SEA ICE THICKNESS AND AGE

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Ice Thickness and age Team

PI	Organization	Team Members	Roles and Responsibilities
J. Key	NESDIS	X. Wang (CIMSS) M. Tschudi (CU/CCAR) D. Baldwin (CCAR)	Ice thickness development and cal/val Ice thickness cal/val Ice thicknesscal/val

Requirements

EDR Attribute	Threshold	Objective
a. Vertical Coverage	Ice Surface	Ice Surface
b. Horizontal Cell Size **1. Clear** **2. All weather**	 1.0 km No capability	 0.5 km 1 km
c. Mapping Uncertainty, 3 sigma **1. Clear** **2. Cloudy**	 5 km No capability	 0.5 km 1 km
d. Measure Range **1. Ice Age**	**Ice Free, New Young, All other ice**	**Ice free, New/Nilas, Grey, Grey-white, First Year Thin, First Year Medium, First Year Thick, Second Year, Multiyear, Smooth and Deformed Ice**
2. Ice Concentration	0/10 to 10/10	0/10 to 10/10
e. Measurement Uncertainty **1. Probability of Correct Typing (Ice Age)** **2. Ice Concentration**	 70% Note 1	 90% 5%
f. Refresh	At least 90% coverage of the global every 24 hours (monthly average)	6 hrs
g. Geographic coverage	All Ice-covered regions of the global ocean	All Ice-covered regions of the global ocean

Notes:

1. VIIRS produces a sea ice concentration IP in clear sky conditions, which is provided as an input to the ice surface temperature calculation

Enterprise Ice Thickness Algorithm:

The One-dimensional Thermodynamic Ice Model (OTIM)

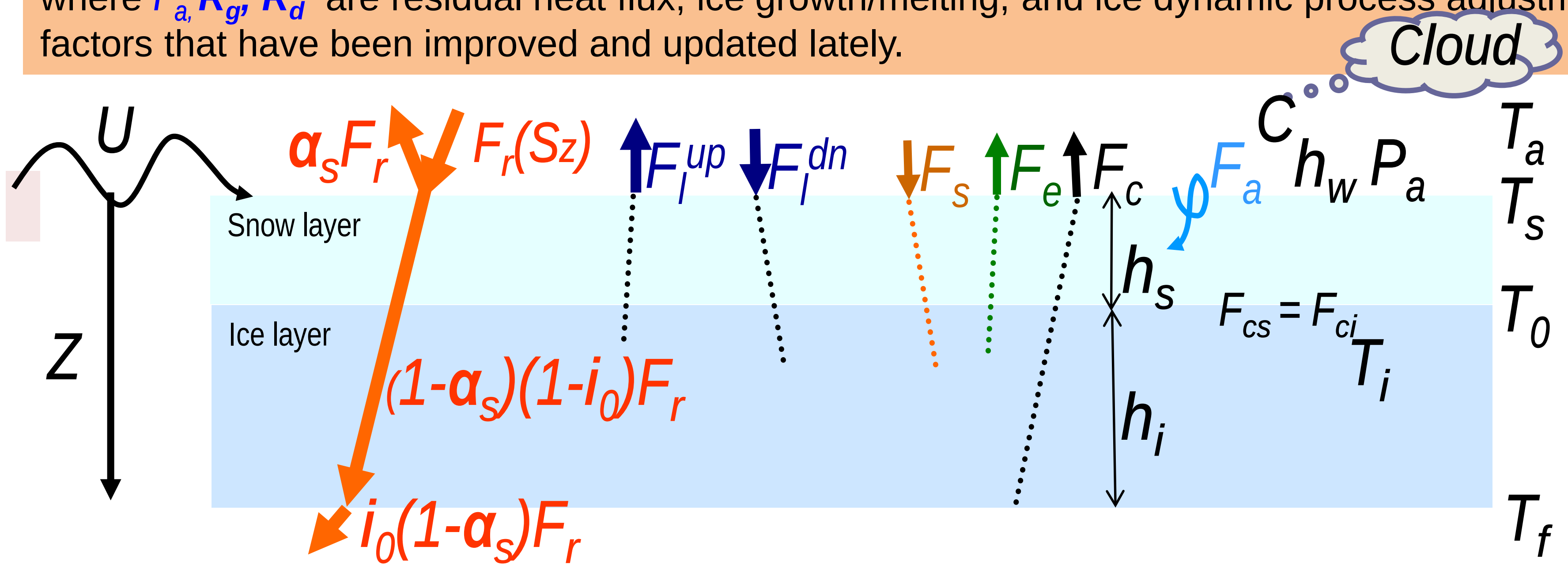
Based on the surface energy budget at thermo-equilibrium state, the fundamental equation is

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

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

$$h_i = f(\boldsymbol{\alpha}_s, i_0, Sz, T_s, T_i, T_a, P_a, h_w, U, C, h_s, F_a, R_g, R_d),$$

