Surface Temperature

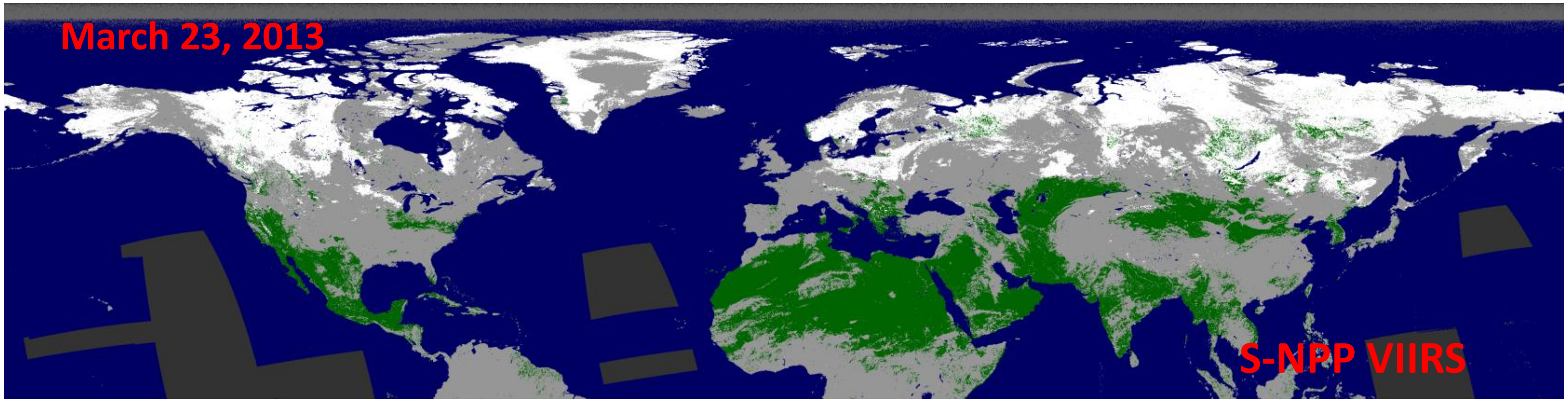
- Team members:
  - CIMSS, CIRES
- Users:
  - National Ice Center (NIC), NWS Ice Desk
  - Eventually modelers (operational and research)
- What instruments use this product?
  - VIIRS, MODIS, AVHRR, ABI, AHI

Path Forward: IST

- Similarity to IDPS EDR:
  - Similar algorithm. Differences in details.
  - Performance is somewhat better overall.
- Status:
  - CDR and ARR complete. Scheduled for operations in 2016.
- Anticipated developments
  - Regenerate regression coefficients with additional raob data
- Upcoming Deliveries/Reviews
  - None
- Risks
  - None

Binary Snow Cover

Snow Cover is the horizontal and vertical extent of snow cover. The binary product gives a snow/no-snow flag.



snow | land | cloud | No data

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

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

Binary Snow Cover Algorithm

- Decision-tree, threshold-based algorithm

- Almost identical to MODIS

- Applied to cloud clear land pixels (uses external cloud mask)

- Requires daytime observation conditions

- Uses

Reflectance in VIIRS bands I1 (R_1) , I2 (R_2), I3 (R_3)
Brightness temperature in VIIRS band I5 (T_5)

- Calculates

NDSI= $(R_1-R_3)/(R_1+R_3)$: Norm. Dif. Snow Index
NDVI= $(R_2-R_1)/(R_2+R_1)$: Norm. Dif. Vegetation Index

