GOES-R AWG Cryosphere Team

Sea and Lake Ice Motion with GOES-R ABI

Presented by Jeff Key[1]

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The Cryosphere Team Members

AWG Cryospere Team Chair: Jeff Key

- Cryosphere Application Team
  - **Jeff Key (Lead; STAR/ASPB)**
  - » Peter Romanov (UMD/STAR)
  - » Don Cline (NWS/NOHRSC)
  - » Marouane Temimi (CREST)

- Fractional Snow Cover (baseline)
  - **Don Cline (Lead; NWS/NOHRSC)**
  - Tom Painter (U. Utah)
  - Andy Rost (NWS/NOHRSC)

- Snow Depth (Option 2)
  - **Peter Romanov (Lead; UMD)**
  - Cezar Kongoli (QSS)

- Ice Cover and Concentration (Option 2)
  - **Yinghui Liu (Lead; CIMSS)**
  - Xuanji Wang (CIMSS)
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  - Marouane Temimi (CREST)
  - Hosni Ghedira (CREST)
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  - Kim Smith (CREST)

- Ice Motion (Option 2)
  - **Yinghui Liu (Lead; CIMSS)**
  - Jeff Key (STAR)
  - Xuanji Wang (CIMSS)

- Ice Age/Thickness (Option 2)
  - **Xuanji Wang (Lead; CIMSS)**
  - Jeff Key (STAR)
  - Yinghui Liu (CIMSS)

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- Algorithm Description
- Examples of Product Output
- Validation Approach
- Validation Results
- Next Steps to Reach 100%
- Conclusion and Perspectives

Sea and Lake Ice Motion with GOES-R ABI:
Executive Summary

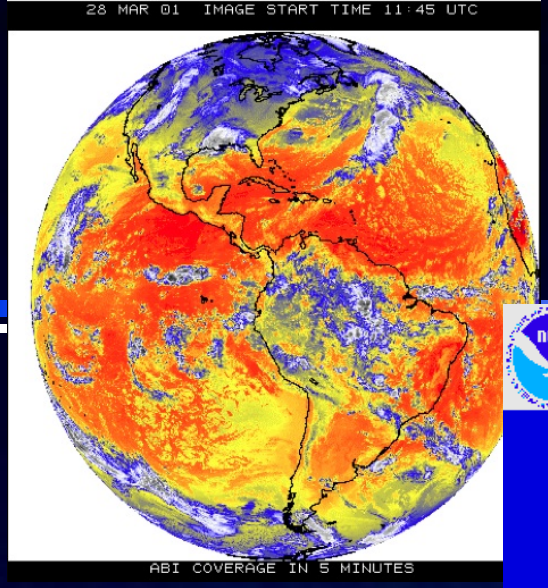
- The GOES-R Sea and Lake Ice Motion is an Option 2 product.
- Software Version 3 was delivered in September 2009.
- The algorithm has been developed and tested using MODIS data and in situ buoy data.
- Validation studies indicate spec compliance.

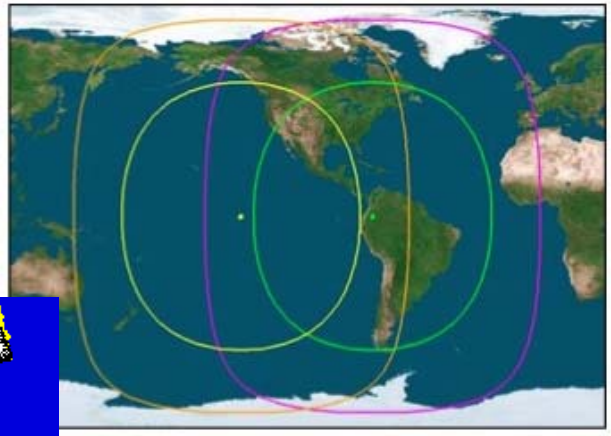
Sea and Lake Ice Motion with GOES-R ABI:
Executive Summary

