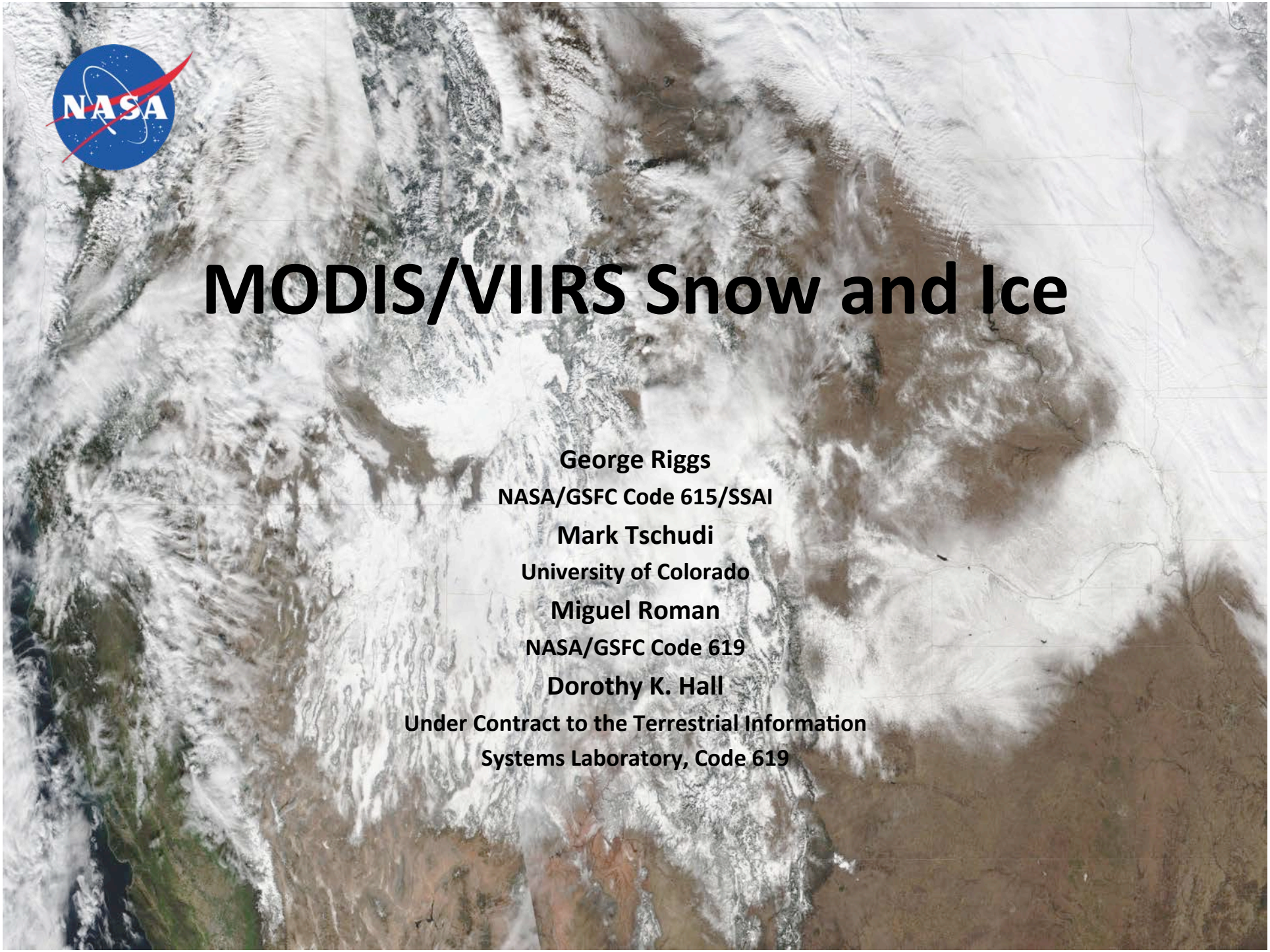


MODIS/VIIRS Snow and Ice

George Riggs

NASA/GSFC Code 615/SSAI

Mark Tschudi

University of Colorado

Miguel Roman

NASA/GSFC Code 619

Dorothy K. Hall

Under Contract to the Terrestrial Information Systems Laboratory, Code 619

MODIS C6 Snow Algorithm

Detection of snow cover extent for hydrologic and climatology applications or research

Snow cover detection uses the Normalized Difference Snow Index (NDSI) technique

Snow cover always has NDSI > 0.0

A surface with NDSI > 0.0 is not always snow cover

Data screens are applied to alleviate snow commission errors and flag uncertain snow cover detections

Fractional snow cover (FSC) is not calculated in C6

MODIS C6 Snow Algorithm

NDSI snow detection applied to all land and inland water pixels.
MOD02HKM TOA reflectance input. MODIS land/water mask used.
Clouds masked with MODIS cloud mask product MOD35_L2.

Data screens applied to alleviate snow commission errors and flag uncertain snow cover detection situations.

- Inland water flag
- Low visible reflectance screen
- Low NDSI screen
- Surface temperature and height screen/flag
- High SWIR screen/flag
- Solar zenith flag

- QA bit flags are set for snow cover detections that are changed to no snow and are set for higher uncertainty in snow cover detection, and for high solar zenith angles.