Binary Snow Cover

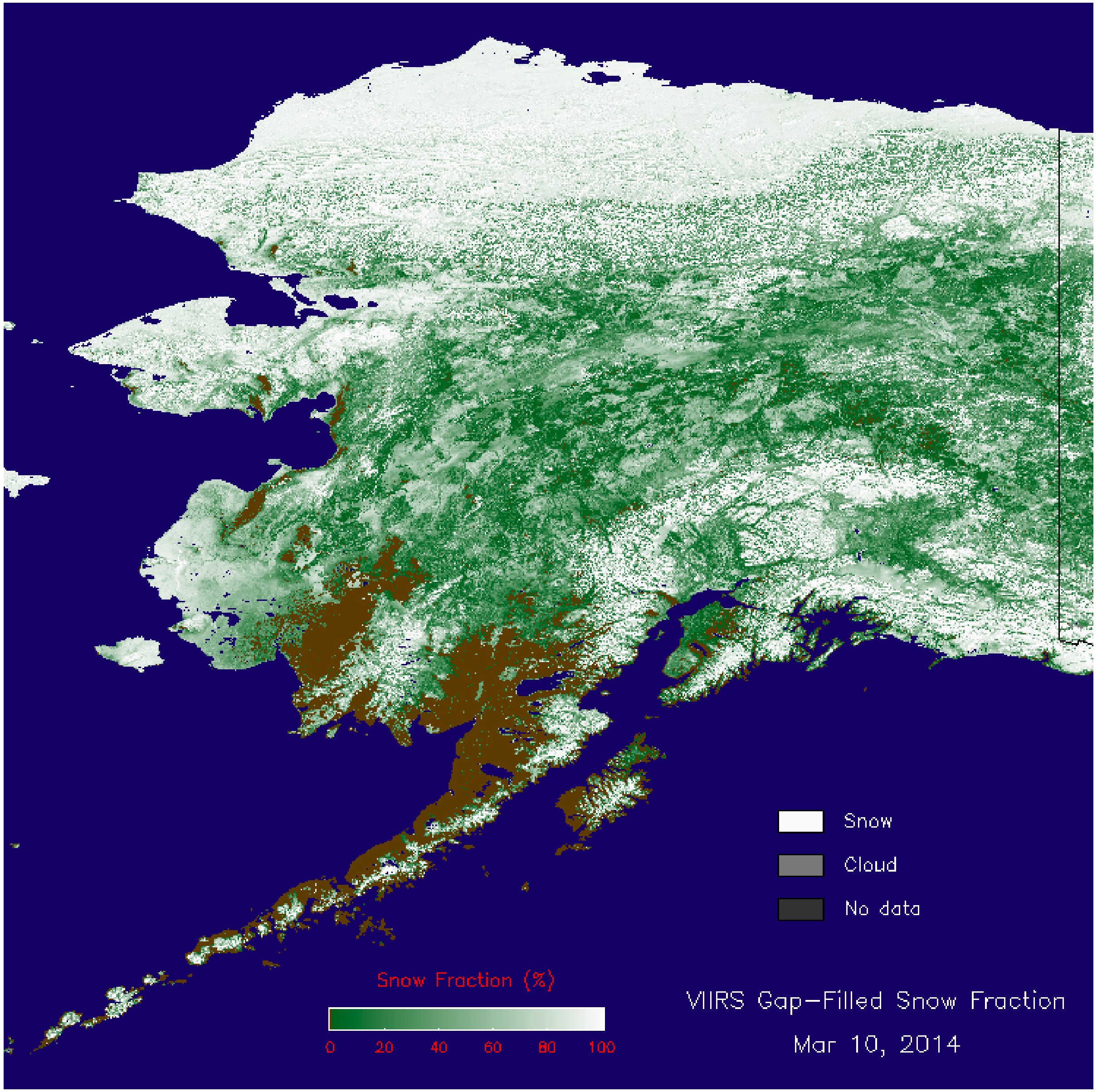
- Team members:
  - CREST/CCNY
- Users:
  - NCEP (anticipated)
  - River Forecast Center (anticipated)
  - National Ice Center (NIC)
- What instruments use this product?
  - VIIRS, MODIS, GOES