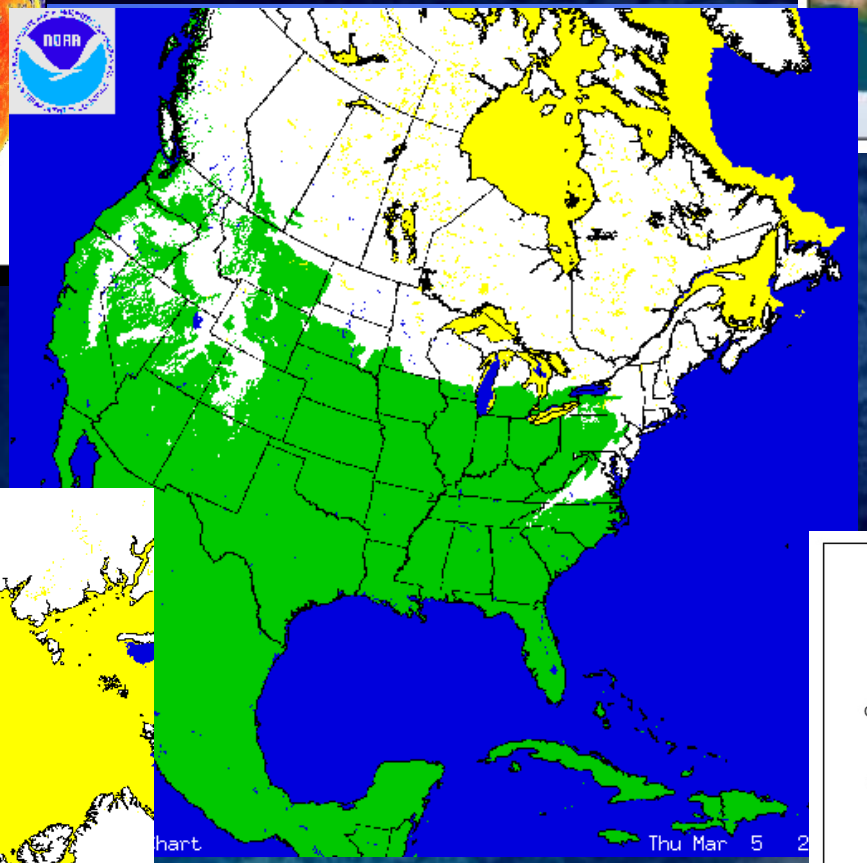
Name	User & Priority	Geographic Coverage (G, H, C, M)	Vertical Resolution	Horizontal Resolution	Mapping Accuracy	Measurement Range	Measurement Accuracy	Product Refresh Rate/Coverage Time	Vendor Allocated Ground Latency	Product Measurement Precision
Sea & Lake Ice: Motion	GOES-R	C: Great Lakes and Chesapeake and Delaware Bays only	N/A	5 km	2.5 km	Direction: 0 to 360º & Displacement: 0 to 0.6 m/s	Direction: 22.5º Speed: 3 km/day	3 hr	3236 sec	Direction: 30º Speed: 3 km/day
Sea & Lake Ice: Motion	GOES-R	FD: Sea ice covered waters in N & S Hemispheres	N/A	15 km	7.5 km	Direction: 0 to 360º & Displacement: 0 to 0.6 m/s	Direction: 22.5º Speed: 3 km/day	6 hr	9716 sec	Direction: 30º Speed: 3 km/day

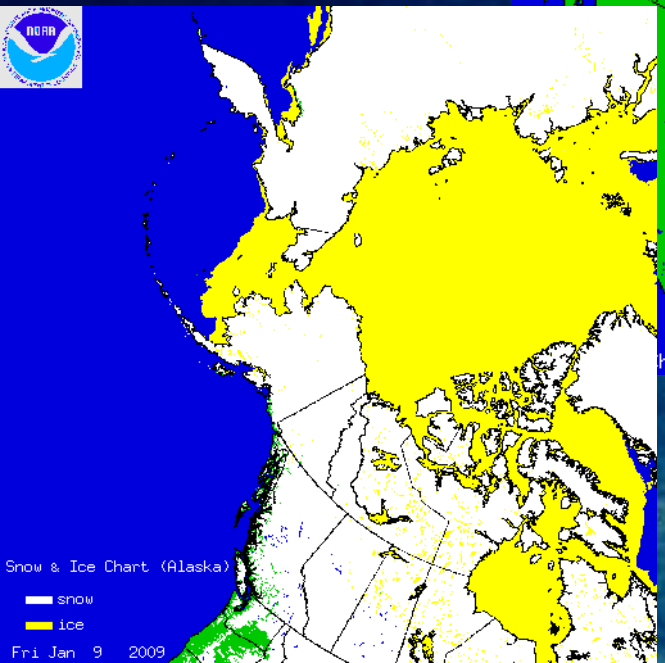
C – CONUS **FD** – Full Disk **1 km/day = 1.16 cm/s**