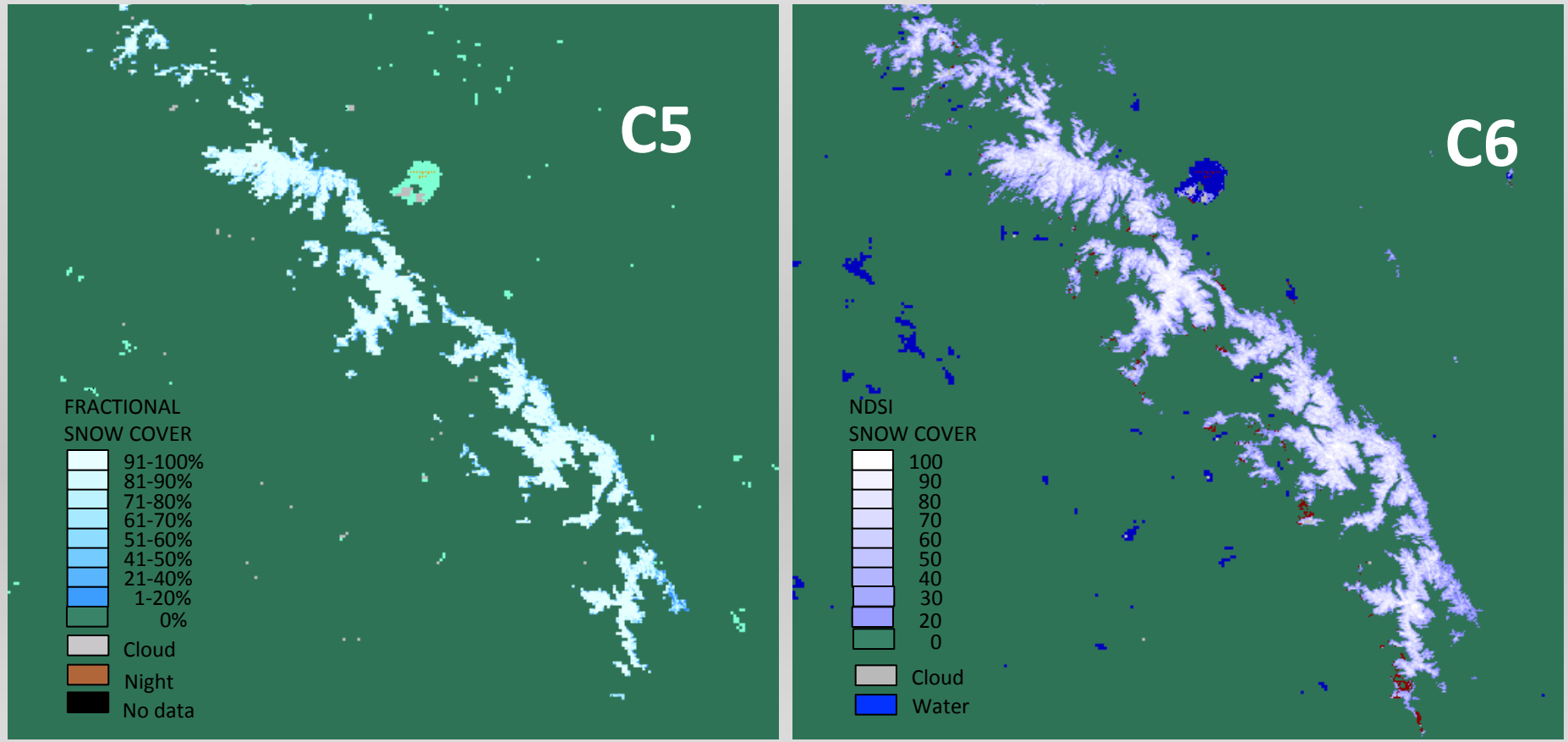
The NDSI values are output for all land and inland water pixels -- cloud mask is not applied.

MODIS C5 to C6 Snow Products Data Content Comparison

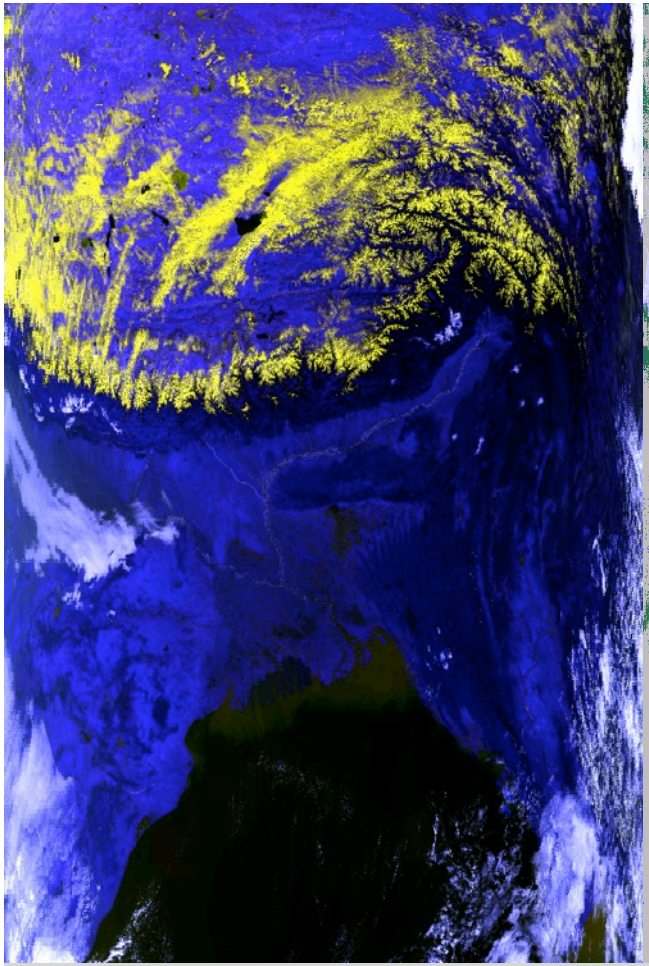
MOD10_L2 SDSs	
C5	C6
Snow_Cover , binary snow cover, with masked features	
Fractional_Snow_Cover, 0-100% with masked features	NDSI_Snow_Cover, -- Snow cover map by NDSI in 0-100 range, with masked features.
	NDSI_Snow_Cover_Algorithm_ Flags_QA – bit flags for data screens applied in the algorithm.
Snow_Cover_Pixel_QA, basic quality value	NDSI_Snow_Cover_Basic_QA, -- basic quality value
	NDSI – NDSI value for all land and inland water pixels in a swath
Latitude (5km resolution)	Latitude (5km resolution)
Longitude (5km resolution)	Longitude (5km resolution)

MOD10A1 SDSs	
C5	C6
Snow_Cover , binary snow cover, with masked features	
Fractional_Snow_Cover, 0-100% with masked features	NDSI_Snow_Cover, -- Snow cover map by NDSI in 0-100 range, with masked features.
	NDSI_Snow_Cover_Algorithm_ Flags_QA – bit flags for data screens applied in the algorithm.
Snow_Cover_Pixel_QA, basic quality value	NDSI_Snow_Cover_Basic_QA, -- basic quality value
	NDSI – NDSI value for all land and inland water pixels in a swath
Snow_Albedo_Daily_Tile	Snow_Albedo_Daily_Tile
	orbit_pnt (*pointer*)
	granule_pnt (*pointer*)