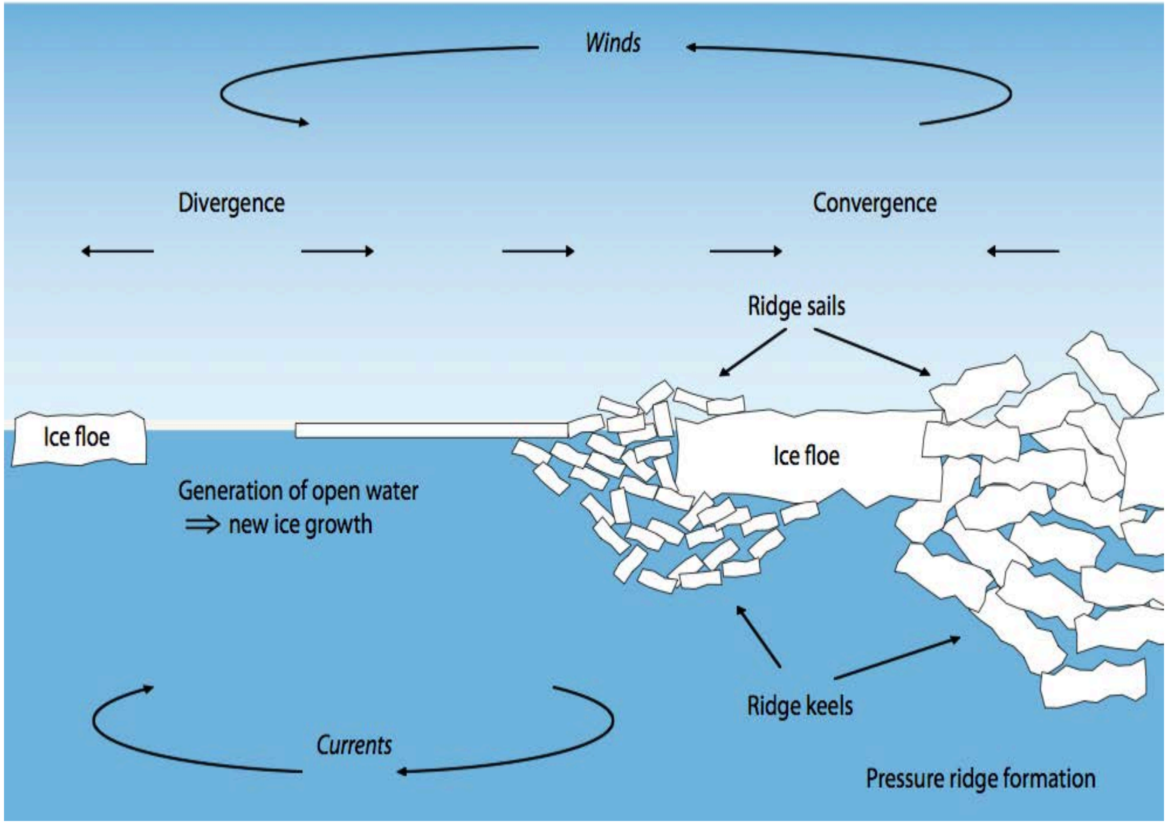
where F_a, $\boldsymbol{R_g}$, $\boldsymbol{R_d}$ are residual heat flux, ice growth/melting, and ice dynamic process adjustment factors that have been improved and updated lately.



Algorithm Improvement and Consistency

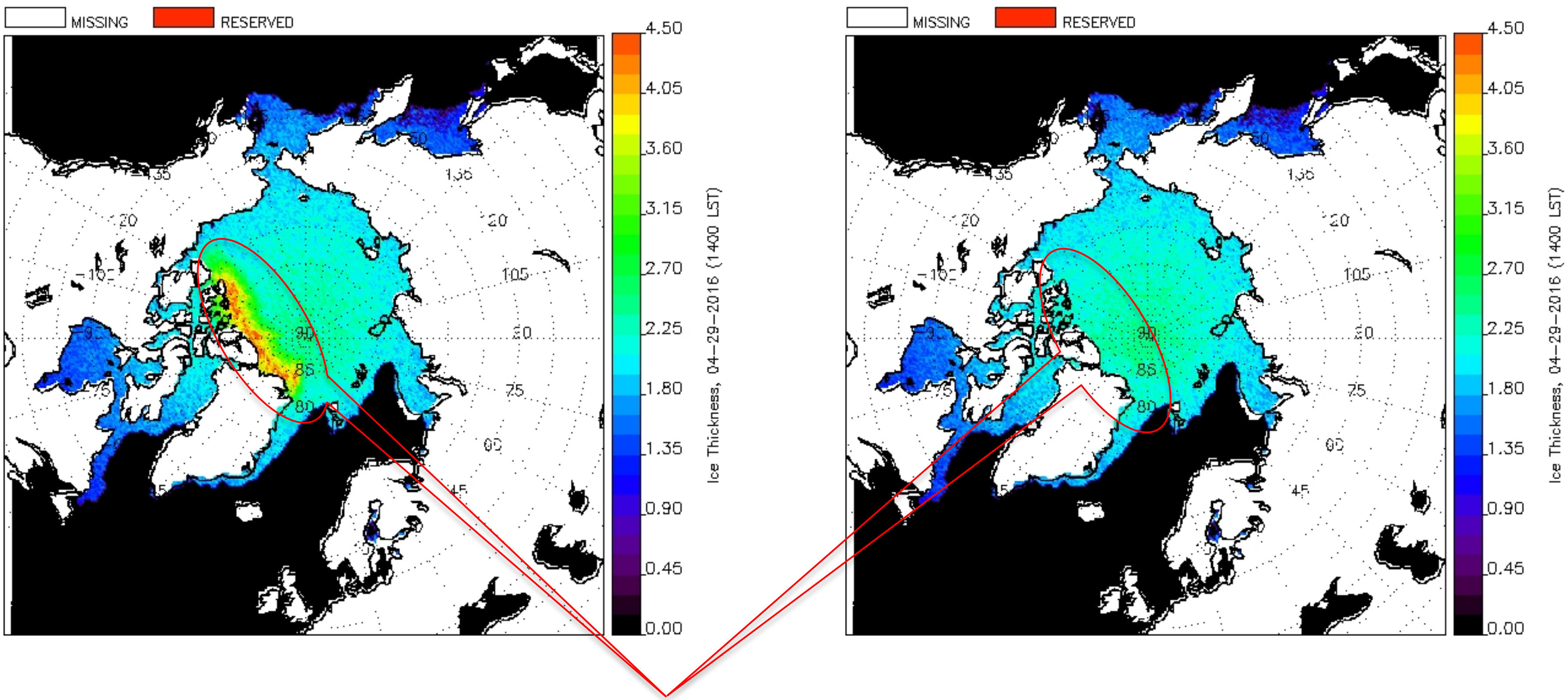
Recent OTIM improvements include: 1) Residual flux F_a from regression equation, not the lookup table that is currently used in the enterprise ; 2) Ice motion physical dynamic factor; and 3) Ice growth/melt thermal dynamic factor, for the purpose of explicit ice physical/thermal dynamic processes consideration and broad applications.

