NPOESS/NPP VIIRS Cryosphere Algorithms

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Introduction

Abstract:

The Visible/Infrared Imaging Radiometer Sensor (VIIRS) is one of the instruments to be flown on board the National Polar Orbiting Operational Environmental Satellite System (NPOESS). First launch of the VIIRS will be on the NPOESS Preparatory Project (NPP) mission. VIIRS data will be used to produce many Environmental Data Records (EDRs). VIIRS Cryosphere products will include EDRs for Snow Cover, Sea Ice Characterization and Ice Surface Temperature. The VIIRS Snow Cover EDR, produced during day, consists of a binary snow cover extent map produced at VIIRS imagery resolution (375 m @ nadir) and a snow fraction product produced at VIIRS moderate resolution (750 m @ nadir). Snow fraction is produced as a 2x2 aggregation of the binary snow map. The VIIRS Sea Ice Characterization EDR, produced both day and night, provides classification of sea ice age at VIIRS moderate resolution. Thinner "New/Young" ice is distinguished from "All Other" thicker first and multiyear ices. The VIIRS Sea Ice Concentration Intermediate Product (IP) will be produced at VIIRS imagery resolution for both day and night. The VIIRS Ice Surface Temperature EDR provides temperatures retrieved at VIIRS moderate resolution for both day and night over ice surfaces. An overview is provided of the current status of the NPOESS/NPP VIIRS suite of Cryosphere products and results are presented based on pre-launch testing using MODIS proxy data as well as global synthetic data.

Algorithm Overview

Snow Cover EDR

The VIIRS Snow Cover algorithm binary extent map is an adaptation of the MODIS SnoMap algorithm (Hall et.al 2001) that classifies snow based upon the Normalized Difference Snow Index (NDSI) with additional reflectance , thermal and NDVI thresholds. The VIIRS adaptation uses an NDSI based on the 0.64 μm and 1.61 μm VIIRS imagery resolution bands. The VIIRS requirement for probability of correct tying is 90%. Snow fraction is produced as a 2x2 aggregation of the binary map .

$$\left.\begin{array}{ll} NDSI = (R_{I1} - R_{I2}) / (R_{I1} + R_{I3}) & > 0.4 \\ R_{I2} & > 0.11 \\ T_{I5} & < 283\ K \end{array}\right\} \text{Snow}$$

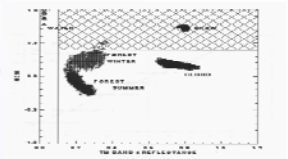
where: R_{I1}, R_{I2}, R_{I3} = TOA reflectance in 0.64 μm (I1), 0.865 μm 1.61 μm (I3); T_{I5} = 11.5 μm (I5) VIIRS bands.

For NDSI between 0.1 and 0.4 NDVI thresholds as a function of NDSI are used

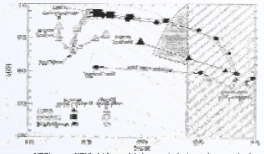
$$NDVI = (R_{I2}-R_{I1})/(R_{I1}+R_{I2})$$

$$ndvi_lower = \alpha_1 + \alpha_2 * NDSI$$

$$ndvi_upper = \beta_1 + \beta_2 * NDSI + \beta_3 * NDVI^2 + \beta_4 * NDVI^3 \quad \textit{(Klein et al., 1998)}$$



Near-infrared reflectance versus NDSI plot for winter and summer Landsat TM scene s of Glacier National Park, Montana (from Hall et al., 1998)



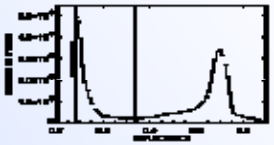
NDSI verses NDVI plot for modeled aspen, jack pine and spruce stands (from Klein , Hall and Riggs, 1998)

Sea Ice Concentration Intermediate Product

- Ice concentration is derived from a tie point equation:

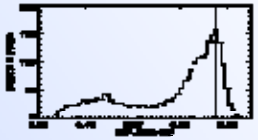
$$f(p) = (\Sigma_j (w_j)(b_{jp} - b_{jwater}) / (b_{jice} - b_{jwater})) / \Sigma_j w_j$$

where:
- $f(p)$ is the calculated ice fraction
- w_j is the relative quality weight in band j
- b_{jice} is the jth brightness value of a pure ice pixel
- b_{jwater} is the jth brightness value of a pure water pixel
- b_{jp} is the jth brightness value of the pixel



Distribution of 0.64 μm reflectance for an ice/water scene

- Ice/water thresholds are derived from the local minimum of the distribution of reflectance and temperature (dashed lines in top figure show the water peak and the ice/water threshold)
- Ice and water tie points are determined for the visible TOA reflectance (VIIRS I1 band), near infrared TOA reflectance (VIIRS I2 band), and surface temperature
- Tie points for a VIIRS imagery resolution pixel are established from the local distribution of reflectance and temperature within a sliding search window centered on that pixel (dashed line in bottom figure shows the local ice tie point)
- Derived tie points are specific to the local region contained within the search window, providing global operational capability



Distribution of 0.64 μm reflectance for a local search window

Sea Ice Age EDR

- Ice is classified as one of three types, Ice-free, New/Young or Other ice.
- 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 ices is achieved by two independent method (algorithms)