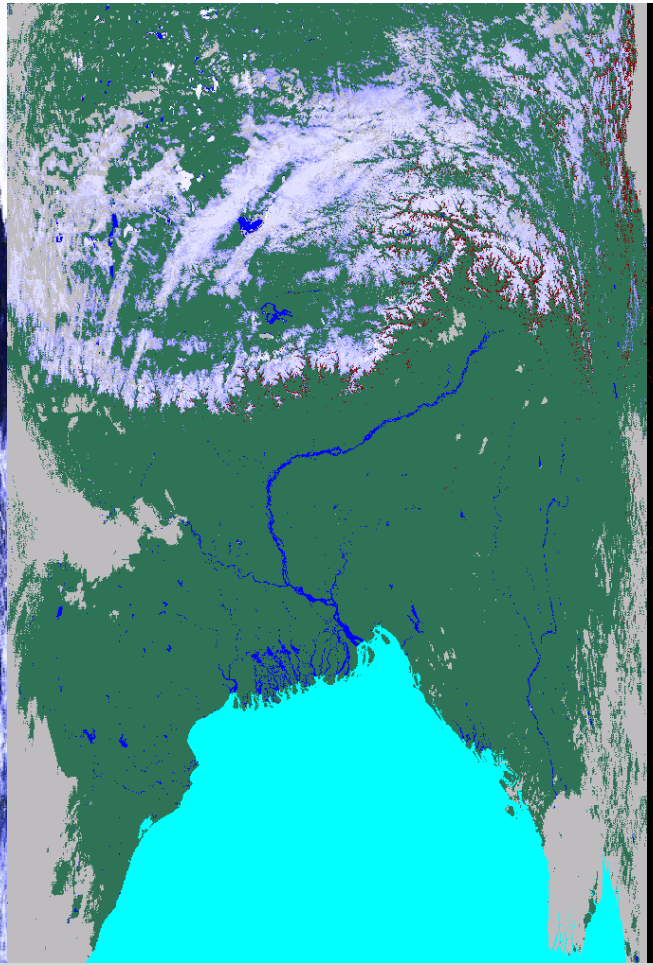
Spring – summer mountain snow cover omission error prevalent in C5 is corrected in C6



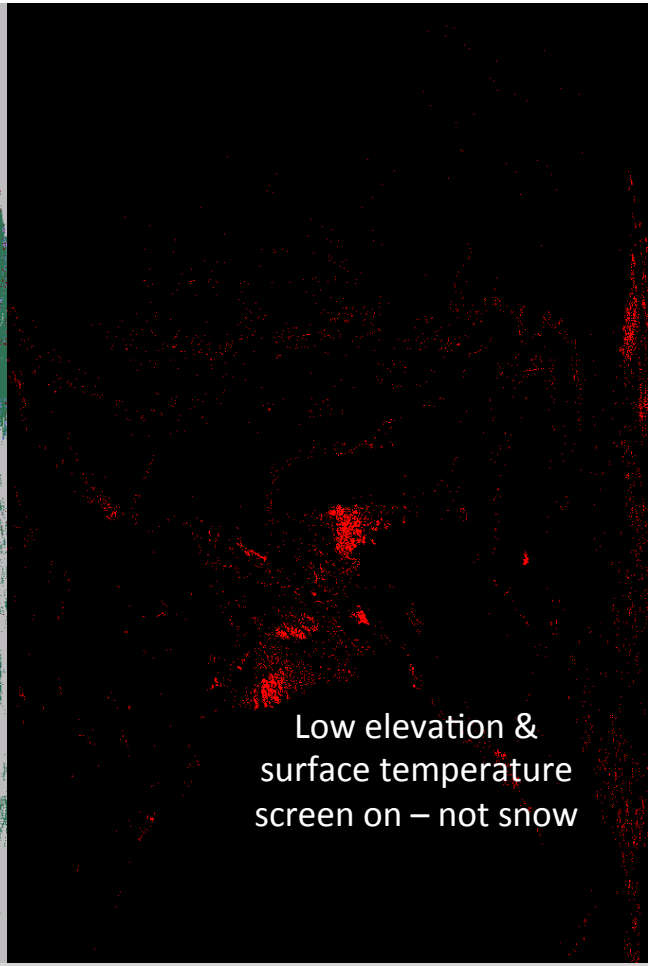
MOD10_L2.A2010170.1900 (19 June) Sierra Nevada region. C6 has greatly improved accuracy compared to C5. C6 snow cover extent is ~2303 km^2 greater than in C5 which is ~ 74% improvement. The surface temperature screen is not applied on mountains in C6.