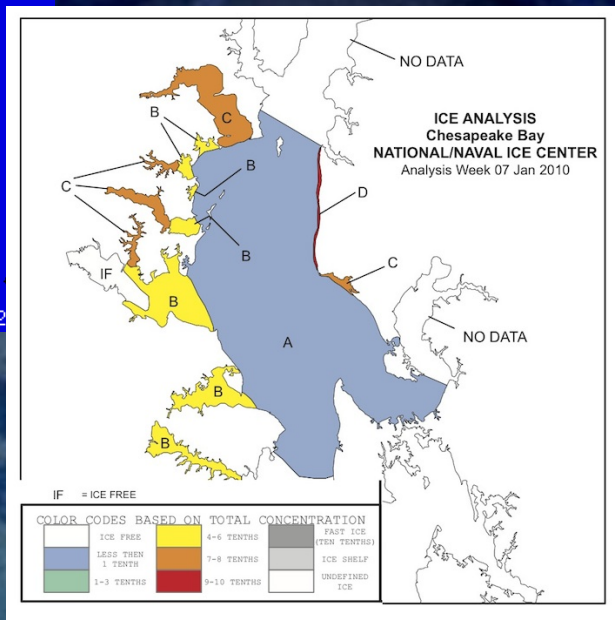
Ice in North America





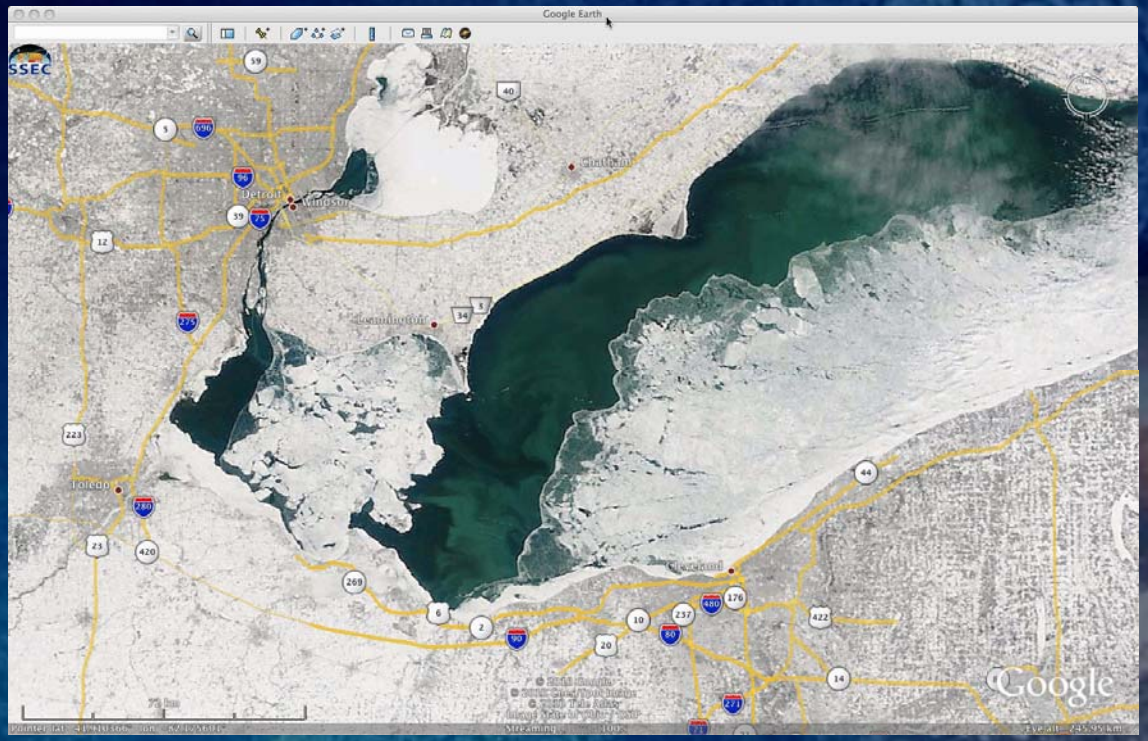




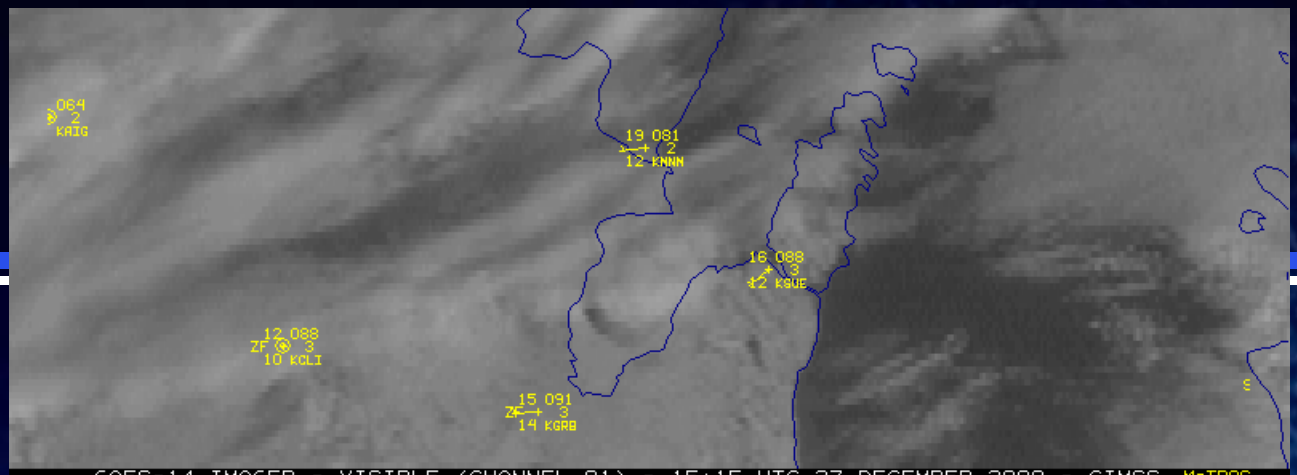


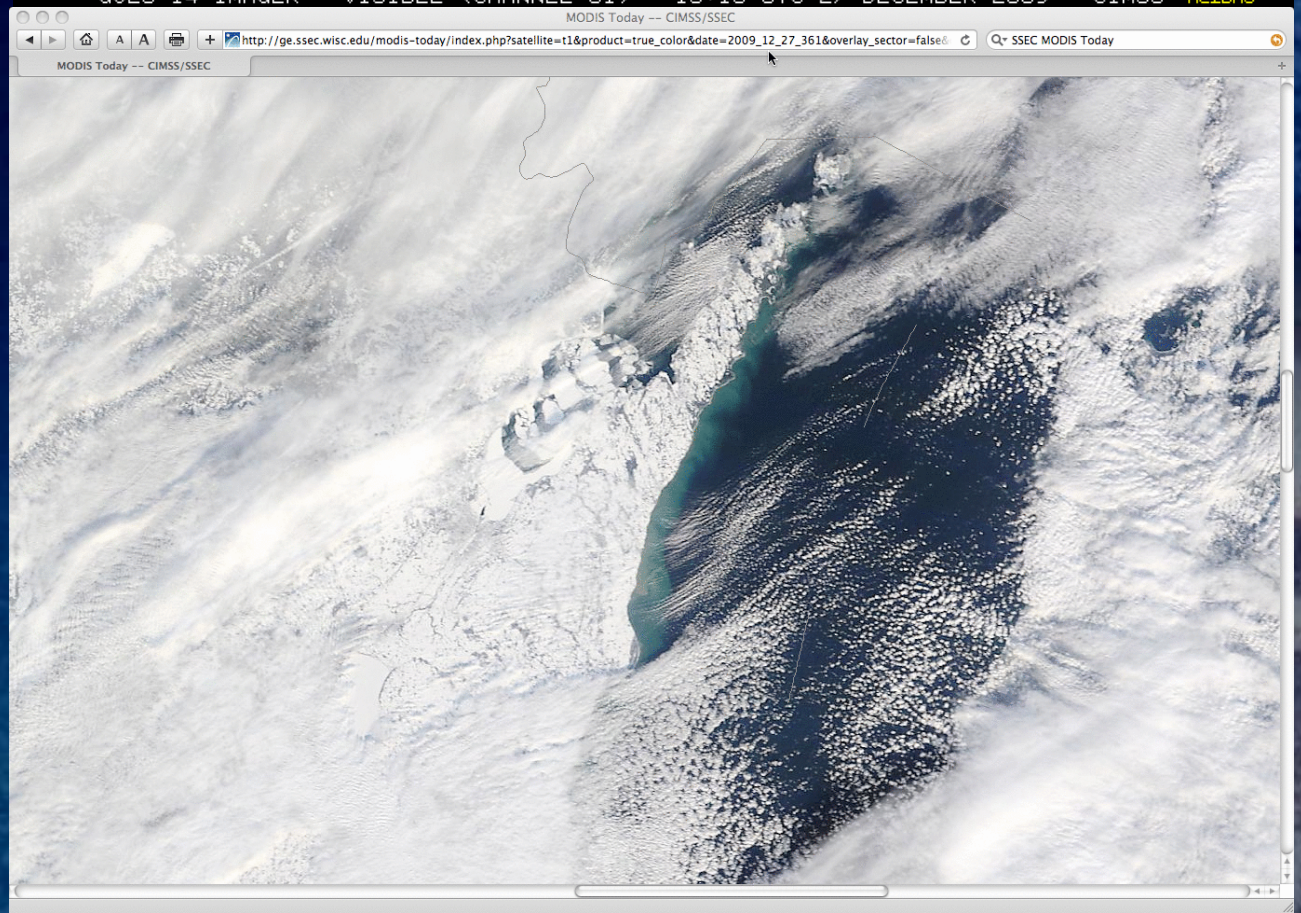
Sea and Lake Ice Motion with GOES-R ABI:
Algorithm Description