Path Forward: Binary Snow Cover

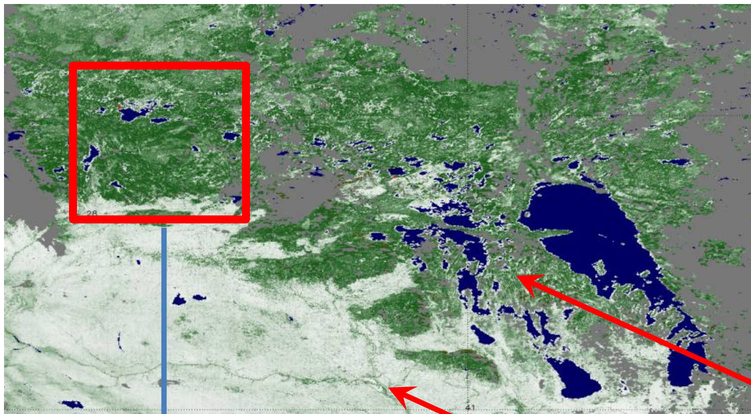
- Similarity to IDPS EDR:
  - Similar in concept though important differences.
  - Performance is somewhat better overall.
- Status:
  - CDR and ARR complete. Scheduled for operations in 2016.
- Anticipated developments
  - Evaluate the utility of geometry-dependent thresholds
  - Implement additional consistency tests (surface temperature gradient test)
  - Explore the use of VIIRS 3.7 µm band data
- Upcoming Deliveries/Reviews
  - None
- Risks
  - None

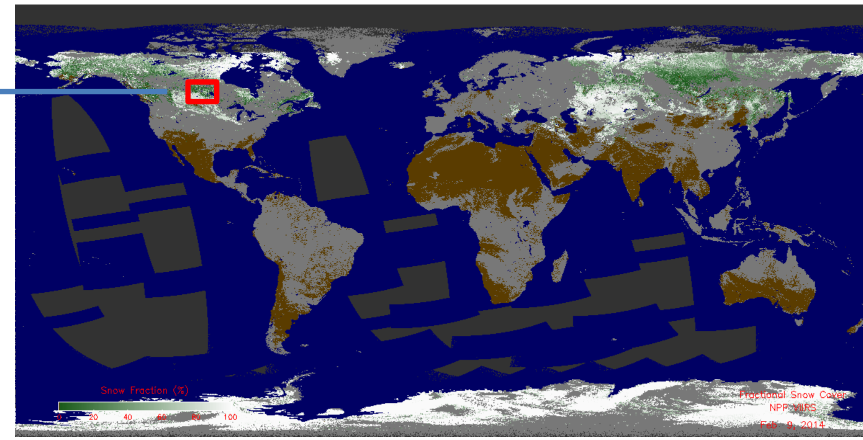
Snow Fraction

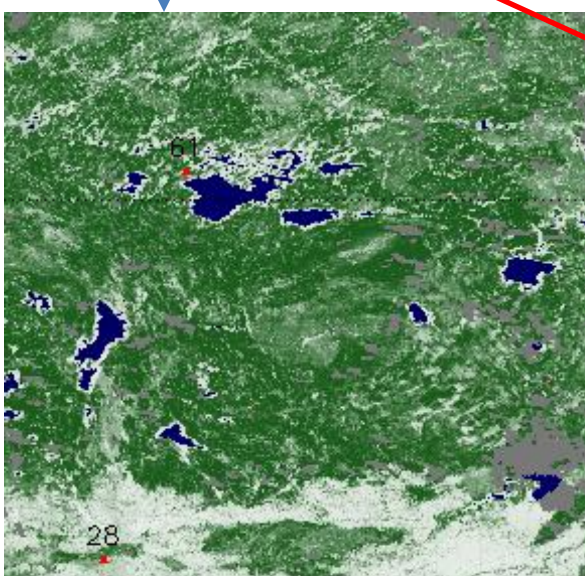
The fractional snow cover is defined as the fraction of a given area of the earth's horizontal surface that is covered by snow as seen from the satellite ("viewable" snow fraction). The fractional snow cover does not account for the snow masked by vegetation.



