Derivation of Ice Thickness and Age for Use with GOES-R ABI Data

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Derivation of Ice Thickness and Age for Use with GOES-R ABI Data:

Outline

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

Executive Summary

- The GOES-R Sea and Lake Ice Thickness and Age is an Option 2 product.
- Software Version 3 was delivered in September 2009.
- The algorithm has been developed and tested using AVHRR, MODIS, SEVIRI data and in situ observed data from submarine, mooring sites, and stations.
- Validation studies indicate spec compliance.

Derivation of Ice Thickness and Age for Use with GOES-R ABI Data:

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: Age	GOES-R	FD	Ice Surface	1 km	3 km	Ice free areas, First year ice Older Ice	80% correct classification	6 hr	3236 sec	1 category

Name	User & Priority	Geographic Coverage (G, H, C, M)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Sea & Lake Ice: Age	GOES-R	FD	Sun at less than 67 degree solar zenith angle	Quantitative out to at least 67 degrees LZA and qualitative at larger LZA	Clear conditions associated with threshold accuracy	Over specified geographic area

FD – Full Disk

Algorithm Description

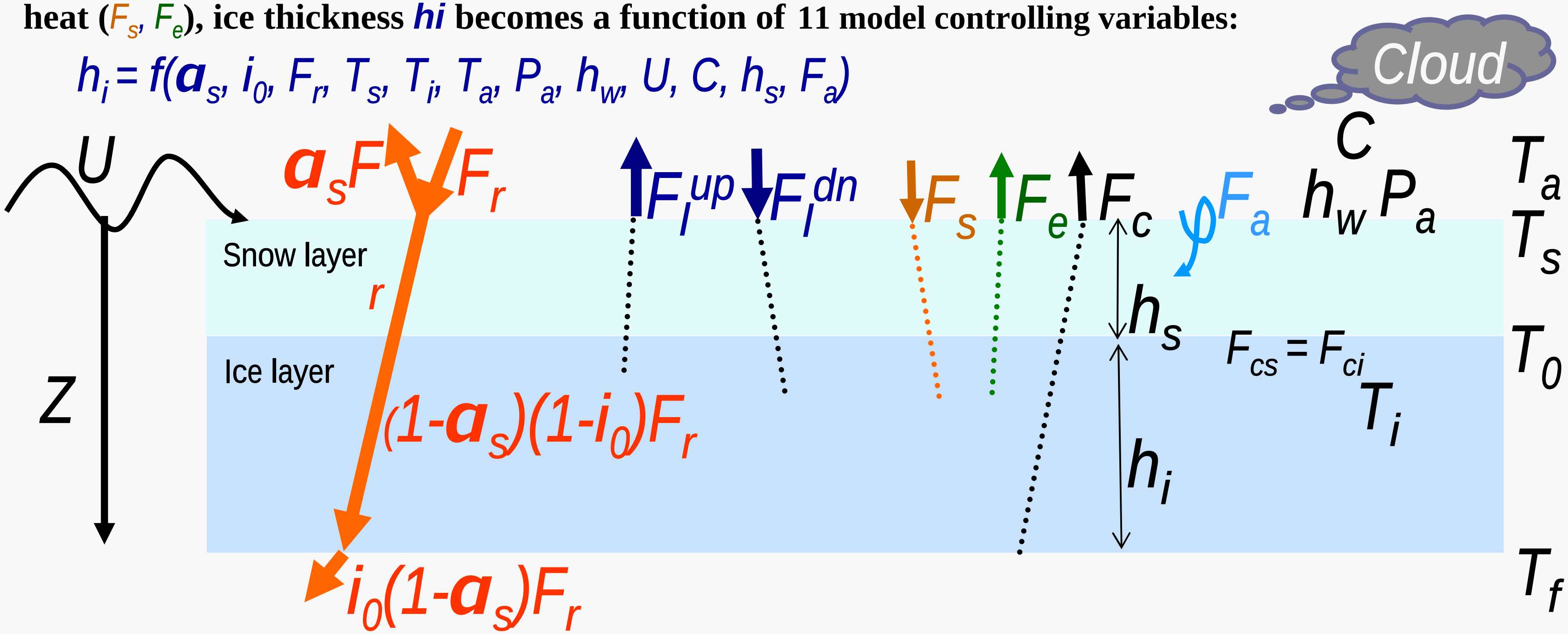
One-dimensional Thermodynamic Ice Model (OTIM)

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_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:

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



Algorithm Description

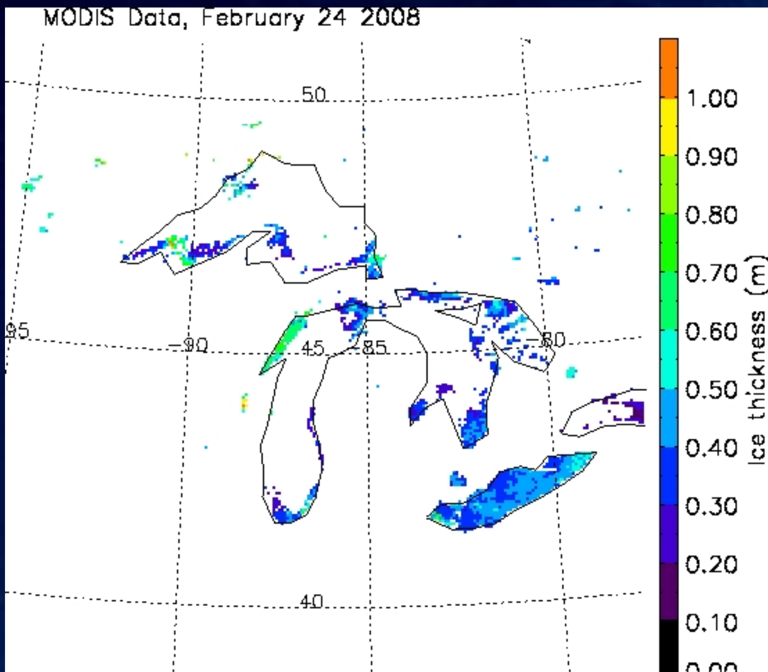
Ice Age Categories:

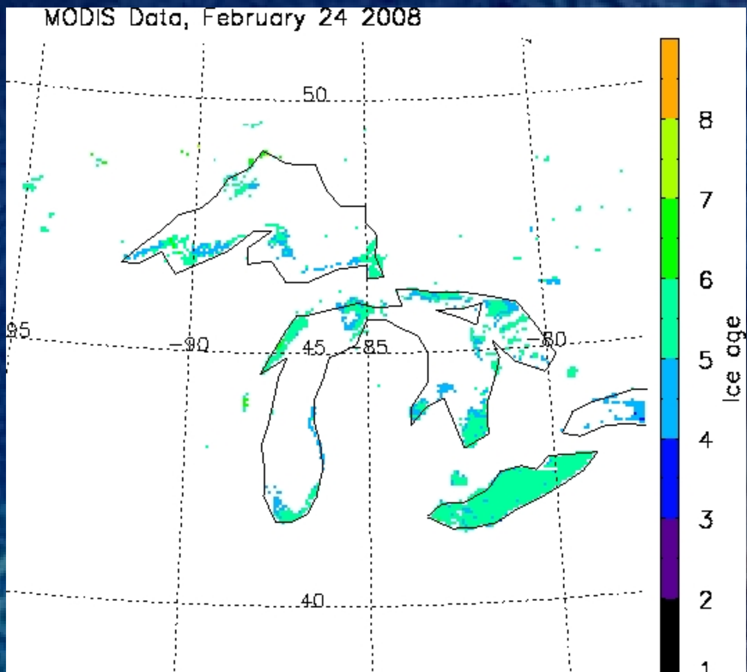
- **Ice free**: *Directly from ice identification/concentration algorithm when ice concentration is less than 15%.*
- **First-year ice**: *Ice thickness < 1.80m. First-year ice includes New Ice (<5cm), Nilas Ice (5~10cm), Grey Ice (10~15cm), Grey-white Ice (15~30cm), Thin First-year Ice (30~70cm), Medium First-year Ice (70~120cm), Thick First-year Ice (120~180cm)*.
- **Older ice**: *Ice thickness >= 1.80m*.

Derivation of Ice Thickness and Age for Use with GOES-R ABI Data:

Examples of Product Output

NASA MODIS Data: Great Lakes





Ice Age Classification:

1: Free of ice (white)

2: New ice

3: Grey ice

4: Grey-white ice

5: Thin first-year ice

6: Median first-year ice

7: Thick first-year ice

8: Old ice

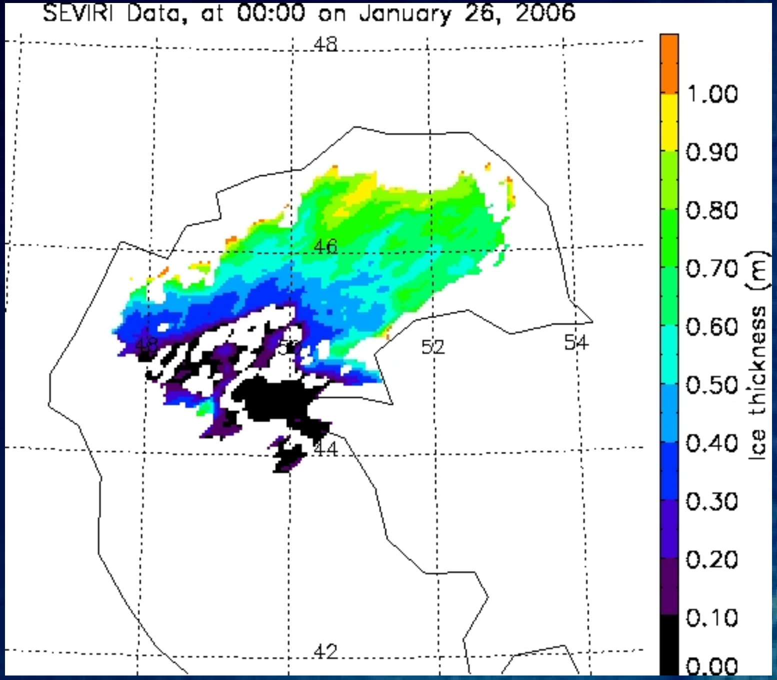
Ice Thickness (m) over Great Lakes area, February 24, 2008.

