VIIRS SEA ICE THICKNESS

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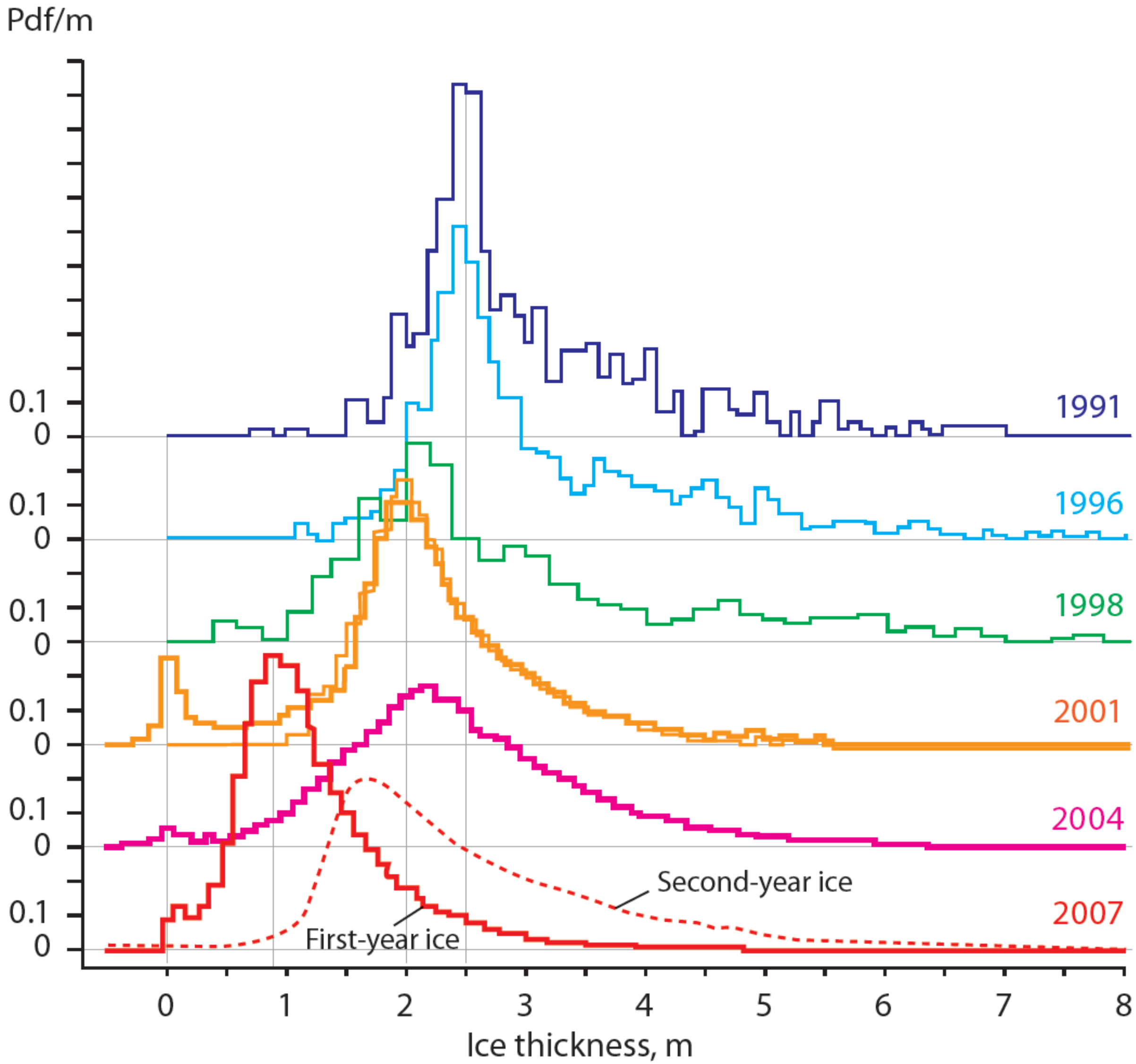
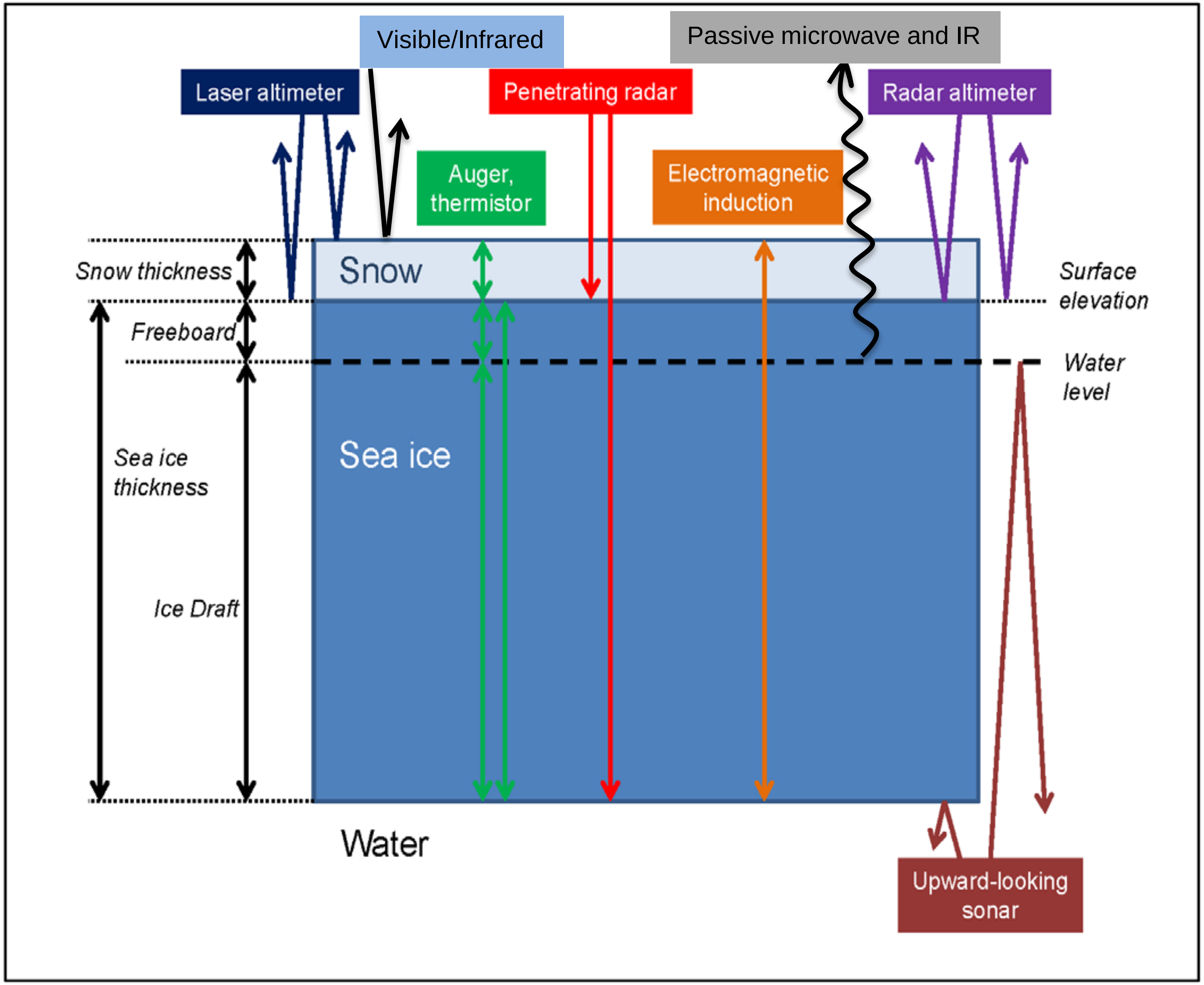
Ice Concentration Team