Snow Fraction

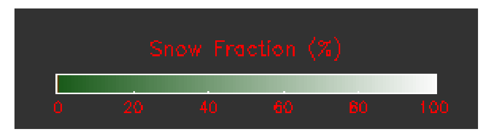






Forest

Prairies



Clouds are shown in gray

<u>VIIRS Global Reflectance-Based Snow Fraction</u>: The spatial pattern of the derived snow fraction is consistent with the pattern of forest cover distribution in Northern Hemisphere

Snow Fraction

Reflectance-based, modified from Romanov et al (2003)

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

- Uses band 1 (visible) reflectance

- R_{land} and R_{snow} are global and are determined empirically. They change with observation geometry

- Algorithm used with GOES Imager and AVHRR

NDSI-based, recent (2015) enhancement of Salomonson & Appel

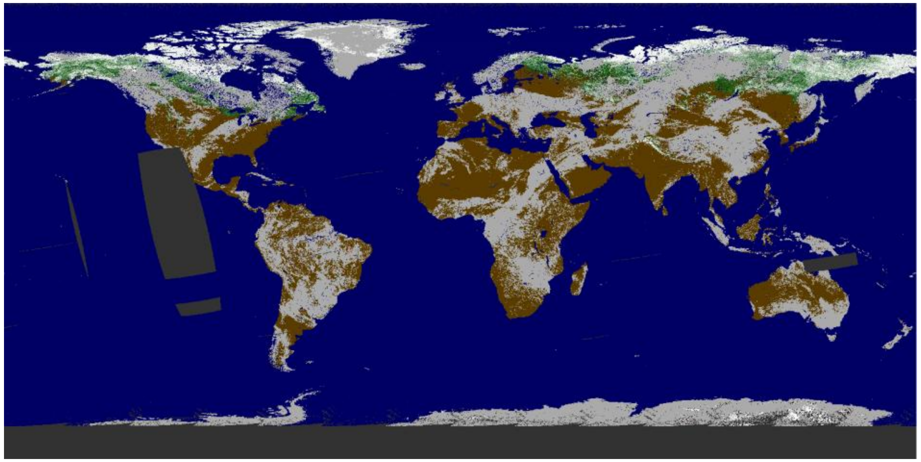
$$SnowFraction = (NDSI - NDSI_{non\text{-}snow}) / (NDSI_{snow} - NDSI_{non\text{-}snow})$$

- Slope and Intercept are local and are established on the fly
- MODIS heritage algorithm
- Adopted as the primary algorithm for JPSS

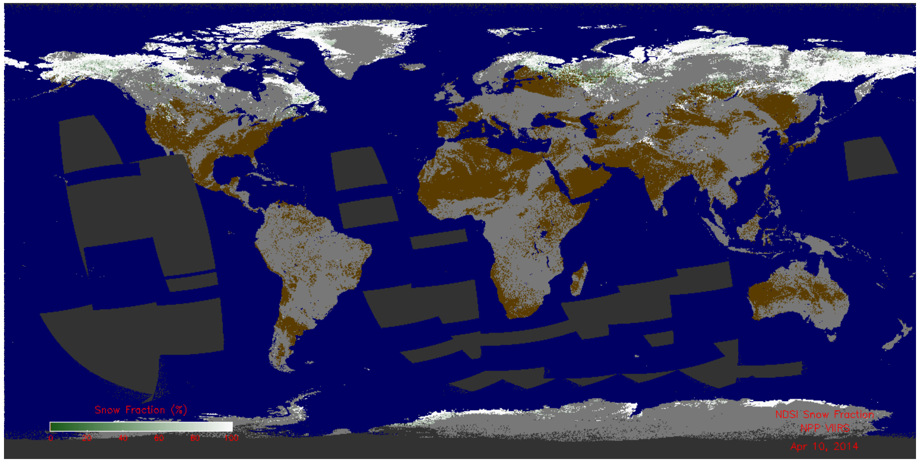
Two Snow Fraction Algorithms

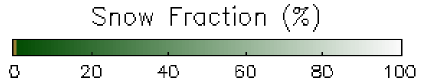
S-NPP/VIIRS Snow Fraction Maps derived from VIIRS observations on April 10, 2014