Ice Age derived from Ice Thickness over Great Lakes area, February 24, 2008.

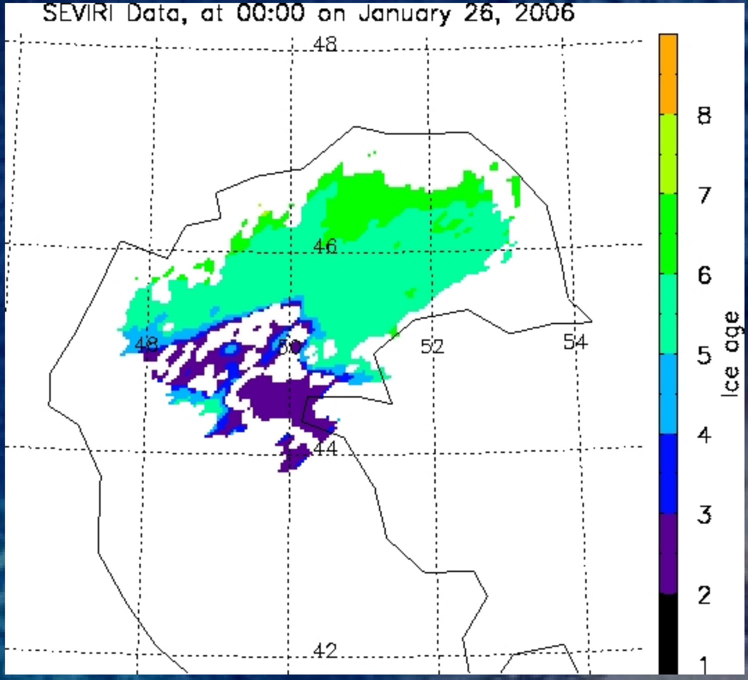
Derivation of Ice Thickness and Age for Use with GOES-R ABI Data:

Examples of Product Output

MSG SEVIRI Data: Caspian Sea



Ice Thickness (m) over Caspian Sea, February 24, 2008.



Ice Age derived from Ice Thickness over Caspian Sea, February 24, 2008.

Ice Age Classification:

1: Free of ice (white)

2: New ice

3: Grey ice

4: Grey-white ice

5: Thin first-year ice

6: Median first-year ice

7: Thick first-year ice

8: Old ice

Validation Approach

- Ice Thickness has been measured on the ground at 11 Canadian weather **stations** since 2002 that are sponsored and archived by Canadian Ice Service (CIS).
- **Submarine** cruise measurements of ice draft data using Upward Looking Sonar (ULS) are available from National Snow and Ice Data Center (NSIDC) during the period of Scientific Ice Expeditions (SCICEX) performed by a U.S. Navy submarine.
- **Moored** Upward Looking Sonar (ULS) measured ice draft/thickness data from NSIDC and Beaufort Gyre Exploration Program (BGEP).
- Ice Age derived from SMMR and SSM/I passive **microwave** data with NASA team algorithm since 1978.

Validation Approach

- Ice Age product validation will be performed with the following test data
  - » Advanced Very High Resolution Radiometer (AVHRR) Polar Pathfinder (APP) Extended (**APP-x**) Data.
  - » **MODIS** data over the Arctic and the Great Lakes.
  - » Meteosat **SEVIRI** data over the Caspian Sea.

Derivation of Ice Thickness and Age for Use with GOES-R ABI Data:

Validation Approach

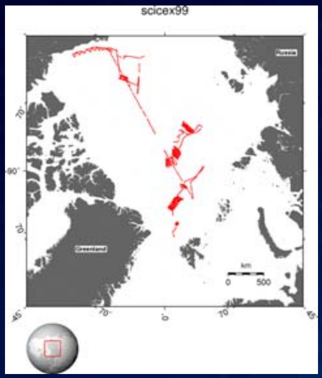
- Method
  - » Direct match-up and comparison in **ice thickness** between OTIM retrievals and surface observations and numerical model simulations (PIOMAS)
  - » Compare **Ice Age** derived from Ice Thickness (this algorithm) with independent Ice Age estimation from Nimbus-7 SMMR and DMSP SSM/I Passive Microwave Data (NASA team algorithm)

- Performance Metrics
  - » Cumulative frequency, bias mean, and absolute bias mean, **accuracy**, **precision**.