Processes that affect ice thickness. *(from SWIPA, 2011)*



OTIM : Ice motion physical dynamic factor

ON **April 29, 2016** **OFF**



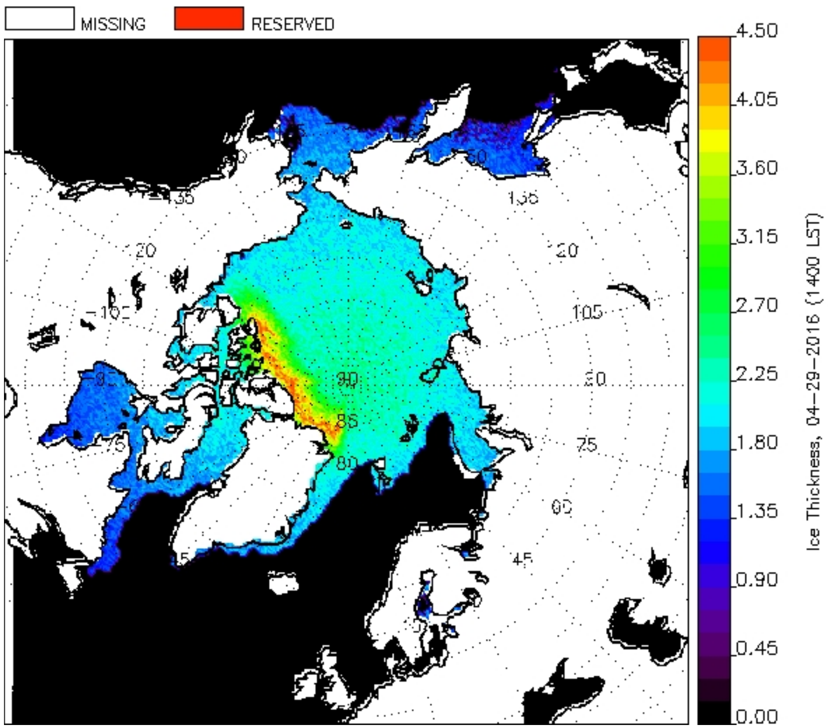
See the difference along the Canadian Archipelagos when Ice motion physical dynamic factor is turned on and off (left and right).

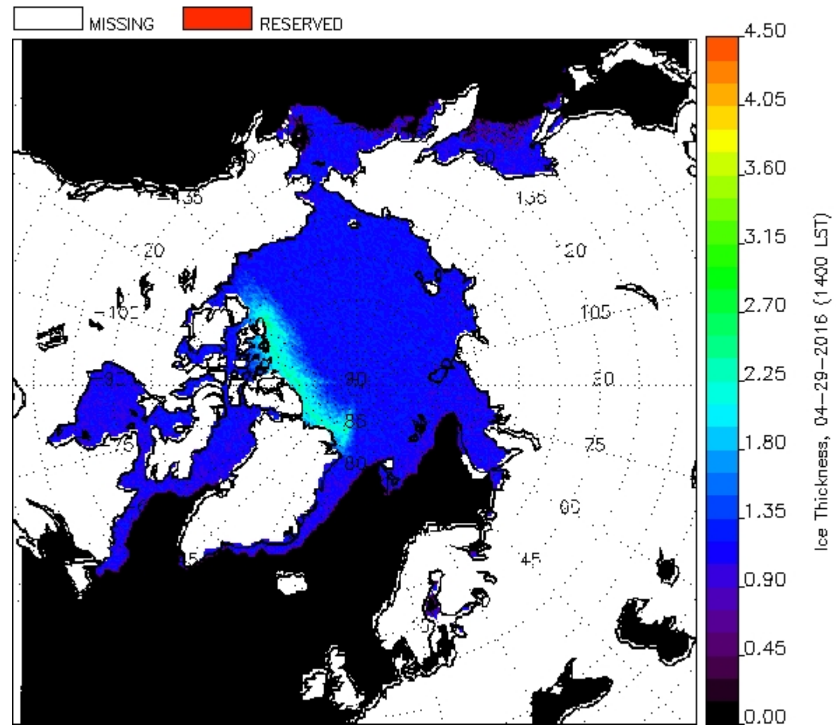
OTIM : Ice growth/melt thermal dynamic factor

ON

April 29, 2016

OFF





See the difference in the two images when Ice growth/melt thermal dynamic factor is turned on and off (left and right).