Reflectance-based



NDSI-based





land cloud No data

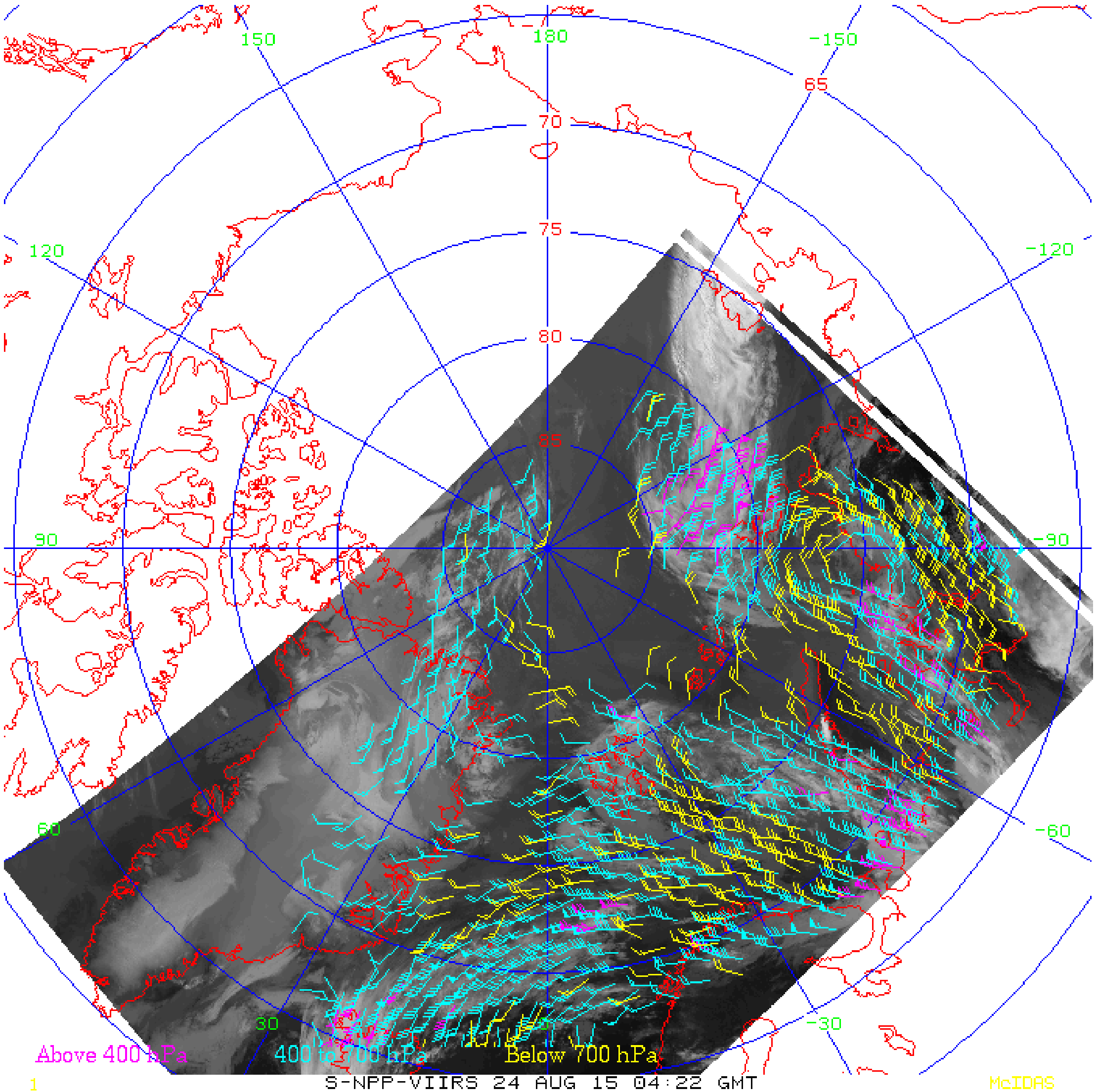
Snow Fraction

- Team members:
  - CREST/CCNY (and formerly I. Appel)
- Users:
  - NCEP (anticipated)
  - River Forecast Center (anticipated)
  - National Ice Center (NIC)
- What instruments use this product?
  - VIIRS, MODIS, GOES (reflectance-based)

Path Forward: Snow Fraction

- Similarity to IDPS EDR:
  - Completely different concept (subpixel fraction vs 2x2 ave)
  - Performance is better and it is a more useful product
- Status:
  - CDR and ARR complete. Scheduled for operations in 2016.
- Anticipated developments
  - Complement the current NDSI and reflectance-based "viewable" snow fraction with the "true" snow cover fraction
- Upcoming Deliveries/Reviews
  - None
- Risks
  - None

Polar Winds



VIIRS polar winds are derived by tracking clouds in infrared imagery. Wind speed, direction, and height are estimated throughout the troposphere, poleward of approximately 70 degrees latitude.