MOD02HKM.A2003003.0440.006.*.hdf
RGB of bands 1,4,6

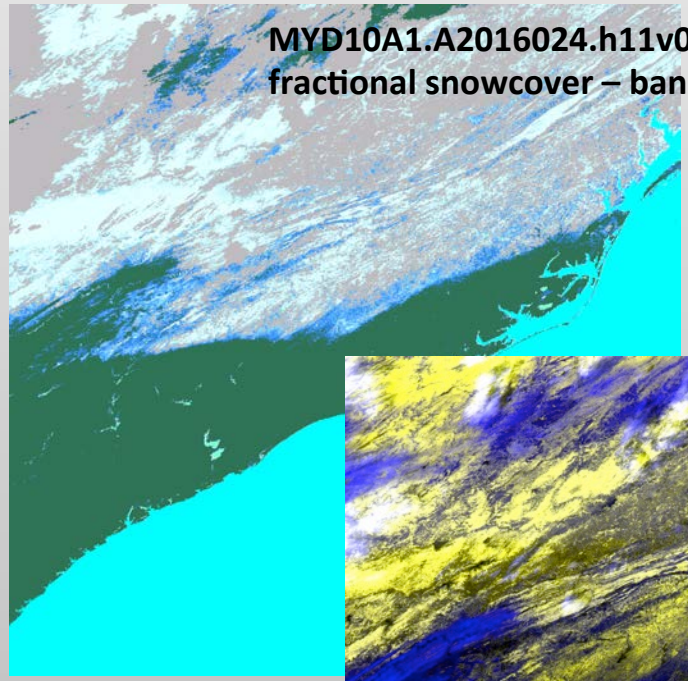


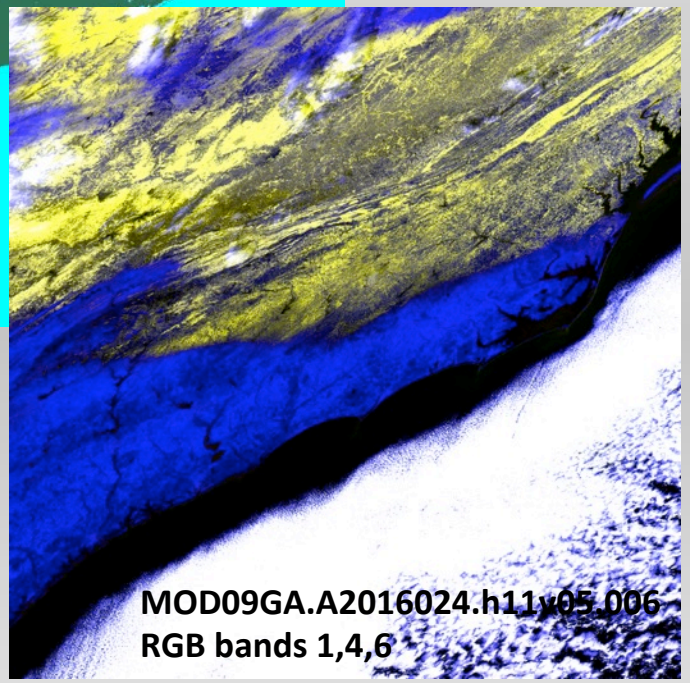
MOD10_L2.A2003003.0440.006.*.hdf
NDSI_Snow_Cover

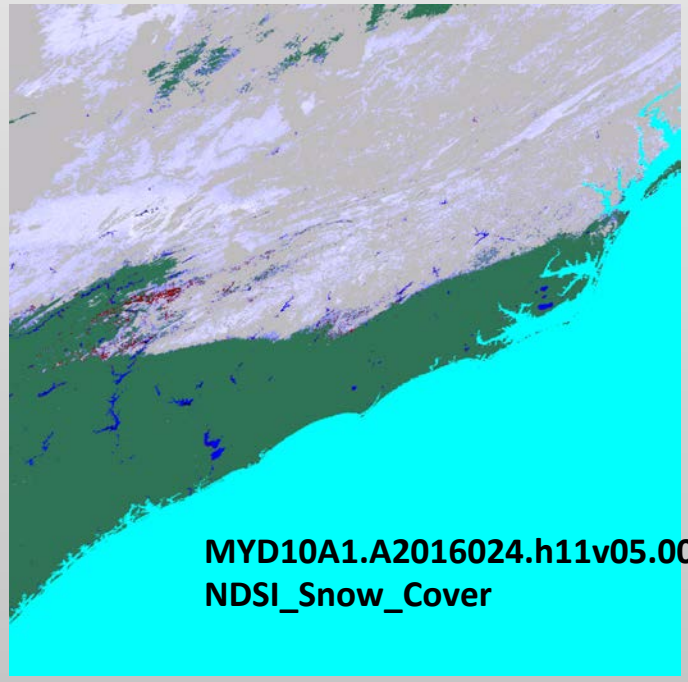


MOD10_L2.A2003003.0440.006.*.hdf
Mask of bit 3 of the QA algorithm flags

The combined surface temperature and height screen effectively blocks erroneous snow cover detections at low elevations that may not be blocked by other data screens, does not affect high elevation snow cover detection. Where that screen blocks snow commission error shown in red on right image. Himalayas in north half of swath, India and Bay of Bengal to the south.

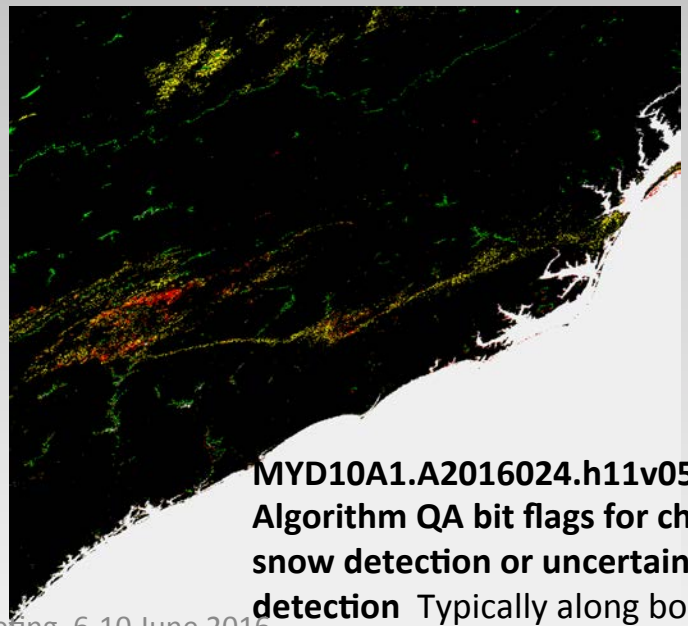






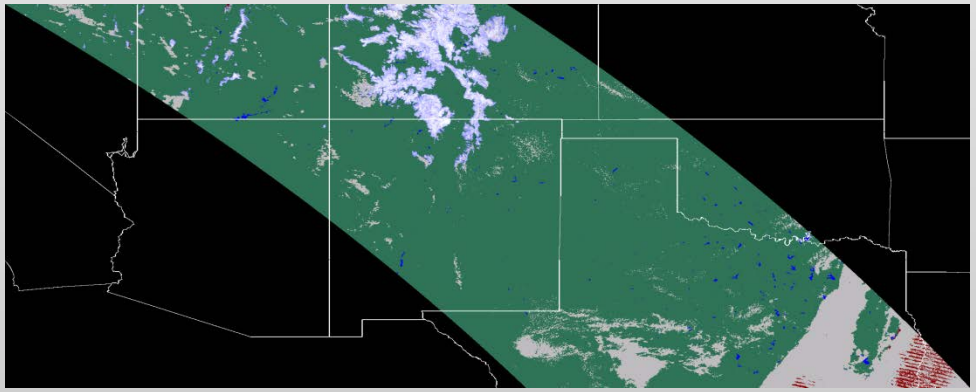
Aqua MYD10 uses QIR of Band 6

In C6 the QIR technique is used to restore Aqua MODIS band6 data for use in the snow algorithm More accurate mapping of snow cover in C6 compared to C5 notably in difficult to detect situations along snow extent boundary as flagged by the algorithm QA bit flags.