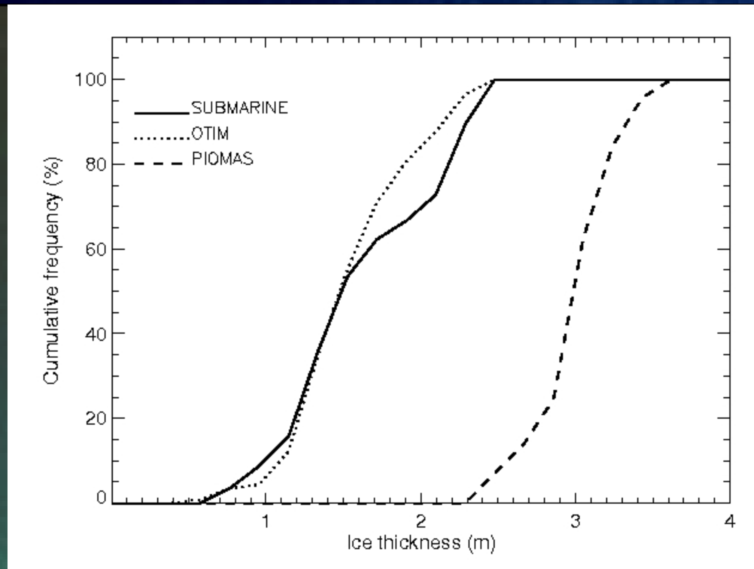
Derivation of Ice Thickness and Age for Use with GOES-R ABI Data:

Validation Results

Comparison of AVHRR Ice Thickness with submarine ULS measurements

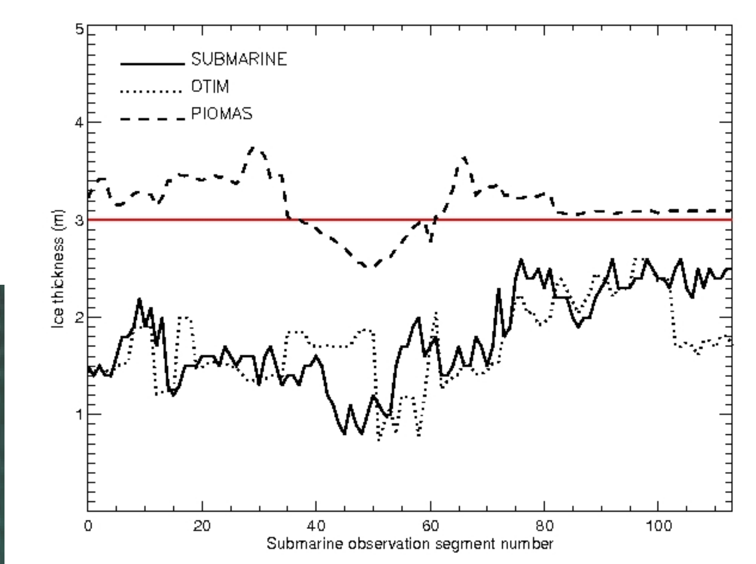


Submarine trajectory, 1999



Ice thickness cumulative distribution retrieved by OTIM with APP-x data, submarine sonar data, and simulated thickness from the PIOMAS model. Submarine ice draft (mean and median only) was converted to ice thickness by a factor of 1.11.

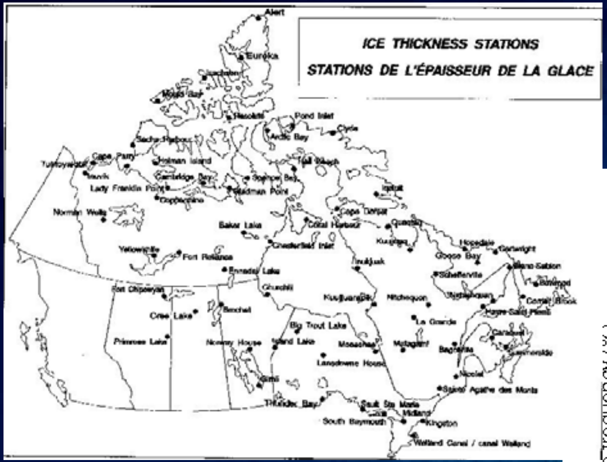
Ice thickness values retrieved by OTIM with APP-x data, submarine sonar data, and simulated thickness from the PIOMAS model along the submarine track segments. Submarine ice draft (mean and median only) was converted to ice thickness by a factor of 1.11.



Derivation of Ice Thickness and Age for Use with GOES-R ABI Data:

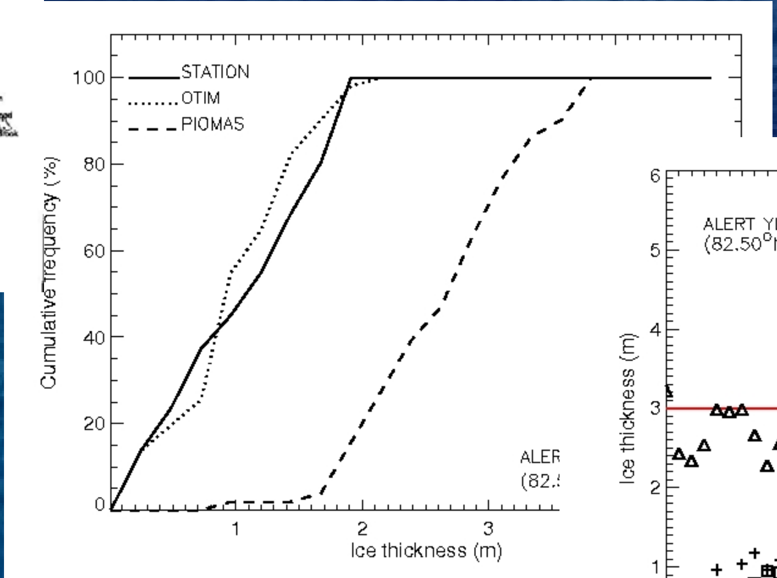
Validation Results

Comparison of AVHRR Ice Thickness with station measurements

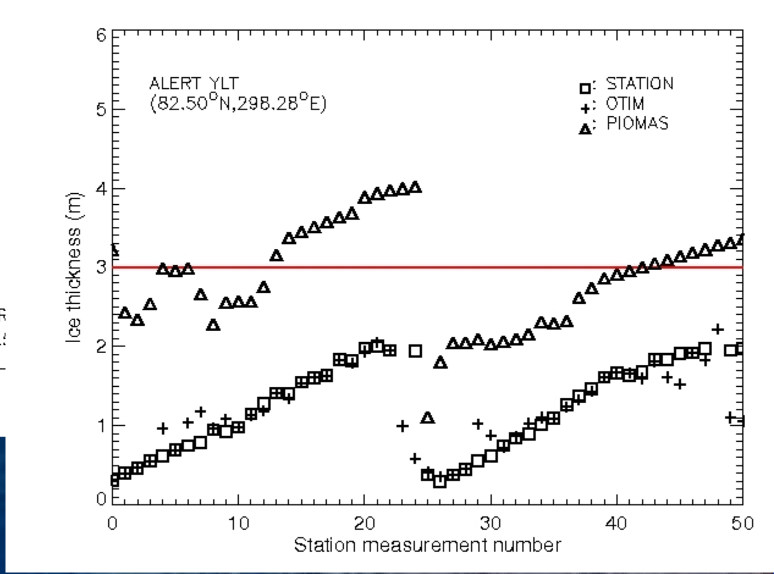


Station location map. Totally 11 Canadian stations participate the New Arctic Program starting from 2002 for ice thickness measurements.

Comparisons of ice thickness cumulative distribution retrieved by OTIM with APP-x data, simulated thickness from the PIOMAS model and station measurements at Alert.



Comparisons of ice thickness values retrieved by OTIM with APP-x data, measurements at Alert, and simulated thickness from the PIOMAS model.



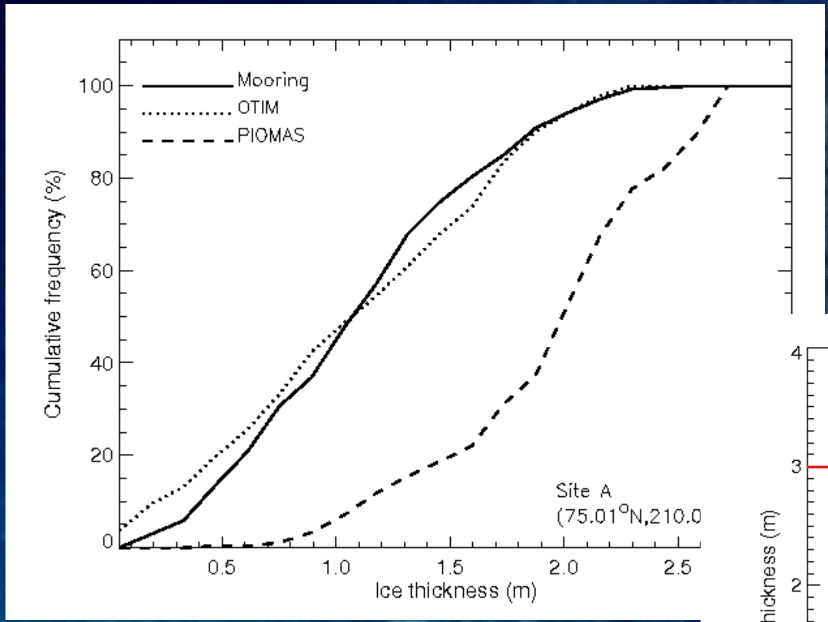
Derivation of Ice Thickness and Age for Use with GOES-R ABI Data:

Validation Results

Comparison of AVHRR Ice Thickness with Moored ULS measurements

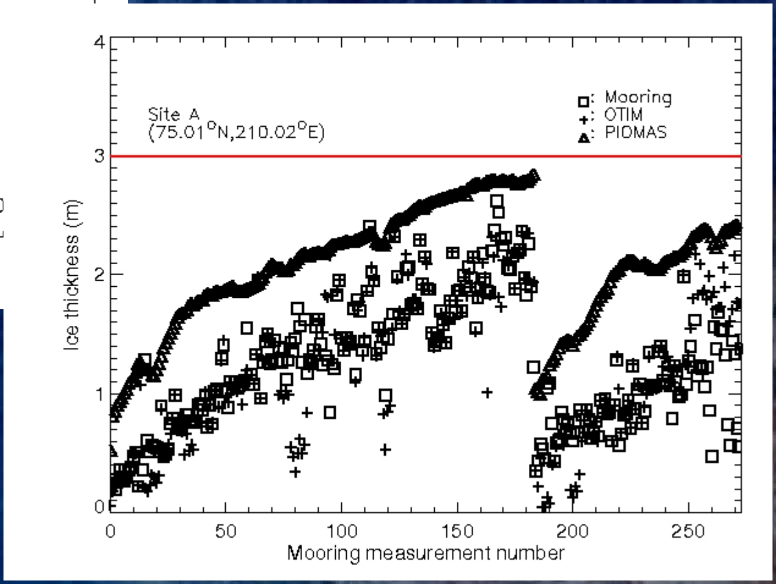
Mooring Location
Site A (*75º0.499'N, 149º58.660'W*)
Site B (*78º1.490'N, 149º49.203'W*)
Site C (*76º59.232'N, 139º54.562'W*)

The location information of the three mooring sites during the Beaufort Gyre Exploration Project starting from 2003.



Comparisons of ice thickness cumulative distribution retrieved by OTIM with APP-x data, simulated thickness from the PIOMAS model, and ULS measurements at the mooring site A.

Comparisons of ice thickness values retrieved by OTIM with APP-x data, simulated thickness from the PIOMAS model and ULS measurements at the mooring site A.



Validation Results

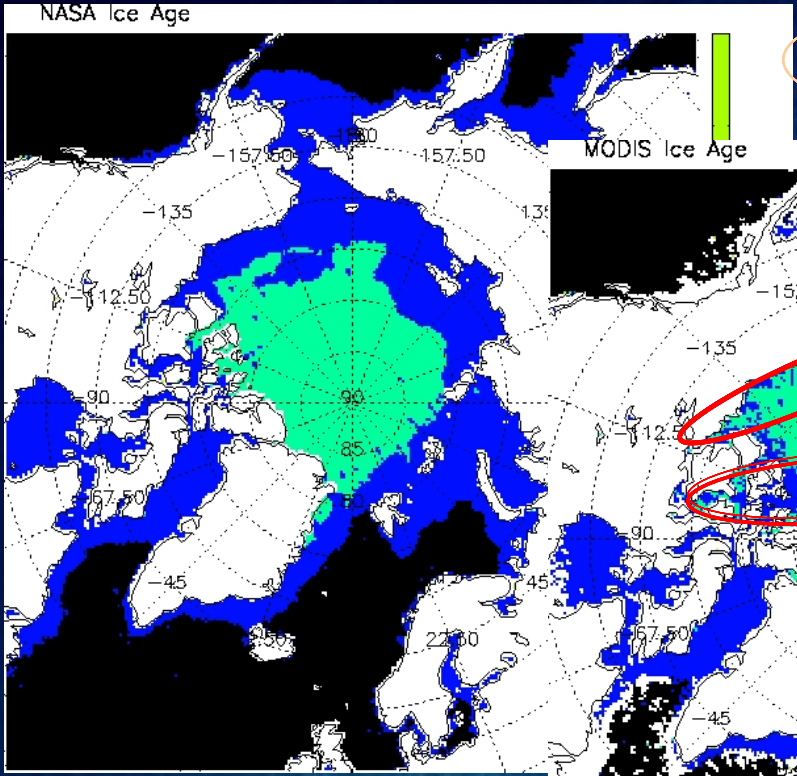
Comparison of OTIM derived Ice Thickness with Submarine and Moored ULS measurements, and station measurements

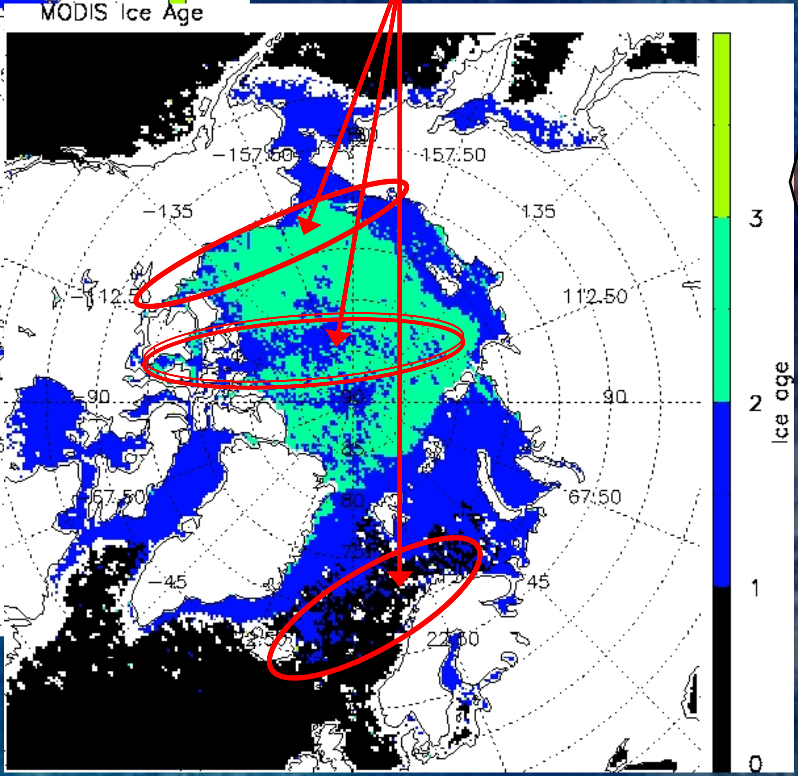
In-situ Measurements OTIM	Thickness mean (m)	Bias mean (m)	Accuracy (%)
Submarine	1.80	-0.07	96%
OTIM	1.73		
Mooring Sites	1.29	-0.09	93%
OTIM	1.20		
Stations	1.31	-0.11	91%
OTIM	1.20		
All	1.47	**-0.09**	**94%**
OTIM	1.38		