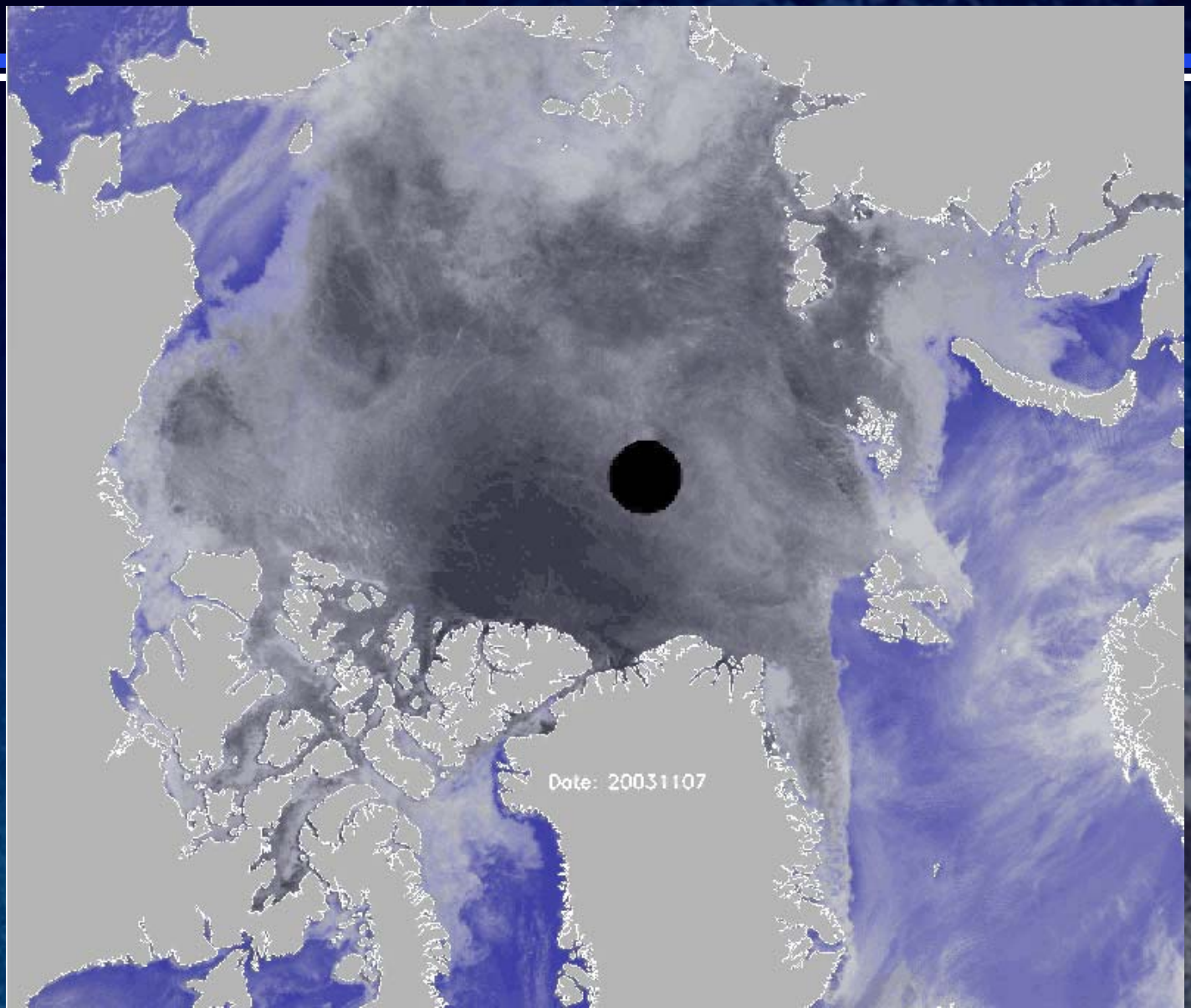
Sea and Lake Ice Motion: instantaneous measurement of the direction and magnitude of the movement of the ice



Ice motion shown in two 250-meter resolution Terra (16:34 UTC) and Aqua (18:17 UTC) MODIS true color images on February 19, 2010.