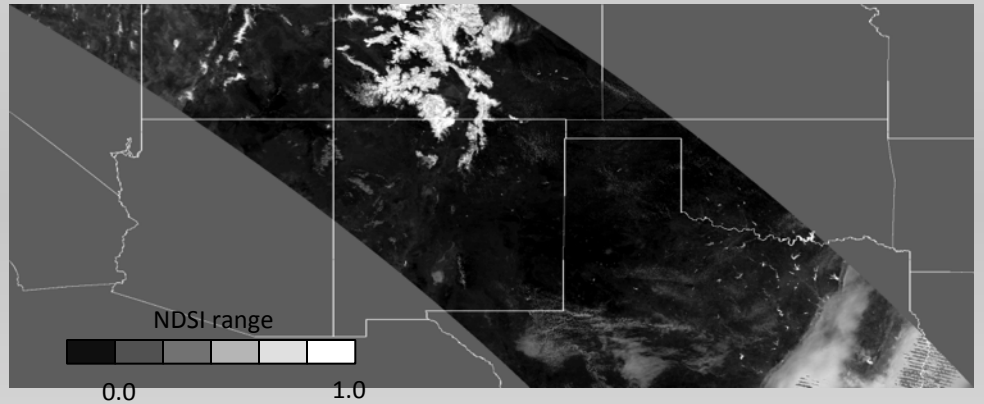


MYD10A1.A2016024.h11v05.006
Algorithm QA bit flags for changed snow detection or uncertain snow detection Typically along boundary of snow cover.

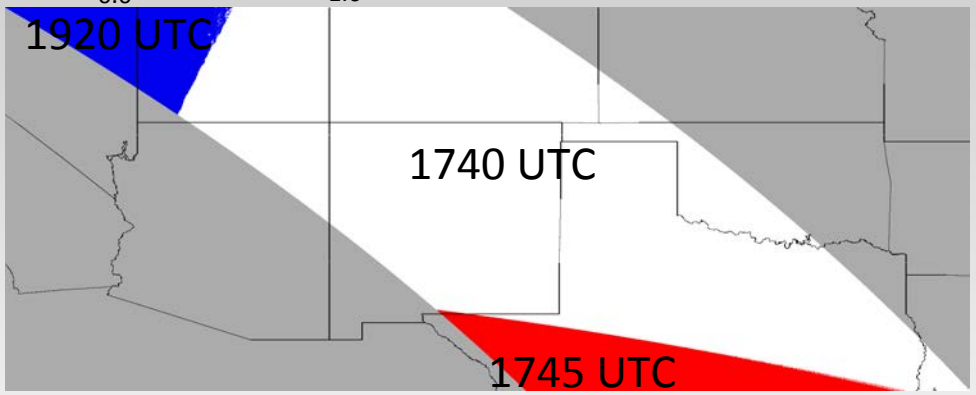
Time of observation included in C6 M*D10A1 products



MOD10A1.A2016112.h09v05.006



NDSI



Granule_ptr
Pointer to input MOD10_L2, use as index to get swath start time from list of product inputs in the metadata.

MODIS C6 Products Released

NSIDC released C6 products in April and May 2016

MODIS C6 user guide is available

C6 data product content is different from C5

Users familiar with the C5 binary snow cover and FSC data will have to adjust to using the new NDSI_Snow_Cover data.

Providing users with the NDSI data enables them to have flexibility in deriving snow cover area SCA maps for their purposes.

Users can use the Algorithm_flags_QA data to evaluate the snow cover data for their particular research or application. Also possible to adjust snow cover extent by combining the algorithm flags, snow cover and NDSI data.

NASA VIIRS VNP10 Snow Cover Algorithm I

Our process is to develop and test the science of the algorithm on our computer using IDL then to code the science into the PGE using the LSIPS computing environment.

Gain access to LSIPS computing environment.

Develop code i.e. the operational PGE in the LSIPS computing environment following the guidelines from LSIPS and using their coding environment setup.

Initial step was to adapt the MODIS C6 algorithm PGE07 to run with VIIRS data inputs.

Next we revised that algorithm into the NASA VIIRS snow cover algorithm PGE507.

Next we coded to output the product in HDF5 using the LSIPS HDF5 libraries. We have coded and tested VNP10_L2 algorithm and output as LSIPS PGE507.

Develop and test code using input data from an LSIPS Archive Set (AS).

LSIPS runs unit and global tests

NASA VIIRS VNP10 Snow Cover Algorithm II

Current version of PGE507 runs with LSIPS IDPS versions of VIIRS data products.

VNP10_L2 product is in HDF5

We have a version of PGE507 that runs with LSIPS NASA VNP* L1B input products. Code revised to read HDF5.

Working in the LSIPS computing environment allows for:

- efficient delivery of algorithm code and download of CM baselined code

- comparison of codes and test runs between the PI coding in LSIPS to unit or global test runs made by LSIPS/LDOPE focus on science and data content consistencies and are not side tracked by differences attributable to different operating systems or PGE versions between the PI's computing environment and LSIPS.

NASA VIIRS VNP10 Snow Cover HDF5 Product Design

VNP10_L2 products are in HDF5. Required redesign of the products from MODIS heritage HDF4-EOS.

Specifications/requirements for the products are emerging from several sources and for differing reasons.

PI develops the science data content for datasets and attributes.

We interact with NSIDC for developing data content regarding snow cover datasets, geolocation data, and for attributes, primarily to support their data services and tools for users.

Conform to NetCDF4 Climate Forecasting Version 1.6 conventions for relevant metadata (HDF5 attributes).

LSIPS – provides attributes relevant to tracking production, PGE and Collection versions, provenance of data product, DOIs…

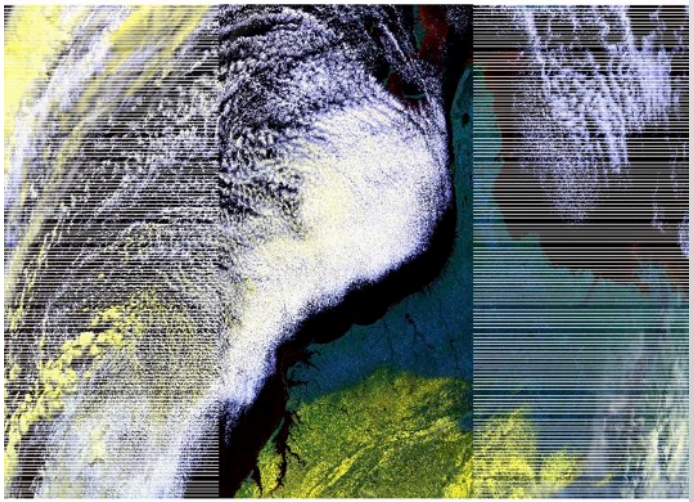
Draft of VNP10_L2 data product user guide has been completed.