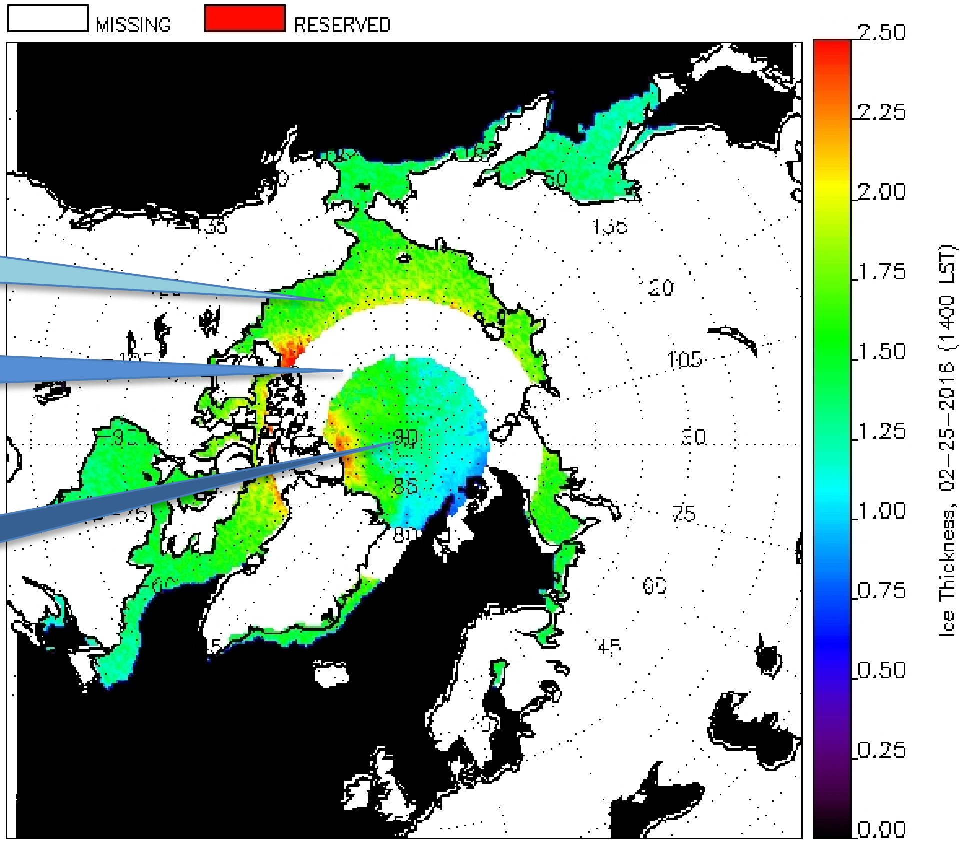
Algorithm Improvement and Consistency

OTIM : Algorithm Day-Night Consistency

Bright area – Day (Solar zenith angle: < 86.5º)

Dim area (Solar zenith angle: 86.5º ~ 90.5º)

Dark area – Night (Solar zenith angle: > 90.5º)

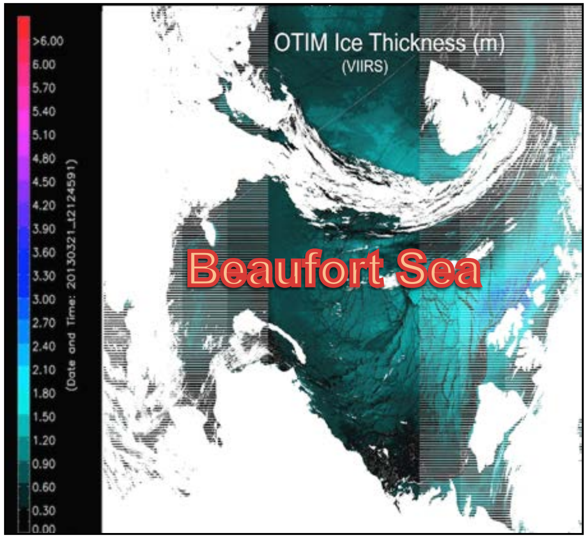


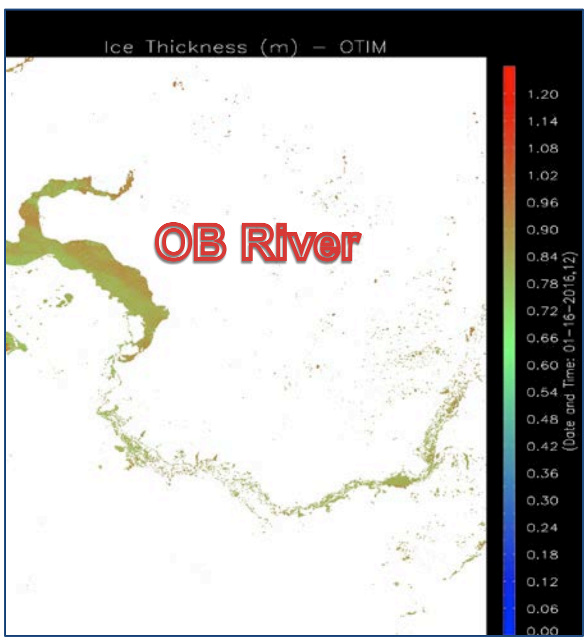
February 25, 2016

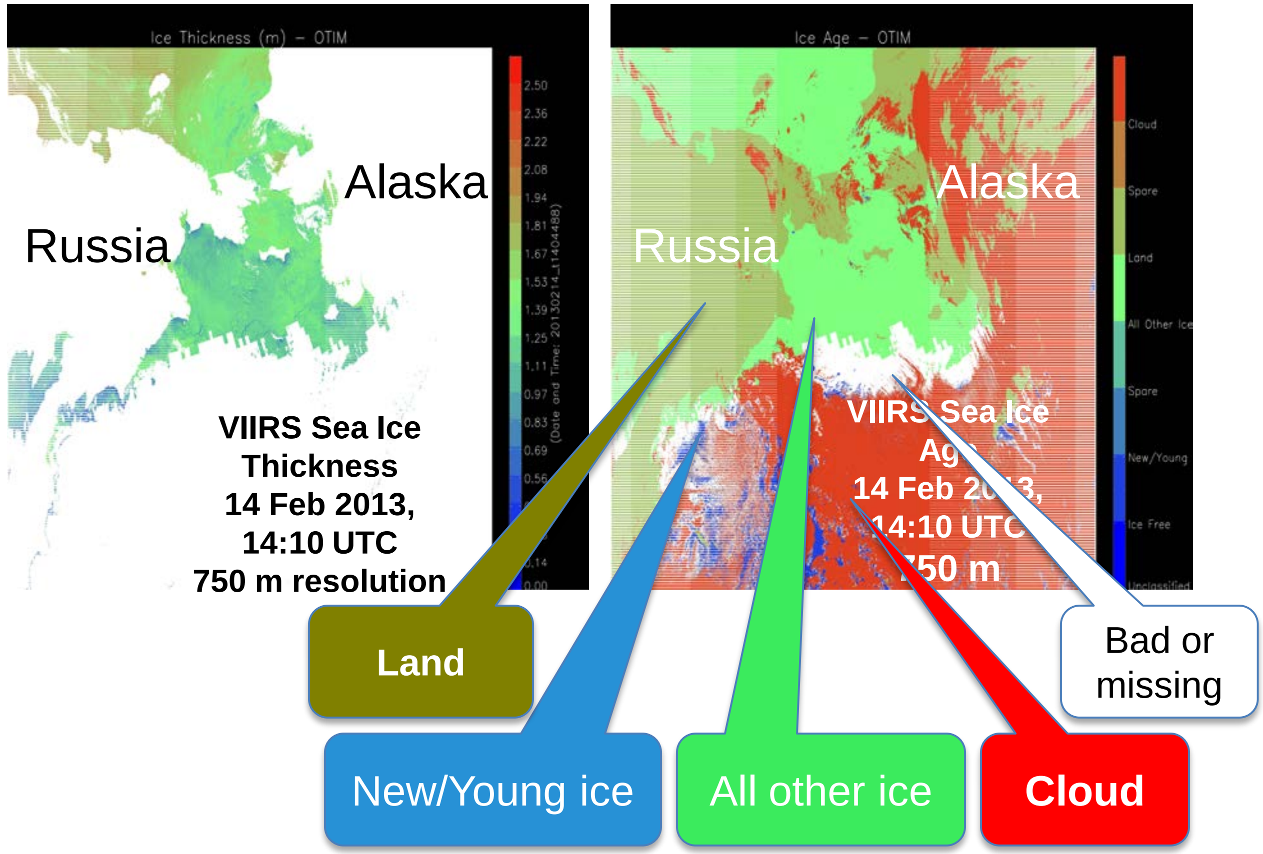
Examples of OTIM Ice Thickness and Age from VIIRS