064
2
KAIG
19 081
2
12 KMNN
16 088
3
12 KGUE
12 088
ZF 3
10 KCLI
15 091
ZF 3
14 KGRB
GOES-14 IMAGER - VISIBLE (CHANNEL 01) - 15:15 UTC 27 DECEMBER 2009 - CIMSS McIDAS


MODIS Today -- CIMSS/SSEC
http://ge.ssec.wisc.edu/modis-today/index.php?satellite=t1&product=true_color&date=2009_12_27_361&overlay_sector=false&
SSEC MODIS Today
MODIS Today -- CIMSS/SSEC


Date: 20031107

Sea and Lake Ice Motion with GOES-R ABI: Algorithm Description

Physical background

The motion of an individual ice floe is governed by the balance of the forces that act on that floe.

$$m\frac{Du}{Dt} = \tau_a + \tau_w + \tau_c + \tau_t + \tau_i$$

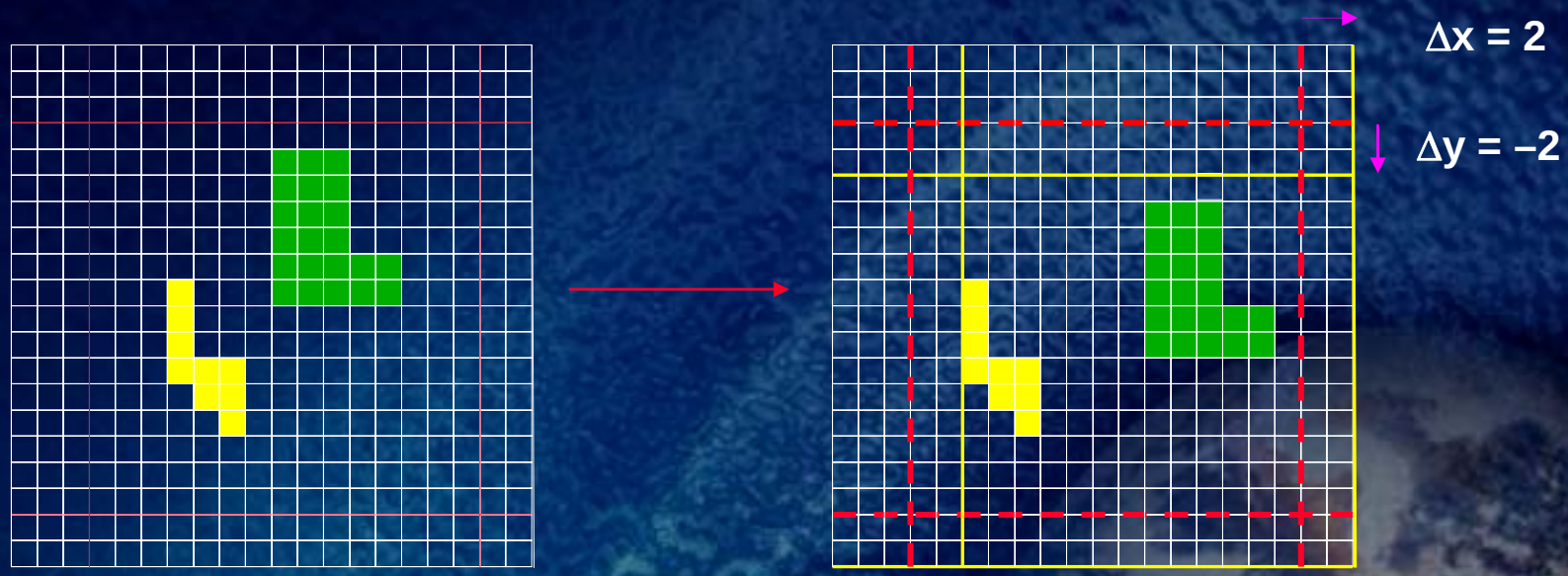
M = mass of the ice
Du = change of velocity
Dt = change of time
τ_a = wind stress
τ_w = water stress
τ_c = Coriolis force
τ_t = force due the tilt of the water surface
τ_i = internal ice stress

Ice motion is 0-10 degrees to the right (NH) of the geostrophic wind (the "turning angle"), depending on ice mass.

The speed of ice movement is ~3% of the wind speed.