NASA VIIRS VNP10 HDF5 Product Description

```
HDF5 “VNP10_L2*.h5" {
FILE_CONTENTS {
 group     /
 group     /GeolocationData
 dataset    /GeolocationData/Latitude
 dataset    /GeolocationData/Longitude
 group     /SnowData
 dataset    /SnowData/Algorithm_bit_flags_QA
 dataset    /SnowData/Basic_QA
 dataset    /SnowData/NDSI
 dataset    /SnowData/NDSI_Snow_Cover
 }
}
```

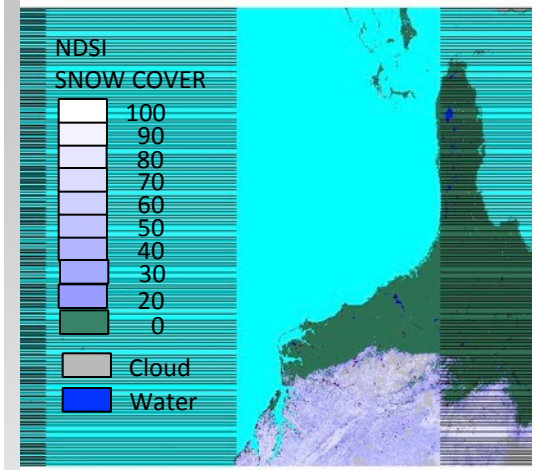
All datasets include attributes. LSIPS generates file level (global) attributes.

NASA VNP10_L2 Example

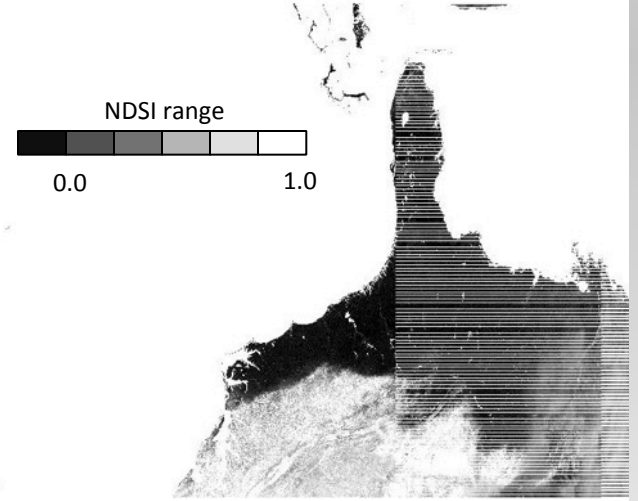


False color image of
NPP_VIAE_L1.A2016024.1810.P1_03110.*.hdf
bands I1,I2, I3, showing snow in hues of yellow.

VNP10_L2.A2016024.1810 .*.h5

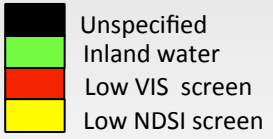


NDSI_Snow_Cover



NDSI

Algorithm_bit_flags_QA



MODIS and VIIRS Snow Cover Continuity

MOD10_L2 C6	VNP10_L2
NDSI_Snow_Cover, -- Snow cover map by NDSI in 0-100 range, with masked features.	NDSI_Snow_Cover, -- Snow cover map by NDSI in 0-100 range, with masked features.
NDSI_Snow_Cover_Algorithm_Flags_QA – bit flags for data screens applied in the algorithm.	NDSI_Snow_Cover_Algorithm_Flags_QA – bit flags for data screens applied in the algorithm.
NDSI Snow_Cover_Basic_QA, basic quality value	NDSI_Snow_Cover_Basic_QA, -- basic quality value
NDSI – NDSI value for all land and inland water pixels in a swath	NDSI – NDSI value for all land and inland water pixels in a swath
Latitude (5 km resolution)	Latitude (375 m resolution)
Longitude (5 km resolution)	Longitude (375 m resolution)

MODIS and VIIRS Snow Cover Continuity

Snow cover algorithms are very similar: MODIS C6 and VIIRS VNP10
Spatial resolution different: MODIS 500 m, VIIRS 375 m

Data product content is same but the file format is different:
MODIS C6 SDSs HDF4-EOS and VIIRS VNP10 datasets, HDF5

Challenges of improving accuracy, primarily alleviating problems of cloud/ snow confusion are similar in both MODIS and VIIRS associated with:

- Subpixel cloud contamination
- Cloud mask setting of snow/ice background flag
- Spectral discrimination of snow free surfaces from snow covered surfaces

SUOMI-NPP VIIRS ICE SURFACE TEMPERATURE (IST)

- The VIIRS Ice Surface Temperature (IST) product
  - 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, shown below, is a statistical regression method that is based on the AVHRR heritage IST algorithm *(Key and Haefliger.,* 1992)

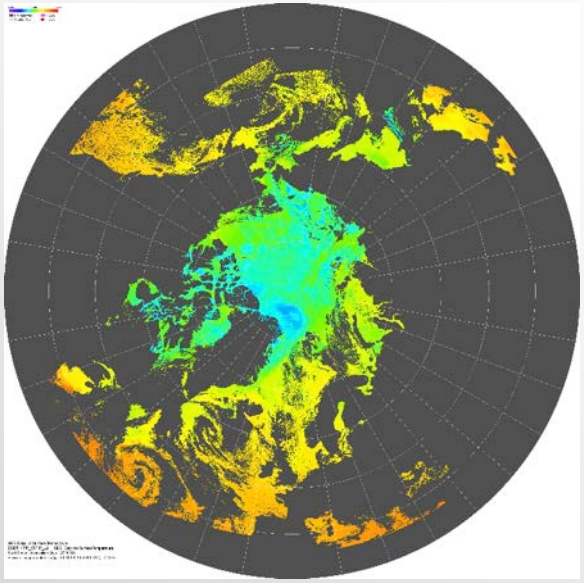
$$IST = a_o + a_1 T_{M15} + a_2 (T_{M15} - T_{M16}) + a_3 (\boldsymbol{T_{M15} - T_{M16}}) (\sec(z) - 1)$$

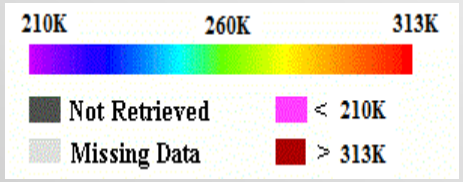
T_{M15} and T_{M16} : VIIRS TOA TB's for the VIIRS M15 and M16 bands
z: the satellite zenith angle
a_o, a_1, a_2, a_3 : regression coefficients.