Derivation of Ice Thickness and Age for Use with GOES-R ABI Data:

Validation Results

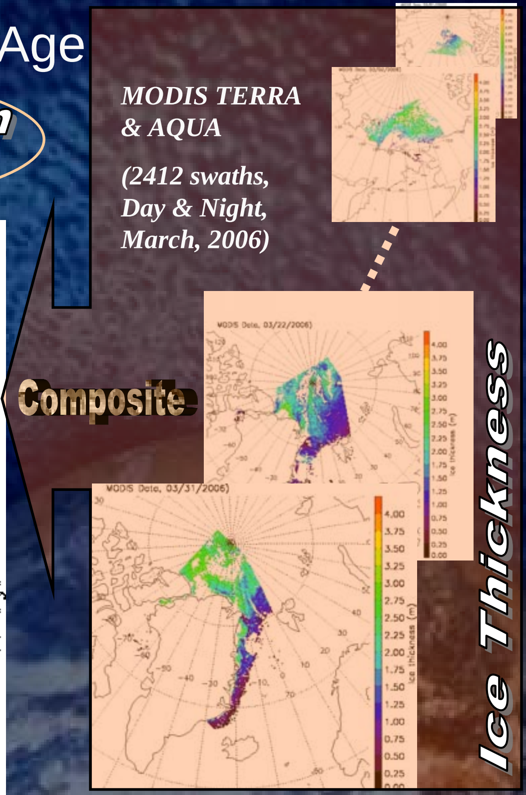
OTIM Ice Age from MODIS data vs Microwave (NASA) Ice Age





Cloud Contamination (Big Issue)

SMMR and SSM/I vs AITA (2006)



0:Ice free

1: First-year ice

2: Older ice

Derivation of Ice Thickness and Age for Use with GOES-R ABI Data:

Validation Results

OTIM Ice Age with MODIS data vs Microwave (NASA) Ice Age

Ice Age (OTIM vs Microwave)	
Statistics	**Accuracy**
Ice Free	***D&N:93%, N:93%, D:~100%***
First-year Ice	***D&N:92%, N:92%, D:~100%***
Older Ice	***D&N:84%, N:84%, D:~100%***
All	***D&N:89%, N:89%, D:~100%***
Error Sources	1. *Ice identification algorithm* 2. *Cloud mask/shadow detection* 3. *Relationship between thickness and age* 4. *Ice motion/Dynamic processes*

D=day; N=night

Validation Results

OTIM Ice Age with MODIS data vs microwave (NASA) Ice Age

Note: *Number in each cell stands for the number of pixels that belong to the ice age category difference corresponding to NASA and OTIM ice age classifications used to do statistics, i.e., accuracy and precision in ice age classification.*	**Ice Age Difference (OTIM vs Microwave)**		
	No Difference	1 Category Difference	2 Category Difference
	(D&N:49820) (N:49822) (D:34774)	(D&N:7154) (N:7146) (D:30)	(D&N:52) (N:52) (D:0)
Precision	**(D&N:0.34 Category) (N:0.34 Category) (D:0.03 Category)**		

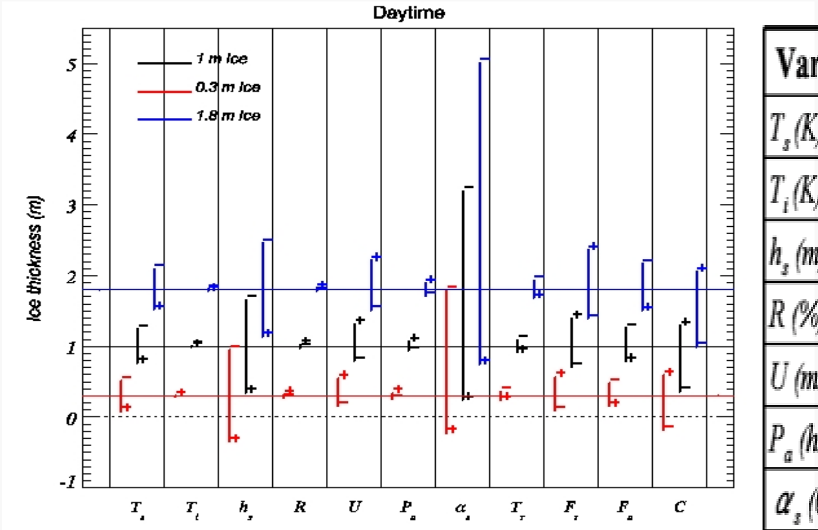
D=day; N=night

Derivation of Ice Thickness and Age for Use with GOES-R ABI Data:

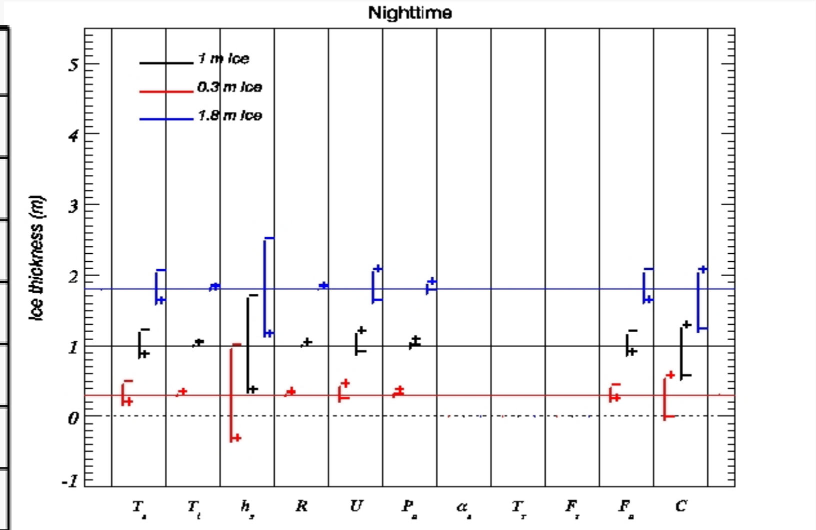
Sensitivity Study

OTIM Uncertainty & Sensitivity

$$(\hat{h}_i - h_i) = \sum (\hat{x}_i - x_i)\frac{\partial h_i}{\partial x_i} \qquad \sigma_{h_i} \le \sum \sigma_{x_i} \left|\frac{\partial h_i}{\partial x_i}\right|$$



Variable	Error
T_s (K)	±2.0
T_i (K)	±5.0
h_s (m)	±50%
R (%)	±10%
U (m/s)	±20%
P_a (hPa)	±50.0
α_s (0~1)	±0.10
T_r (0~1)	±0.05
F_r (w/m²)	±20%
F_a (w/m²)	±2.00
C (0~1)	±0.25



The largest uncertainty sources are in order: α_s, h_s, F_r, C, U, T_s, F_a, T_r, P_a, R, T_i.

The overall uncertainty could be as high as 200% if solar radiation is involved for this version of the OTIM due to the large impact of α_s uncertainty.

The largest uncertainty sources are in order: h_s, C, U, T_s, F_a, P_a, R, T_i.

The overall uncertainty could be as high as 67% or half meter as confirmed by validation results if snow depth error reaches 50% or more.

Derivation of Ice Thickness and Age for Use with GOES-R ABI Data:

Next Steps to Reach 100%

- Algorithm Improvements
  - Improve OTIM performance with respect to its built-in parameterization schemes.
  - Parameterize OTIM residual heat flux to make the model more robust to deal with all kinds of seasonal and environmental conditions.
  - Improve the relationship between ice thickness and ice age.
- Validation Improvements
  - Collect and use more in-situ truth data from submarine and moored upward looking sonar, weather stations, and field experiments to validate and improve OTIM.
  - Collect and test more proxy data such as from MODIS, SEVIRI, and AVHRR to demonstrate that the Ice Age algorithm will meet requirements in comparison with other independent ice age products such as from microwave data.
- Other Improvements
  - Run more cases offline and within the Framework to validate the product for the 100% delivery.

Conclusion and Perspectives

- ABI allows us to monitor ice conditions at high temporal and spatial resolution.
- The Sea & Lake Ice Age Product has been run offline and within the framework and the results are exactly the same.
- The Sea & Lake Ice Age Product uses MODIS and AVHRR data as proxy and is validated against Upward Looking Sonar (ULS) measurements from submarine and mooring sites, stations observations, and microwave data to demonstrate that the Ice Age algorithm meets product requirements of 80% correct accuracy and less than one category precision.
- The Sea & Lake Ice Age Product algorithm offline and within the Framework has been tested with MODIS and SEVIRI proxy data for the Great Lakes and Caspian Sea, and will be run with more proxy data from MODIS to insure the product delivery to meet the requirements.
- This algorithm will be further modified to improve the accuracy. Additional validation data will be employed.

Ice in North America