Sea and Lake Ice Motion with GOES-R ABI:
Algorithm Description

Ice Motion in 2 consecutive images



Sp spatial scale of each cell
Δx = 2 displacement in pixel space in x direction
Δy = - 2 displacement in pixel space in y direction
ΔT = time interval between two observations

U = sp × Δx / ΔT speed in pixel space in x direction
V = sp × Δy / ΔT speed in pixel space in y direction

Green pixels: ice cover

Yellow pixels: cloud

Sea and Lake Ice Motion with GOES-R ABI: Algorithm Description

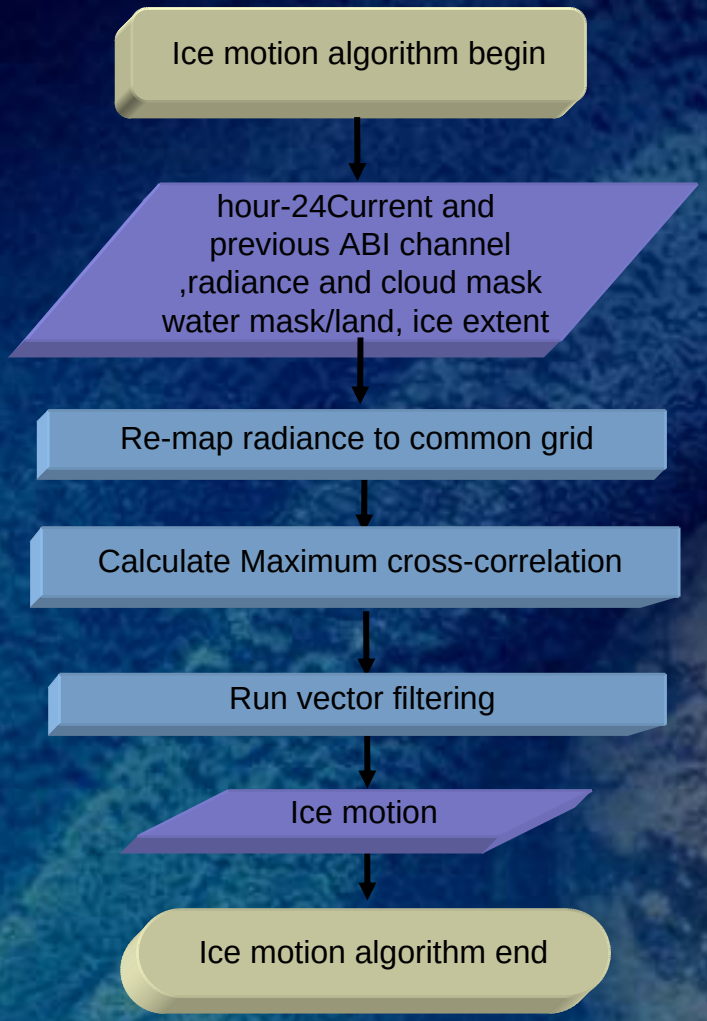
GOES-R ABI data used in this algorithm

Future GOES Imager (ABI) Band	Nominal Wavelength Range (μm)	Nominal Central Wavelength (μm)	Nominal Central Wavenumber (cm-1)	Nominal sub-satellite IGFOV (km)	Sample Use
1	0.45-0.49	0.47	21277	1	
2	0.59-0.69	0.64	15625	0.5	
3	0.846-0.885	0.865	11561	1	
4	1.371-1.386	1.378	7257	2	
5	1.58-1.64	1.61	6211	1	
6	2.225 - 2.275	2.25	4444	2	
7	3.80-4.00	3.90	2564	2	
8	5.77-6.6	6.19	1616	2	
9	6.75-7.15	6.95	1439	2	
10	7.24-7.44	7.34	1362	2	
11	8.3-8.7	8.5	1176	2	
12	9.42-9.8	9.61	1041	2	
13	10.1-10.6	10.35	966	2	
14	10.8-11.6	11.2	893	2	Ice motion
15	11.8-12.8	12.3	813	2	
16	13.0-13.6	13.3	752	2	

Current Input Possible Added Input

Sea and Lake Ice Motion with GOES-R ABI:
Algorithm Description

High Level Flowchart of the ice motion algorithm



Sea and Lake Ice Motion with GOES-R ABI:
Algorithm Description

Maximum Cross-Correlation (MCC) procedure is used to determine the pixel displacement between two windows (15×15) in two consecutive images.

» Set the maximum possible pixel displacement between two windows as 5.

» Cross-correlations between one window in the first image and 121 windows, centering the window in the first image, in the second image are calculated.

» The window in the second image that has the maximum cross-correlation with the window in the first image is the destination window. The distance between these two windows is the displacement of the ice pixels.

» Speed of the ice cover in pixel space is calculated as the displacement over the time difference between the two windows.

Sea and Lake Ice Motion with GOES-R ABI:
Algorithm Description

Cross Correlation (CC) between two windows (15×15) is calculated as:

$$CC = \frac{n \times \sigma_{i1i2} - \sigma_{i1} \times \sigma_{i2}}{\sqrt{(n \times \sigma_{i11} - \sigma_{i1} \times \sigma_{i1}) \times (n \times \sigma_{i22} - \sigma_{i2} \times \sigma_{i2})}}$$

n = total number of pixels in a window

σ_{i1} = sum of all the pixels in the window in the first image

σ_{i2} = sum of all the pixels in the window in the second image

σ_{i11} = sum of all the squares of pixels in the window in the first image

σ_{i22} = sum of all the squares of pixels in the window in the second image

σ_{i1i2} = sum of all pixels in the window in the first image times the corresponding pixel in the second image.

* Cloudy pixels are excluded.

Algorithm Description

Vector Filtering for Quality Control

Spatial coherence filtering is done on the resulting vectors from the initial calculation of the motion and is done in three steps.