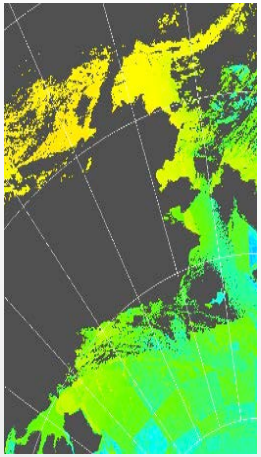
- Threshold Measurement Uncertainty = **1K** over a measurement range of 213–280 K.

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

IST NEEDED BY NASA'S OPERATION ICEBRIDGE (OIB)

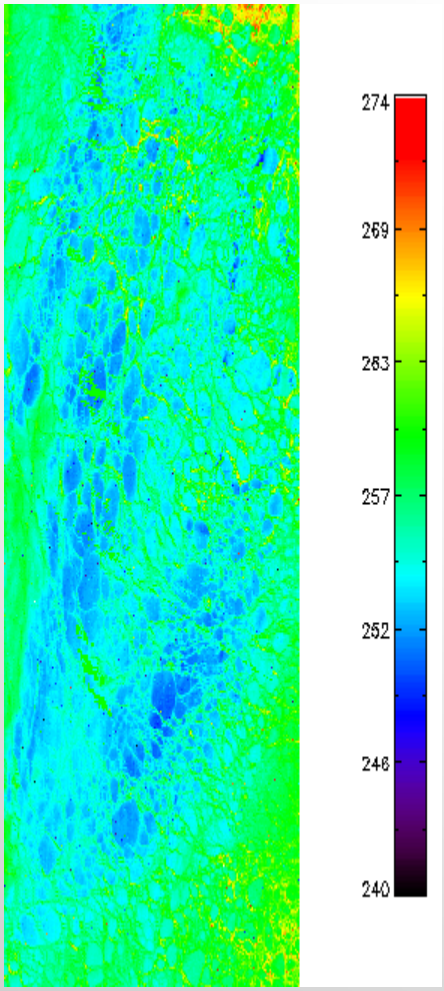






- IST: April 24, 2016
- Produced by http://landweb.nascom.nasa.gov (NASA Goddard)
- Utilized by NASA OIB Science Team during OIB Spring 2016 P-3 deployment
- Needed to assess melt onset in Beaufort Sea
  - Performance of OIB RADARs affected when surface layer begins to melt
- Will also be compared to OIB onboard IST imagers

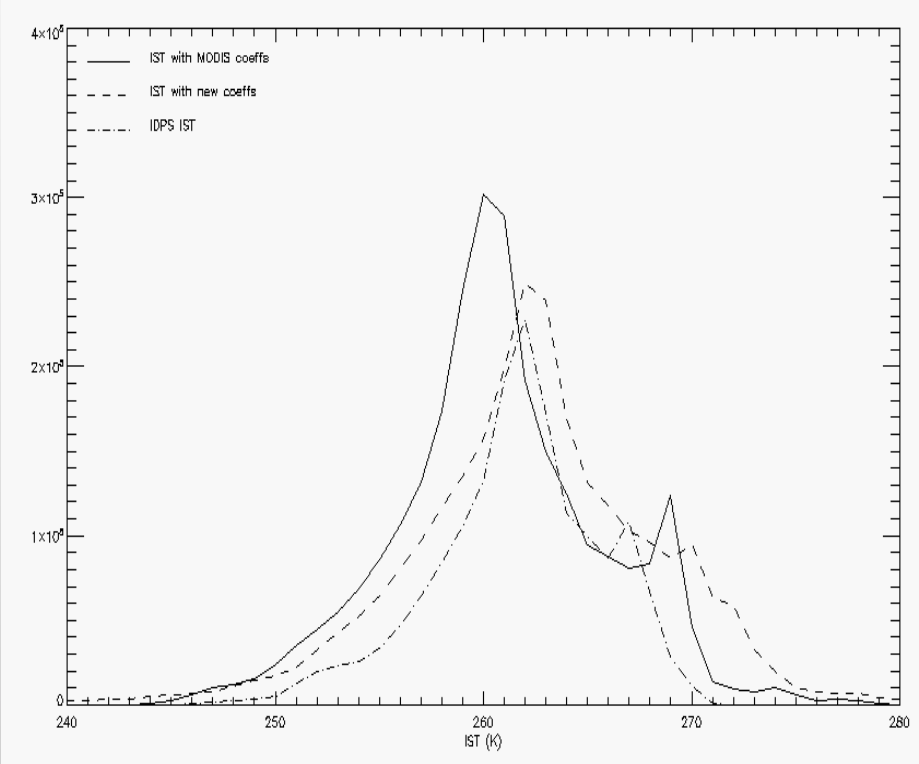
NASA VIIRS IST



- Initial code generated from MODIS code by NASA's Land Science Investigator-led Processing System (LSIPS)
- Code being updated for VIIRS (calibration coefficients, etc.)
- New Quality Flags to be added
- Inter-comparison: MODIS, NCEP
- Validation: IceBridge, buoys
- First draft of ATBD delivered Jan. 2016

Left: VIIRS IST (K) from the NASA VIIRS IST product
uses new calibration coefficients from J. Key
Sept 12, 2014, 21:10 UTC
Beaufort Sea, AK