Ice Thickness and Age

OTIM - Energy Budget Approach

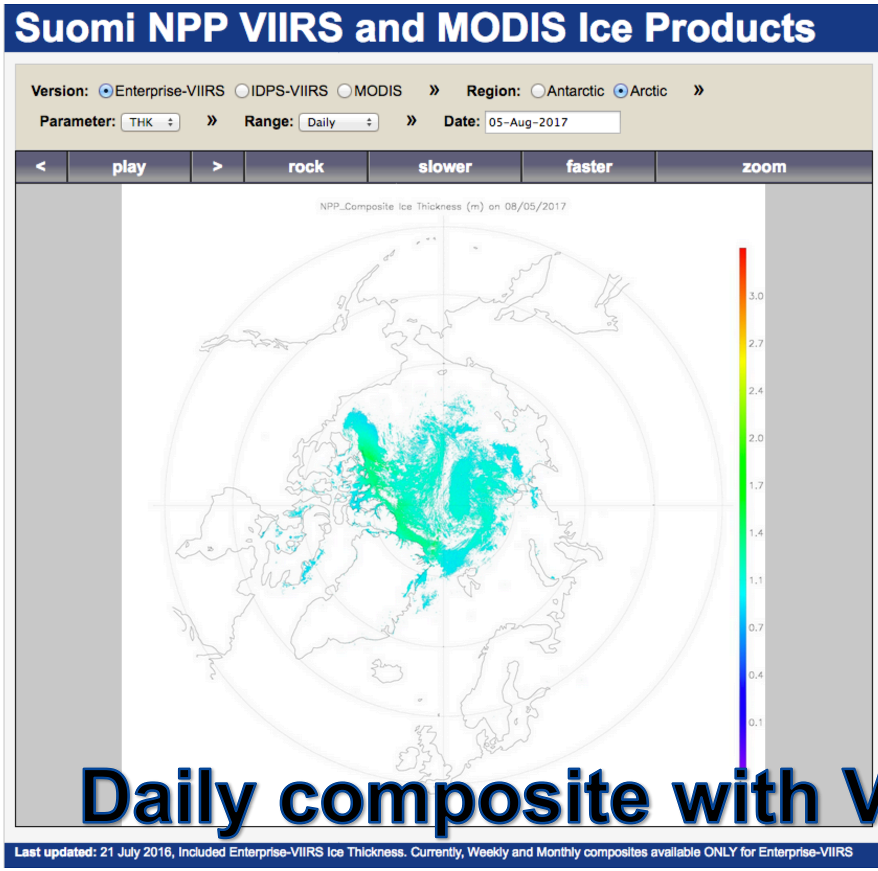


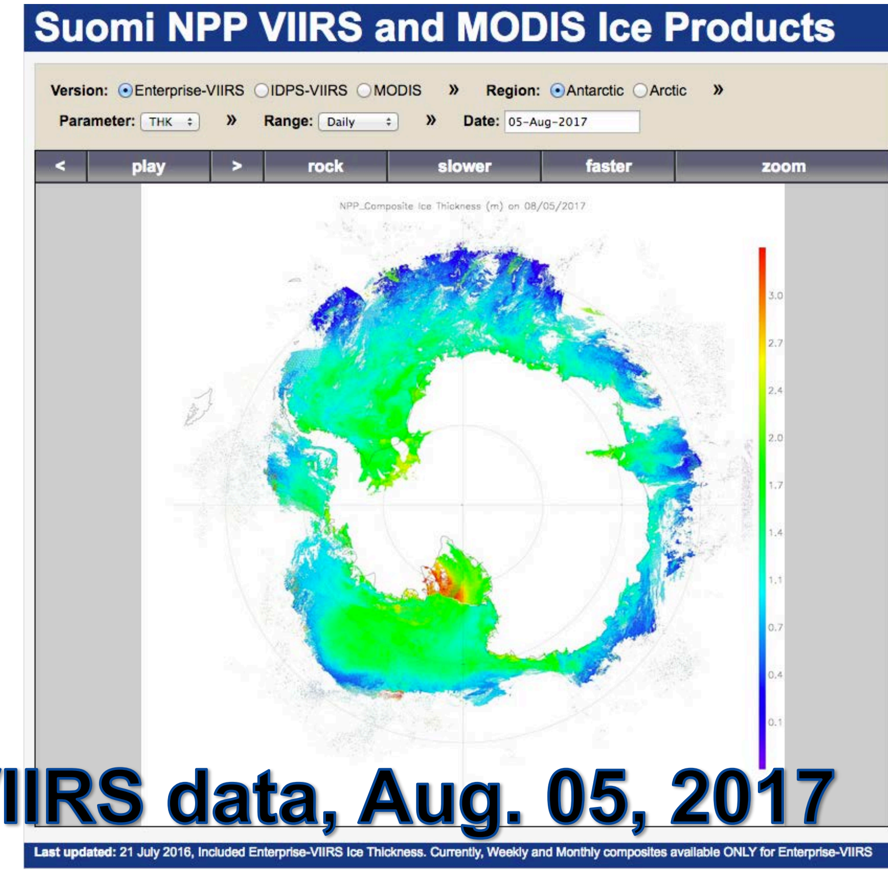




Near real-time VIIRS Sea Ice Thickness

The OTIM retrieved near real-time Arctic and Antarctic sea ice thickness with Suomi NPP VIIRS data under clear sky condition is now available at CIMSS. They will be added to the STAR LTM website in the near future.