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

Arctic Sea Ice Thickness Distributions



Measuring Ice Thickness



(adapted from Meier et al., 2014)

Requirements

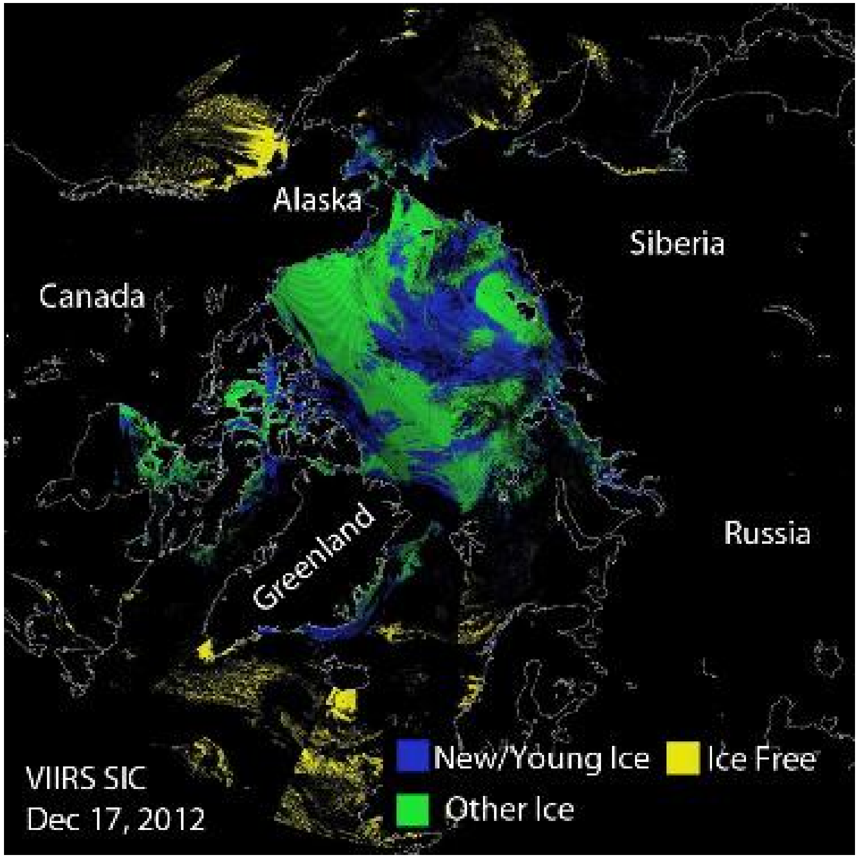
EDR Attribute	Threshold	Objective
a. Vertical Coverage	Ice Surface	Ice Surface
b. Horizontal Cell Size **1. Clear** **2. All weather**	 1.0 km No capability	 0.5 km 1 km
c. Mapping Uncertainty, 3 sigma **1. Clear** **2. Cloudy**	 5 km No capability	 0.5 km 1 km
d. Measure Range **1. Ice Age** **2. Ice Concentration**	 Ice Free, New Young, all other ice 0/10 to 10/10	Ice free, Nilas, Grey, Grey-white, First Year Medium, First Year Thick, Second Year, Multiyear, Smooth and Deformed Ice 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