Left: VIIRS winds from Sodankylä, Finland on 24 August 2015

Unique VIIRS Characteristics for Winds

- VIIRS’ unique characteristics relevant to a polar winds product include:
  - **Higher spatial resolution (750 m for most bands; 375 m for some)**
  - **Wider swath than MODIS**
  - **Constrained pixel growth: better resolution at edge of swath**
  - **Day-night band (DNB)**
  - Disadvantage: No thermal water vapor band so no clear-sky WV winds
- The VIIRS polar winds processing **utilizes the GOES-R AMV algorithm**.

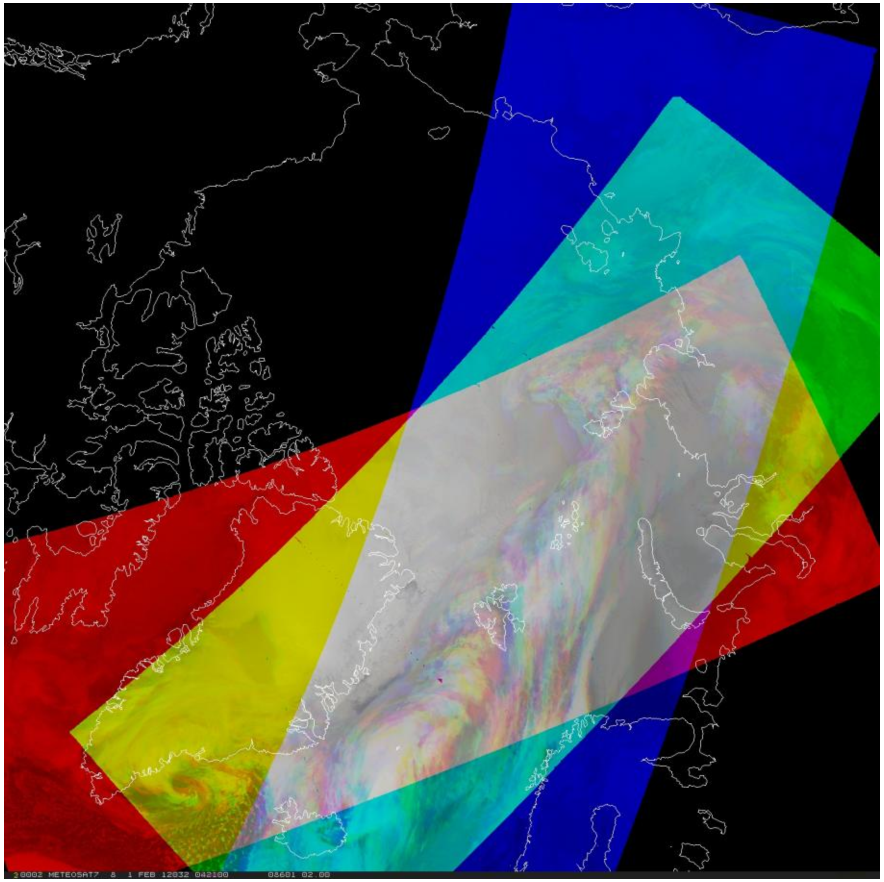
VIIRS Winds Algorithm

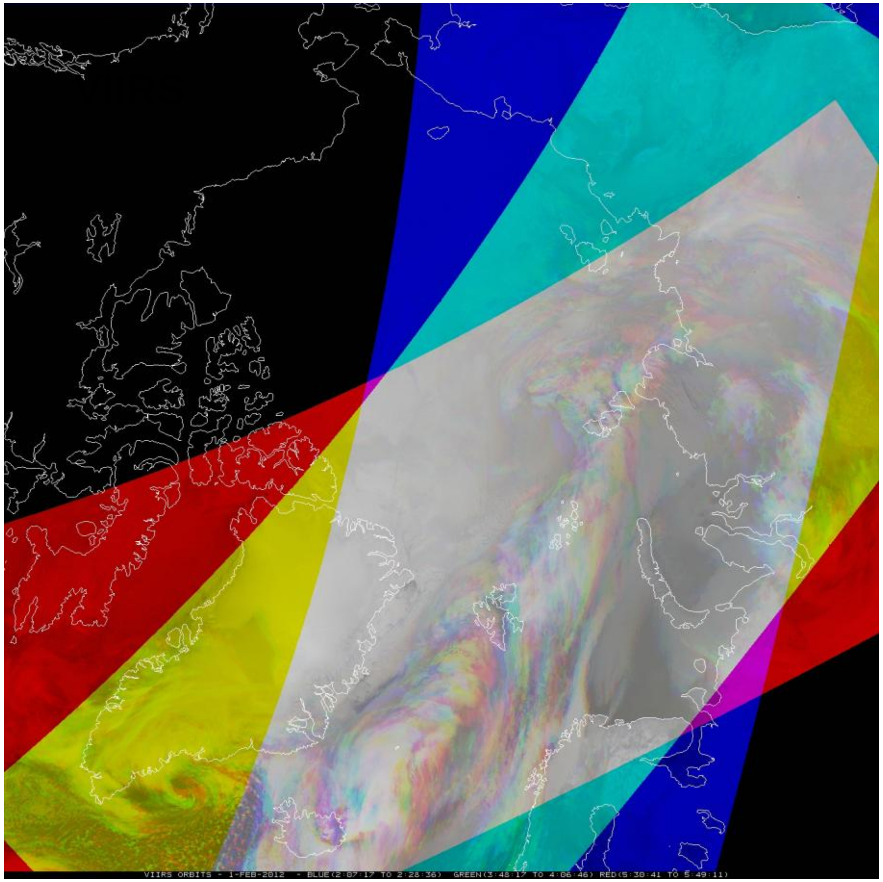
The derived motion wind approach consists of the following general steps (each step will be described in more detail in subsequent slides):

1. Locate and select a suitable target in second image (middle image; time=t_0) of image triplet
2. Use a pattern matching algorithm used in conjunction with a nested tracking algorithm to derive the motion most representative of the target scene.
    3. Track target backward in time (to first image; time=$t-\Delta t$) and forward in time (to third image; time=$t+\Delta t$) and compute corresponding displacement vectors. Compute mean vector displacement valid at time = t_0.
4. Assign a representative height to target
5. Perform quality assurance on derived wind vectors. Flag suspect vectors. Compute and append quality indicators to each vector

VIIRS Winds Algorithm

Winds are derived in the area of overlap in three orbits. VIIRS has a wider swath (3000 km) than MODIS (2320 km), so the coverage is better and extends further south.