Daily composite with VIIRS data, Aug. 05, 2017

https://stratus.ssec.wisc.edu/ice-products/anibrowser/

Validation

Statistical results of the comparison in sea ice thickness between **APP-x (OTIM), PIOMAS, CryoSat-2, and IceBridge** for matched locations.

Period	Statistics	APP-x	PIOMAS	CryoSat-2	IceBridge
MAR (4819)	Mean	2.45	2.44	2.49	2.27
	STD	0.56	0.55	0.60	1.03
	Median	2.39	2.49	2.39	2.16
	Mode	2.33	2.89	2.32	1.89
	Skewness	0.44	0.04	0.92	0.70
APR (292)	Mean	2.94	2.80	3.23	3.38
	STD	0.54	0.58	1.01	1.25
	Median	2.92	2.94	3.52	3.05
	Mode	2.42	2.33	3.63	3.70
	Skewness	0.06	-0.05	-0.42	0.62
MARAPR (5111)	Mean	2.47	2.46	2.53	2.33
	STD	0.57	0.56	0.65	1.08
	Median	2.41	2.51	2.41	2.22
	Mode	2.33	2.04	2.32	3.17
	Skewness	0.41	0.05	0.95	0.76
	Bias statistics and dataset correlation with IceBridge				
MAR	mean	0.18	0.18	0.23	-
	STD	0.76	0.77	0.94	-
	Correlation	0.70 (<0.001)	0.68 (<0.001)	0.44 (<0.001)	-
	Median	0.28	0.25	0.30	-
	Mode	0.70	none	none	-
	Skewness	-0.88	-0.81	-0.65	-
APR	mean	-0.44	-0.58	-0.13	-
	STD	1.00	1.02	1.85	-
	Correlation	0.64 (<0.001)	0.60 (<0.001)	0.33 (<0.001)	-
	Median	-0.23	-0.35	0.02	-
	Mode	0.27	-0.31	0.40	-
	Skewness	-0.32	-0.30	-0.48	-
MARAPR	mean	0.18	0.18	0.29	-
	STD	0.68	0.69	0.84	-
	Correlation	0.70 (<0.001)	0.68 (<0.001)	0.40 (<0.001)	
	Median	0.25	0.23	0.29	-
	Mode	none	none	none	-
	Skewness	-0.88	-0.85	-0.79	-

Descriptive statistics of the ice thickness (top half) in four datasets and their differences and correlation with IceBridge thickness (bottom half) in the two IceBridge periods (meters). MAR is March; APR is April; MARAPR is March and April, over 2011-2013. The number in parentheses beneath the period name is the total number of pixels used for the comparison in that period. P-values are given in parentheses beneath the correlation coefficients.

Overall, the APP-x ice thickness from OTIM is the closest to the IceBridge measurements in terms of mean bias (0.18 m), STD (0.68m), and correlation (0.70).

Validation

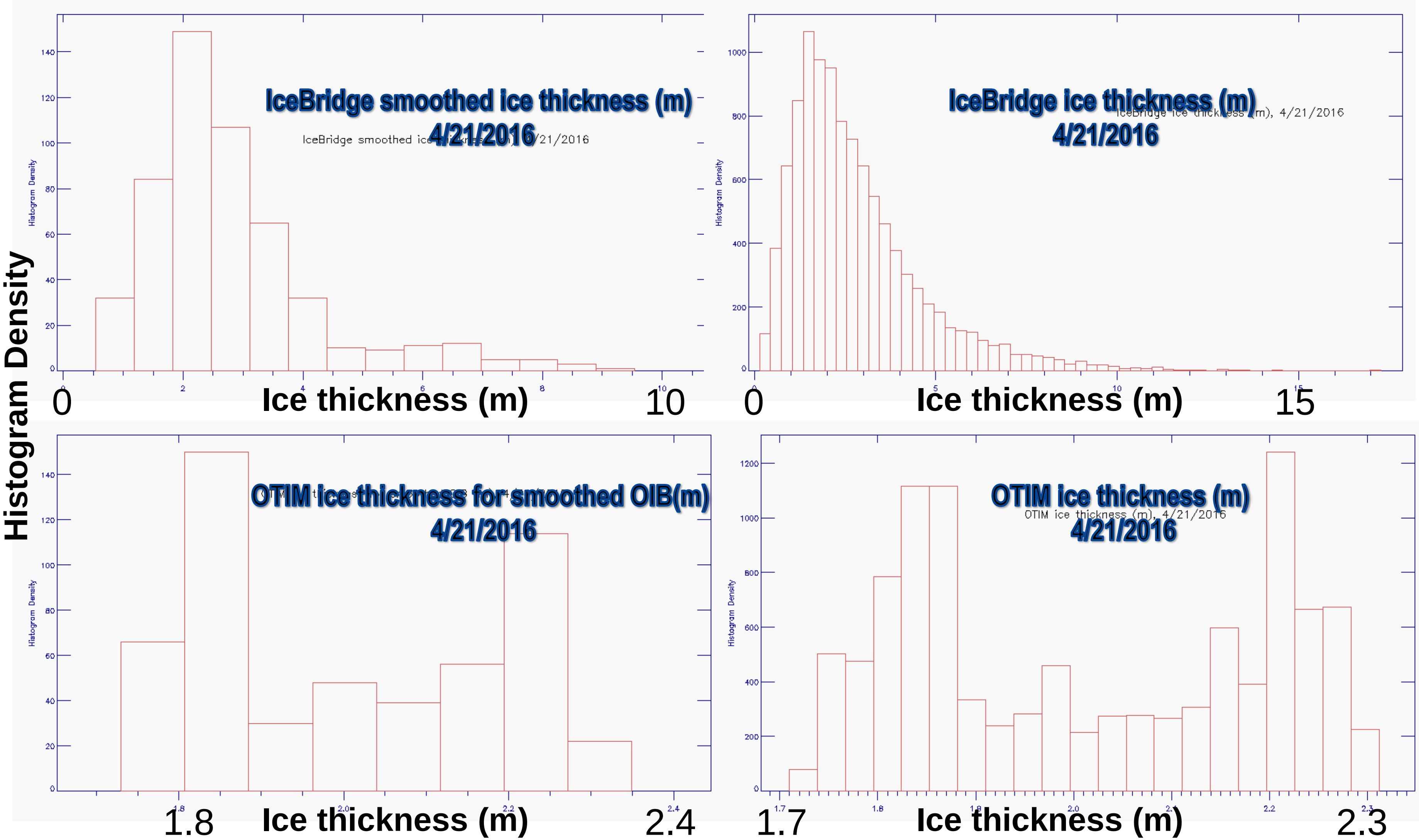
Statistical results of the comparison in sea ice thickness between **S-NPP (OTIM) and NASA IceBridge** (aircraft lidar + snow radar) for matched locations.