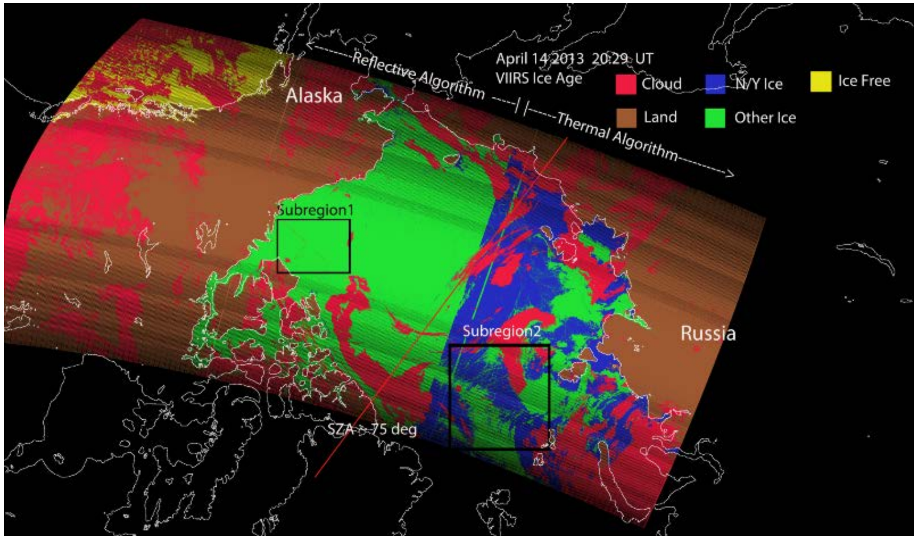
IDPS VIIRS Sea Ice Characterization EDR

- The operational (IDPS) VIIRS Sea Characterization EDR classifies the ocean surface as *Ice Free*, *New/Young* and *Other Ice*.

- Discrimination of New/Young ice from thicker ice is achieved by two algorithms: (1) Energy balance at night and (2) reflectance during the day.



- Many problems were found, including day-night inconsistency (see below).



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Enterprise Ice Thickness Algorithm: The One-dimensional Thermodynamic Ice Model (OTIM)

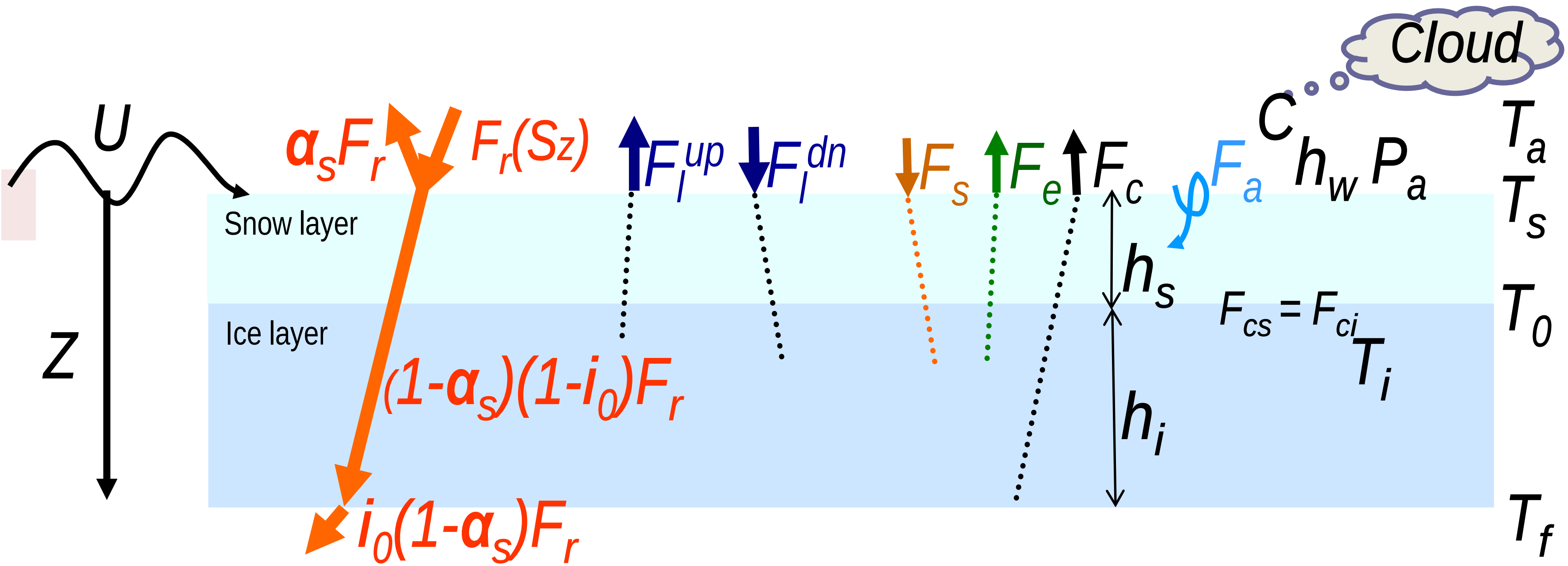
Based on the surface energy budget at thermo-equilibrium state, the fundamental equation is