NASA IST VS. IDPS IST



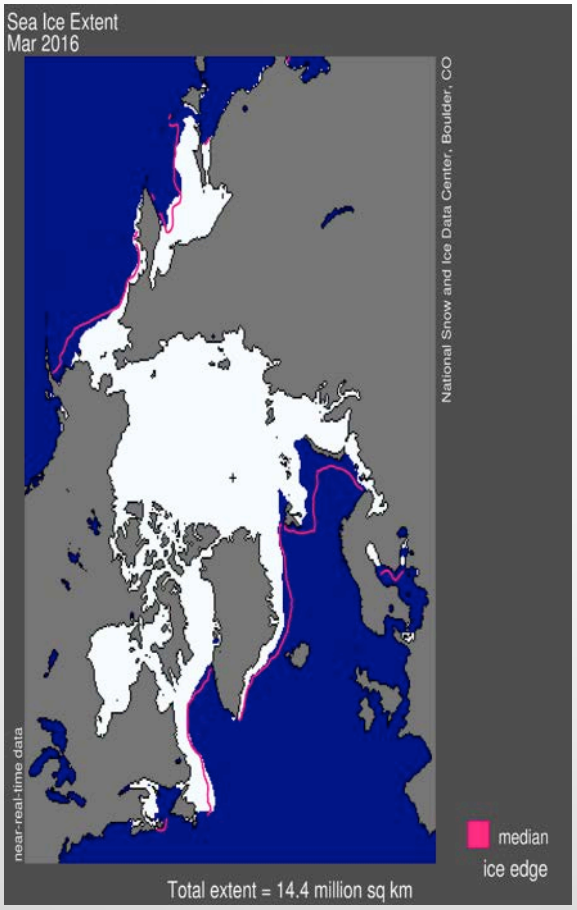
IST for previous scene:

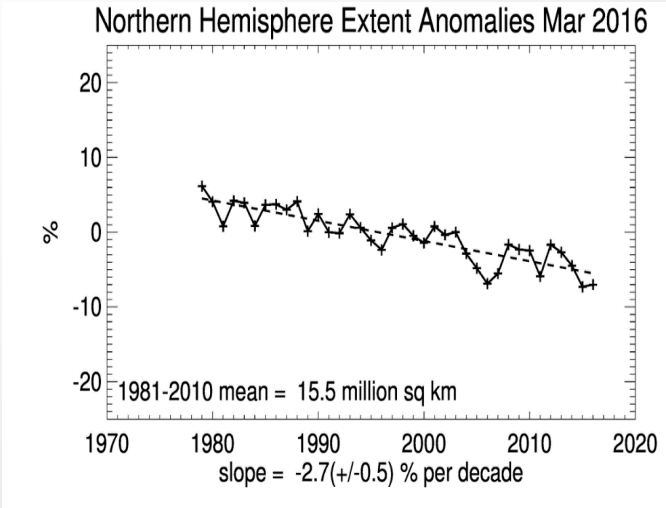
_____ NASA VIIRS IST algorithm with MODIS calibration coefficients
- - - - NASA VIIRS algorithm with updated calibration coefficients
_ . _ . NOAA IDPS IST

- NASA IST looks comparable to the IDPS IST

NASA VIIRS SEA ICE COVER

- Sea ice cover can aid in the estimation of sea ice extent using pmw data
- Sea ice extent = areal coverage of sea ice over the Arctic (km^2)
- Sea ice extent is important for trends in ice extent, sea ice modeling, navigation, operations, …





NASA VIIRS SEA ICE COVER ALGORITHM

- Utilizes the Normalized Difference Snow Index (NDSI):

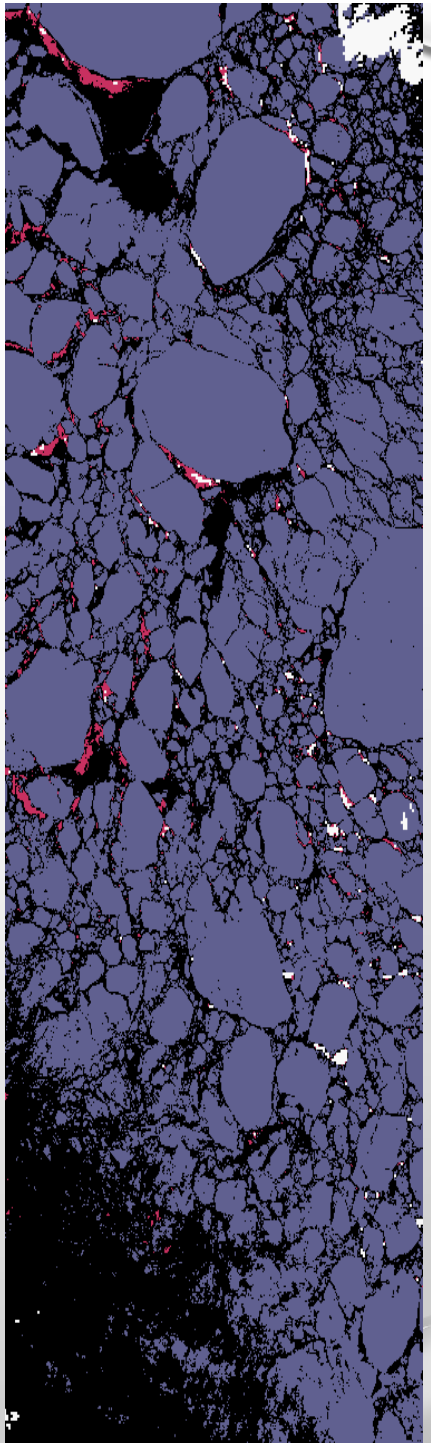
NDSI = [VIIRS M4 (0.555µm) – VIIRS M10 (1.61µm)] / [VIIRS M4 + VIIRS M10]

- If NDSI ≥ 0.4 and VIIRS M4 > threshold, then pixel contains snow covered sea ice

- Relatively thin sea ice (< 10 cm, with no snow cover) which has a lower albedo may not be detected using the NDSI. Methods to detect thin sea ice are being investigated.

NASA VIIRS SEA ICE COVER TEST RUN

- Sea ice extent code using VIIRS channels
- April 7, 2015
- Beaufort Sea – multiyear ice floes
- Can envision a follow-on sea ice concentration product



NASA LSIPS ACCESS SUMMARY

- Have received / used NASA token
- Have NASA Launchpad access
- Took necessary training
- Have been activated on cluster
- At “press time,” working an access issue to the LSIPS


THANK YOU