Case no	Date	S-NPP		IceBridge		S-NPP minus IceBridge			
		mean	STD	mean	STD	mean	STD	percent (%)	matched pixels
1	2014.03.12	1.18	0.52	1.45	0.69	-0.27	0.55	-5.34	495
2	2014.03.13	2.48	0.55	2.24	0.52	0.24	0.55	16.49	438
3	2014.03.24	1.88	0.78	2.33	0.48	-0.45	0.78	-6.31	803
4	2014.03.31	2.28	0.21	2.56	0.35	-0.28	0.43	-8.97	37
5	2015.03.24	2.06	0.59	2.45	0.43	-0.39	0.75	-11.63	1050
6	2015.03.29	1.72	0.43	1.88	0.54	-0.16	0.74	-1.69	5153
Average		1.93	0.50	2.15	0.50	**-0.22**	**0.63**	-2.91	7976 (total)

From 24 cases of S-NPP granule data when IceBridge has measurements, 6 cases out of the total 24 cases from S-NPP have good overlapped locations with IceBridge where they both have ice thickness values for comparison.

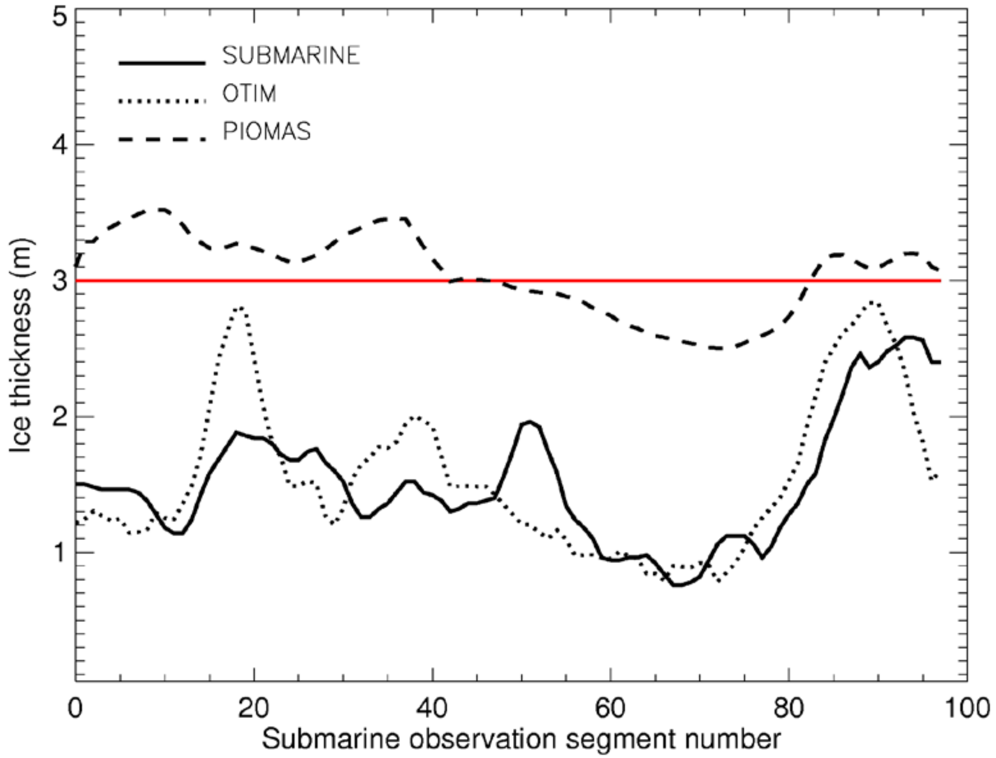
Validation

Statistical results of the comparison in sea ice thickness between S-NPP (OTIM) and NASA IceBridge (aircraft lidar + snow radar) for matched locations.