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

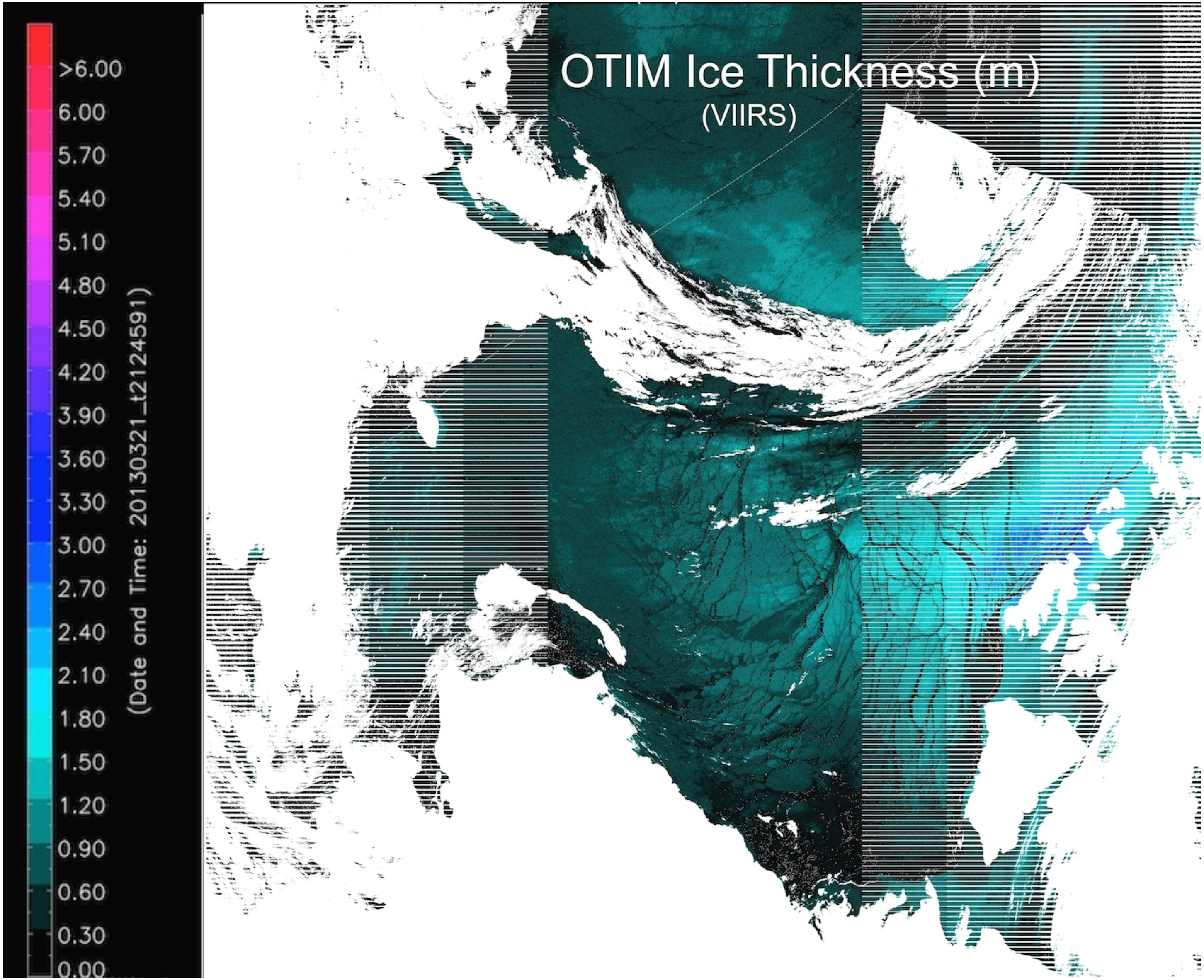
After parameterizations of thermal radiation (F_r, F_l^{up}, F_l^{dn}) and turbulent (sensible & latent) heat (F_s, F_e), ice thickness h_i becomes a function of 11 model controlling variables plus two factors:

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

where $\boldsymbol{R_g}$, $\boldsymbol{R_d}$ are ice growth/melting and ice dynamic process adjustment factors.