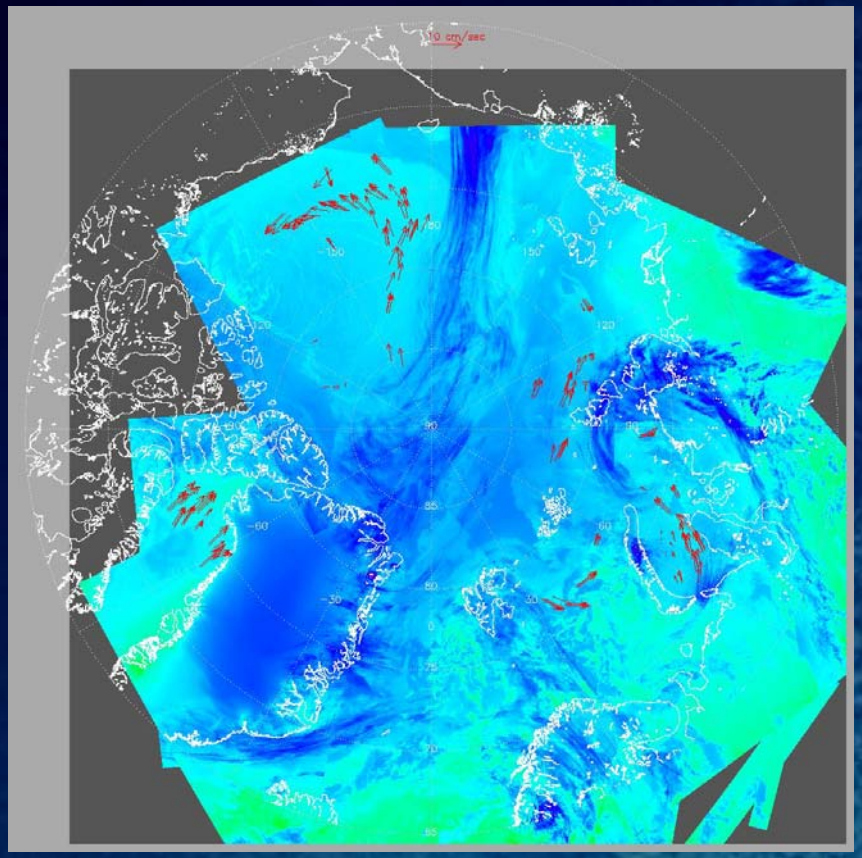
- » All vectors with correlations below 0.7 are eliminated. This is to ensure only highly correlated values are output.
- » Vectors are kept if there are neighboring vectors with a similar pixel displacement.
- » Vectors with speeds of 0 and greater than 10 cm/s (probably clouds).

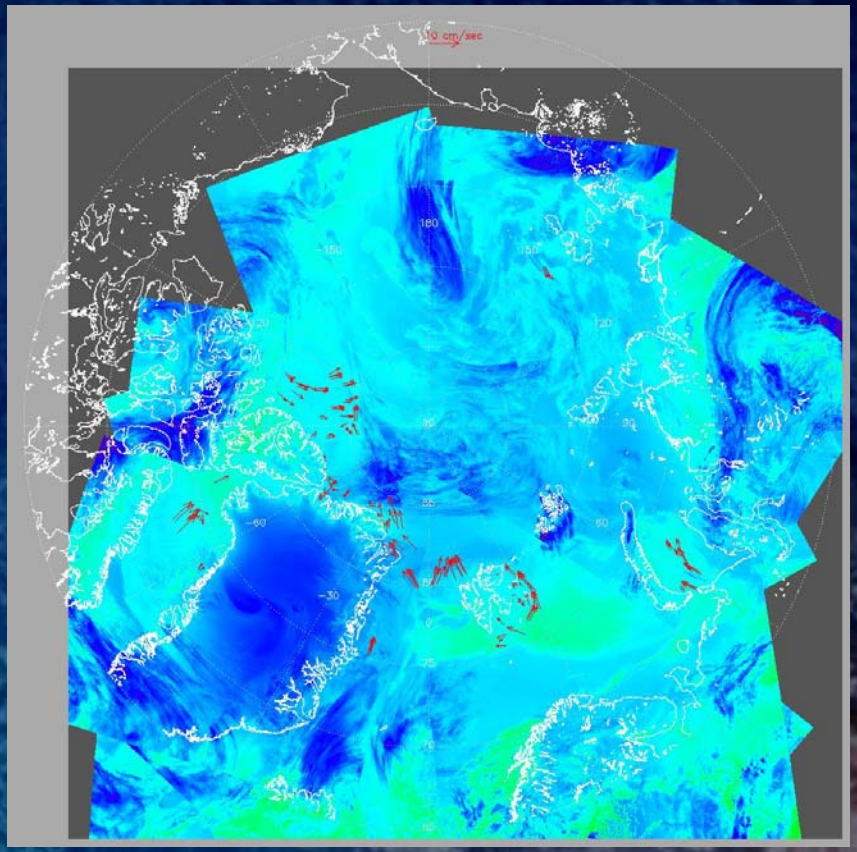
Algorithm Summary

Procedures of ice motion algorithm:

- Load 11 micron image and Cloud Mask from 24 prior in common grid.
- Load current 11 micron image and Cloud Mask in common grid.
- Make common cloud mask for both current and cloud mask from 24 hours prior.
- Calculate motion
- Perform vector filtering
- Output vectors of points and motion

Sea and Lake Ice Motion with GOES-R ABI:
Examples of Product Output





Composite of 11 micron brightness temperature as background and ice motion vectors from MODIS, using data from Tromso, Norway, for May 8 (left), and for May 20 (right), 2008

Sea and Lake Ice Motion with GOES-R ABI: Validation

Ice motion retrieved from MODIS data as proxy were validated with ice motion derived from buoy data as truth.