1. At nighttime and for low sun angle conditions, an energy balance derivation of ice thickness from ice temperature.

$$Q_s = Q_\Sigma(1-a) + E_a - E_s + Q_t + Q_e \qquad H = \frac{\lambda_i(T_s - \theta)}{Q_\Sigma(1-\alpha) + E_a - E_s + Q_t + Q_e} - \frac{\lambda_i h}{\lambda_s}$$

where:
- Q_s = resultant heat flux from the atmosphere to the ice (snow) surface
- Q_Σ = total incident short-wave solar radiation
- α = surface albedo
- E_a = long-wave radiation from the atmosphere;
- E_s = long-wave radiation from surface,
- Q_t = turbulent heat exchange;
- Q_e = heat exchange due to evaporation.
- H = ice thickness,
- h = snow depth
- λ_i = thermal conductivity of sea ice;
- λ_s = thermal conductivity of snow

2. At daytime, application of a reflectance/thickness relation obtained from a LUT.

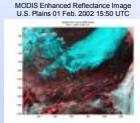
Ice Surface Temperature EDR

Baseline split window algorithm statistical regression methods uses two VIIRS LWIR bands, 10.76 μm (M15) and 12.01 μm (M16) for both day and night, similar to the Advanced Very High Resolution Radiometer (AVHRR) IST algorithm (Yu *et al.*, 1995). The baseline split window algorithm reverts to a single-band, 12.01 μm (M16) algorithm for both day and night for fallback situations.

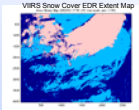
$$IST = a_o + a_1 T_{M15} + a_2(T_{M15} - T_{M16}) + a_3(\sec(z) - 1) \qquad \text{(VIIRS IST baseline split window algorithm)}$$

$$IST = a_o + a_1 T_{M16} + a_2(\sec(z) - 1) \qquad \text{(VIIRS IST single band fallback algorithm)}$$

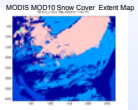
Snow Cover EDR Results



MODIS Enhanced Reflectance Image U.S. Plains 01 Feb. 2002 15:50 UTC



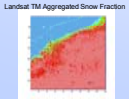
VIIRS Snow Cover EDR Extent Map



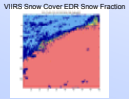
MODIS MOD10 Snow Cover Extent Map

VIIRS Snow Cover Binary Map Performance Based on Comparison with MODIS MOD10 Heritage

Scene	Date/Time	Snow Matched (%)	No Snow Matched (%)	False Alarms (%)	Accuracy (%)	PCT Total (%)
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]



Landsat TM Aggregated Snow Fraction



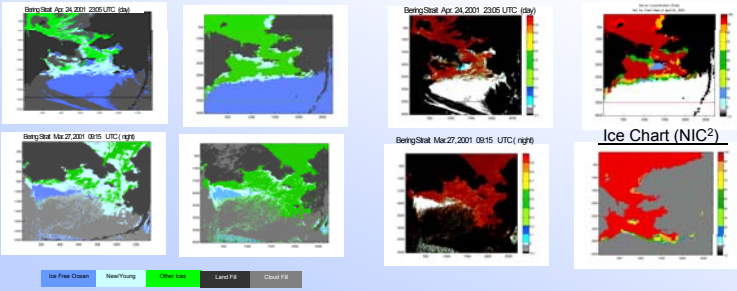
VIIRS Snow Cover EDR Snow Fraction

VIIRS Snow Cover Binary Map Performance Based on Comparison with Landsat TM Scene

Scene	Date/Time	Snow Matched (%)	No Snow Matched (%)	False Alarms (%)	Accuracy (%)	PCT Total (%)
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Sea Ice Age EDR and Ice Concentration IP Results

VIIRS Ice Age | Ice Age Manual Analysis | VIIRS Ice Concentration | Ice Chart (NSDIC[1])



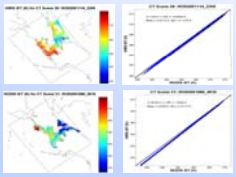
Ice Chart (NIC[2])

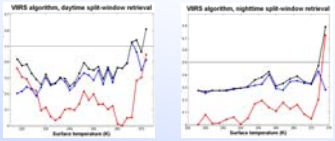
IST EDR Split Window Algorithm Results

MODIS Proxy Data | Global Synthetic Data (with sensor noise)

Day

Night





Day | Night

Concluding Remarks

The VIIRS Cryosphere algorithm have been tested using MODIS proxy data, Global Synthetic Data and other available reference data sets. Preliminary results produced from the VIIRS Cryosphere algorithms indicate that the VIIRS Snow Cover algorithm will have comparable performance to that that of the heritage MODIS SnowMap product. The VIIRS Sea Ice Concentration IP ice fractions appear to be consistent with those of NIC Ice charts. Comparison of VIIRS Sea Ice Age EDR with truth ice age derived from NSIDC digitized Ice Chart data[1], and threshold based manual derived truth indicates a strong bias toward retrieval of New/Young ice. The predicted accuracy, precision, and uncertainty for the IST EDR based on the NGAS global synthetic data are 0.025, 0.409, and 0.410 for daytime, and 0.014, 0.387, and 0.387 for nighttime, respectively using the baseline split-window algorithms, meets the uncertainty of 0.5 K requirement, and performance is comparable to the MODIS algorithm.

(1) National Ice Center. 2006. National Ice Center Sea Ice Charts and Climatologies in Gridded Format. Edited by F. Fetterer and C. Fowler. Boulder, CO: National Snow and Ice Data Center. Digital media. (2) National Ice Center. 2004. National Ice Center Sea Ice Chart (digitized from GeoTIF)