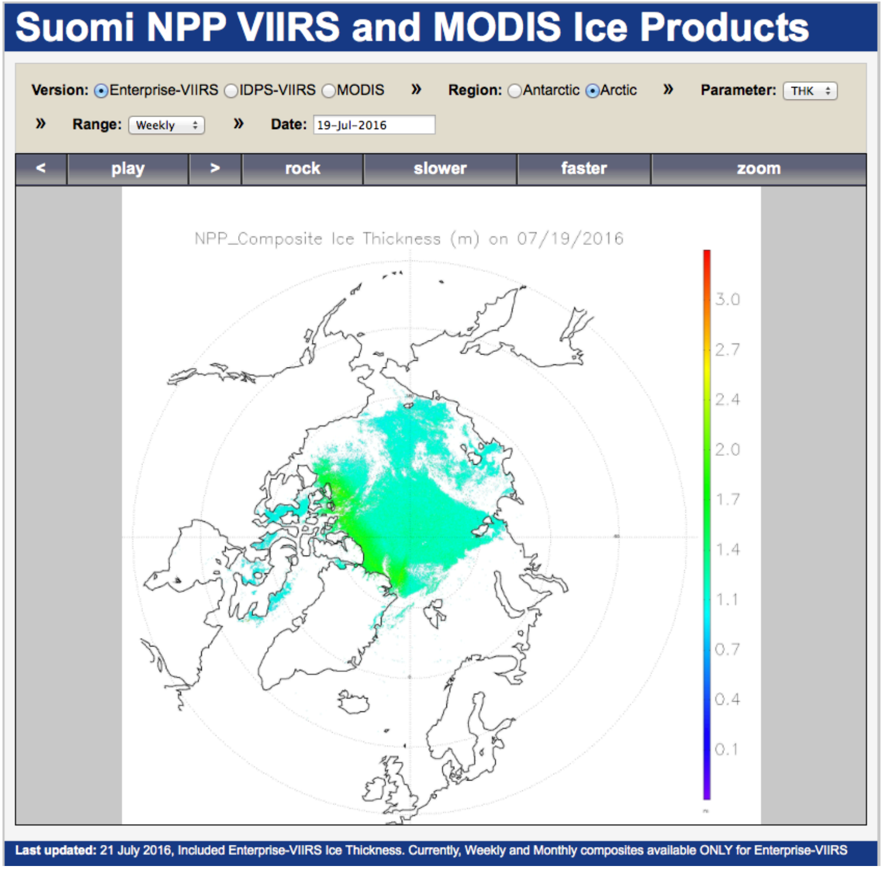


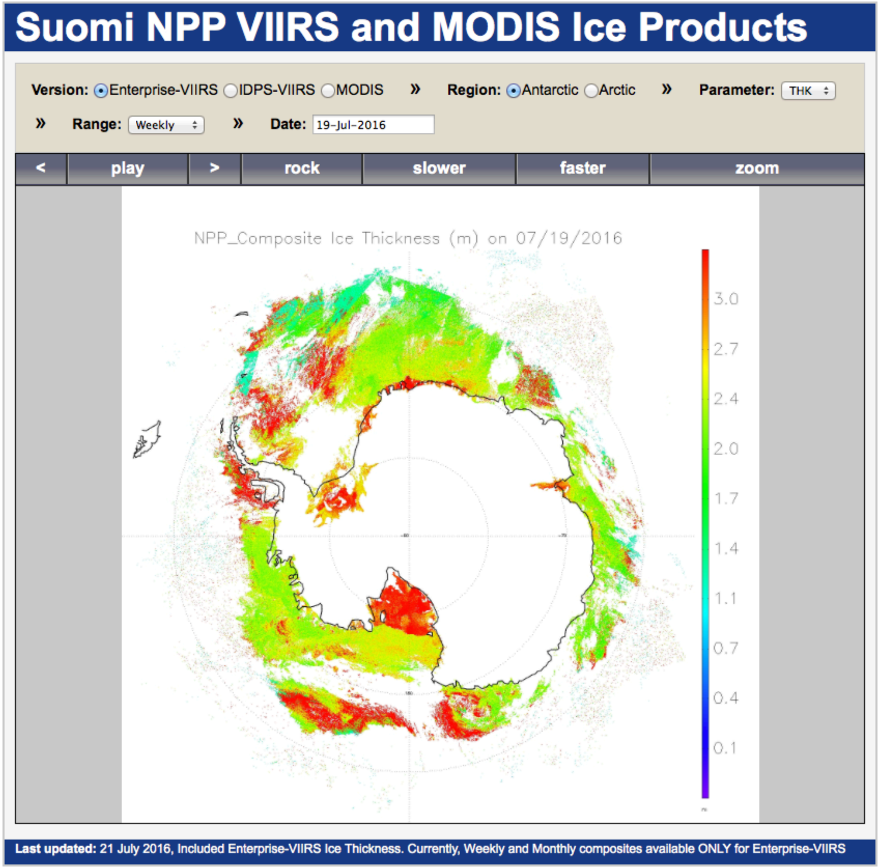
Example of OTIM Ice Thickness from VIIRS