- Ice motion derived from buoy data deployed in the International Arctic Buoy Programme is available from 2006 to 2009 over the Arctic Ocean. These buoy data provide positions and time of each buoy. Direction and speed of ice motion can be derived from these information. Ice motion from buoy data from May 4 to May 9, 2008, and Feb 18 to Feb 20, 2008 were calculated.
- Ice motion retrievals were from MODIS data using the GOES-R ABI algorithm.
- Comparison is done when a pair of retrieved ice motion and ice motion from buoy data is within 50 km.

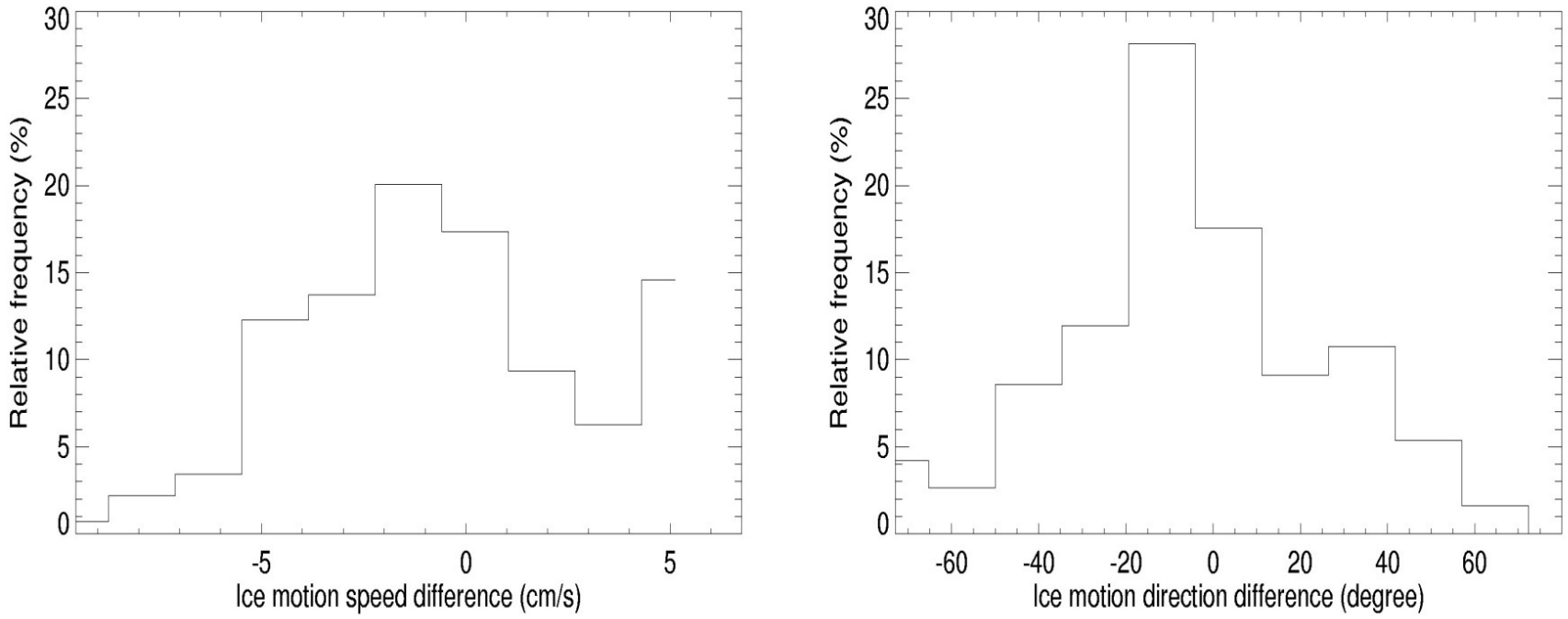
Sea and Lake Ice Motion with GOES-R ABI: Validation

Validation of Ice Motion Product with Buoy Data (1654 pairs)

Ice motion product performance by comparison with buoy data: 1654 pairs	Mean bias (cm/second)	Root mean squared error (cm/second)
Ice motion speed	0.25	3.4
Required measurement accuracy and precision	3.5 (3 km/day)	3.5 (3 km/day)
	Mean bias (degree)	Root mean squared error (degree)
Ice motion direction	2.9	30.0
Required measurement accuracy and precision	22.5	30.0

Sea and Lake Ice Motion with GOES-R ABI: Validation

Ice motion product performance: error distribution by comparison with ice motion from buoy data: 1654 pairs



Frequency distributions of ice motion speed (left) and direction (right) differences between MODIS retrieved and from buoy data.

Next Steps to Reach 100%

Algorithm Improvements:

- Optimize the sub-window size. Current size of the search window is 15 pixel by 15 pixel
- The shape of the sub-window will be tested to get the best results. The current shape of the sub-window is 15 pixels square. The lake ice near the shore is irregular in shape, and this should be taken into consideration.

Validation Improvements:

- More validation with buoy data over the Arctic Ocean, including more cases in different seasons
- Validation with possible in-situ ice motion data over the Great Lakes.

Other Improvements:

- The impact of instrument noise on the retrieval results is being investigated.

Sea and Lake Ice Motion with GOES-R ABI:
Conclusion and Perspectives

- ABI allows us to monitor ice conditions at high temporal and spatial resolution.
- The ice motion product is generated using a maximum cross-correlation procedure based on 11 µm brightness temperatures from the present time and 24 hours prior. The cloud mask and ice mask are also used.
- Validation of ice motion vectors using MODIS data as proxy with ice motion derived from buoy data show that current products meet the required accuracy and precision of ice motion speed and direction.
- This algorithm will be further modified to improve the accuracy. Additional validation data will be employed.