Validation

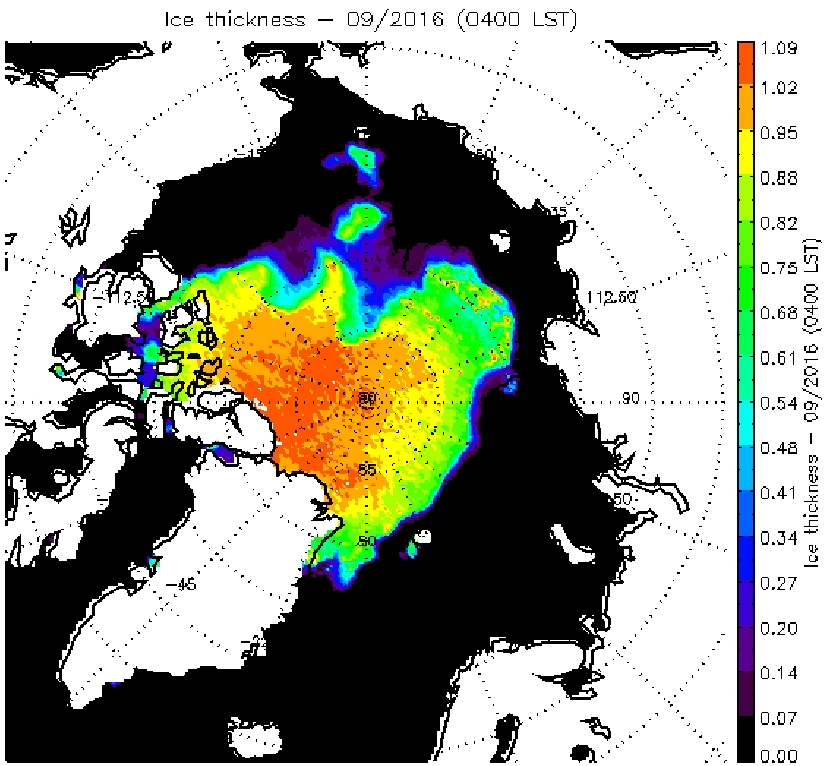
Validation has been done with upward-looking sonar from submarines and moored buoys in situ thickness measurements ICESat, CryoSat-2, IceBridge, and an ice-ocean model.

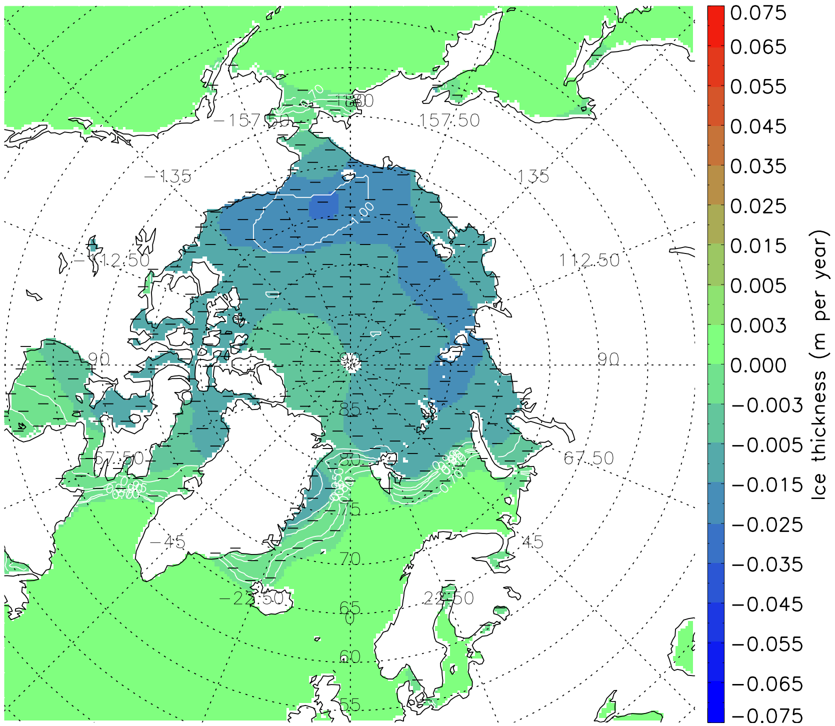


Right: Validation with submarine sonar and modeled ice thicknesses.

	OTIM	Submarine
Thickness Mean (m)	1.55	1.51
Bias (m)	0.04	
RMS difference (m)	0.52	

Trends in Sea Ice Thickness





Left: Arctic sea ice thickness from OTIM in **September 2016**. Center: Arctic sea ice thickness trends from OTIM in Autumn (Sept. – Nov.) over 1982-2016.

AVHRR TRENDS CAN BE EXTENDED INTO THE VIIRS ERA AND THAT THE ALGORITHM USED WITH AVHRR IS THE SAME AS THE VIIRS ALGORITHM.

JPSS-1 Readiness

- Significant algorithm changes from S-NPP to JPSS-1:
  - Daytime-nighttime consistency has been significantly improved.
- Post-Launch Cal/Val Plans
  - Most important new dataset will be ICESat-2 (delayed until early 2018) and CryoSat-2.
  - IceBridge flights will continue to be important
  - Near real-time validation will be set up using Cryosat-2 and SMOS
- Accomplishments and Highlights Moving Towards J1
  - Improvements to the model, e.g., residual heat flux that for better daytime (sunlit) retrievals
  - Near real-time generation
  - Application to 30+ years of AVHRR
- Major Risks/Issues/Challenges/ and Mitigation
  - Limitations need to be made clear to users, e.g., upper limit of ice thickness retrieval (~5 m) and larger uncertainty in melt conditions
  - Ultimately, either a VIIRS product adjusted by Cryosat-2/ICESat thicknesses, or a blended product may provide the best estimate.

Summary & Path Forward

- Summary
  - The **VIIRS Ice Thickness/Age product is ready for J1**
- Path Forward
  - FY17 Milestones: Add ICESat-2 to validation plans (CY 2018); begin to test regional bias corrections with altimeter-based ice thickness
  - Alternate Algorithms and Future Improvements: no alternate algorithms; add VIIRS surface radiation

Snow and Ice Product Users (planned)

Operational Ice Services

- U.S. National Ice Service
- North American Ice Service
- NWS Alaska Sea Ice Program

Modeling

- (Need to set up collaborations and funding) Naval Research Lab, Arctic Cap Nowcast/Forecast System (ACNFS), NCEP
- Universities (Washington, Hamburg)