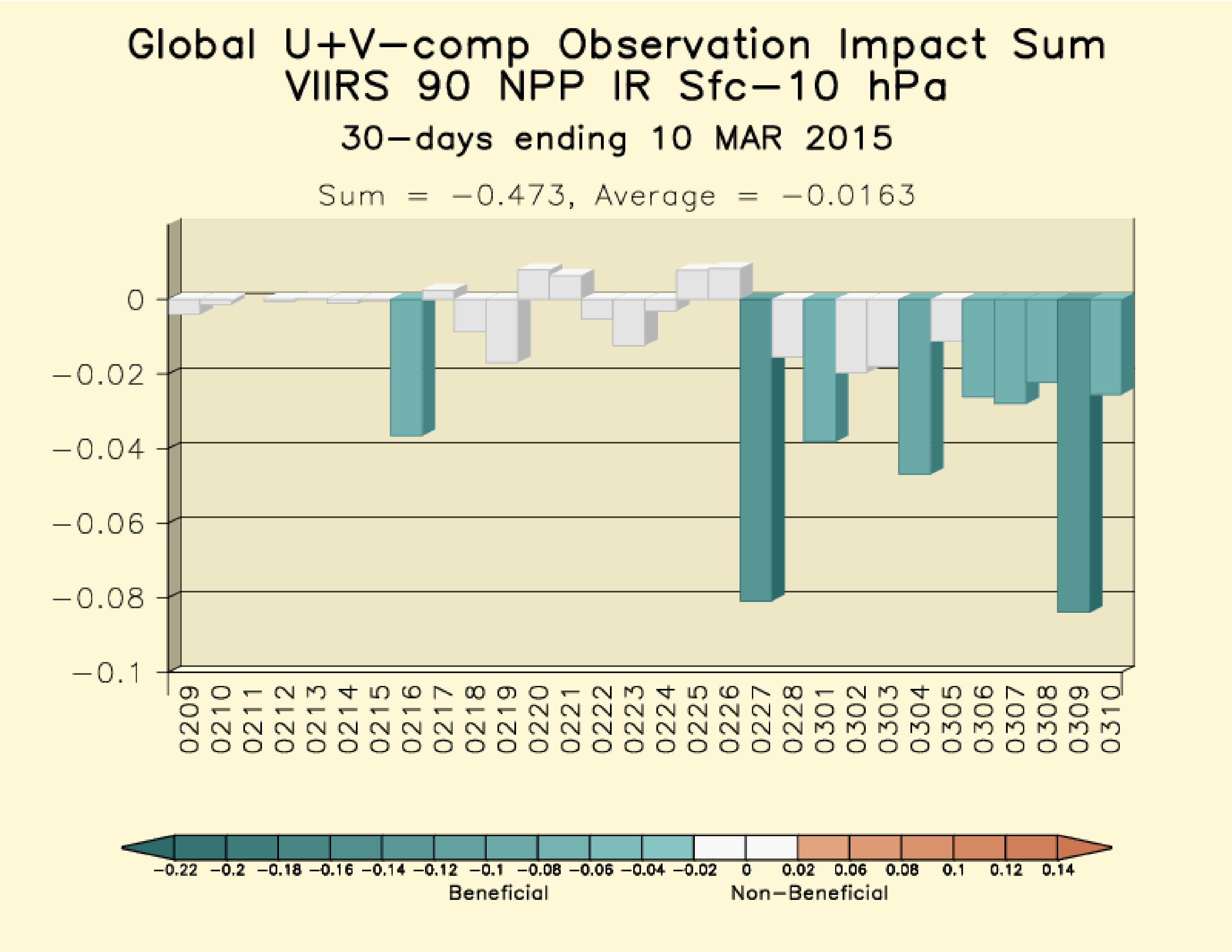


A wider swath means more winds with each orbit.

VIIRS Winds

- Team members:
  - CIMSS
- Users:
  - 13 NWP centers in 9 countries for the various polar winds products.
- What instruments use this product?
  - VIIRS, MODIS, AVHRR, ABI (not polar)

VIIRS Winds Model Impact at NRL



Path Forward: Winds

- Status:
  - Operational since May 2014.
- Anticipated developments
  - Change from the IDPS VCM to the Enterprise cloud mask.
  - Investigate the feasibility of dual S-NPP/JPSS-1 pairing for global winds.
  - More direct broadcast sites.
  - Adapt VIIRS algorithm to MODIS and AVHRR (in progress).
  - Investigate the use of a shortwave IR band (in progress).
- Upcoming Deliveries/Reviews
  - None
- Risks
  - None

Lessons Learned: All Products

1. Implementation of product in NDE system
   - Everything takes longer than expected.
   - The process is more flexible than the IDPS work (thank you!).
2. Interdependency with other NDE products
   - The VIIRS winds product currently uses the IDPS VIIRS Cloud Mask (VCM). It will be changed to the Enterprise cloud mask this summer (2016).
   - The snow and ice products are also dependent upon the cloud mask, which tends to have large uncertainties in the polar regions.

Summary

- All products are either operational (winds) or will be operational later this year.
- The process of transitioning to NDE was relatively smooth, with lots of help from the AIT (ASSISTT).
- Outstanding issues: We need reprocessing infrastructure.