Near real-time VIIRS Sea Ice Thickness

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



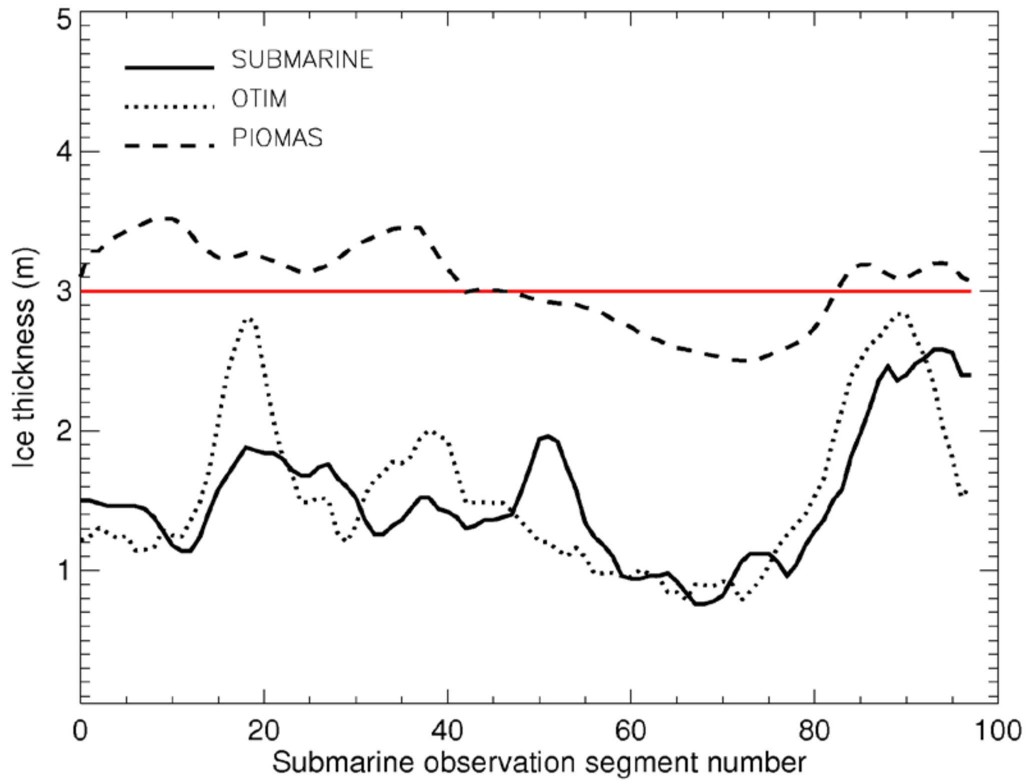


https://stratus.ssec.wisc.edu/ice-products/anibrowser/

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	

Validation

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

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.

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)
  - IceBridge flights will continue to be important
  - Near real-time validation will be set up using SMOS and Cryosat-2
- Accomplishments and Highlights Moving Towards J1
  - Minor 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 (~3 m) and larger uncertainty in melt conditions
  - Ultimately, either a VIIRS product adjusted by Cryosat/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

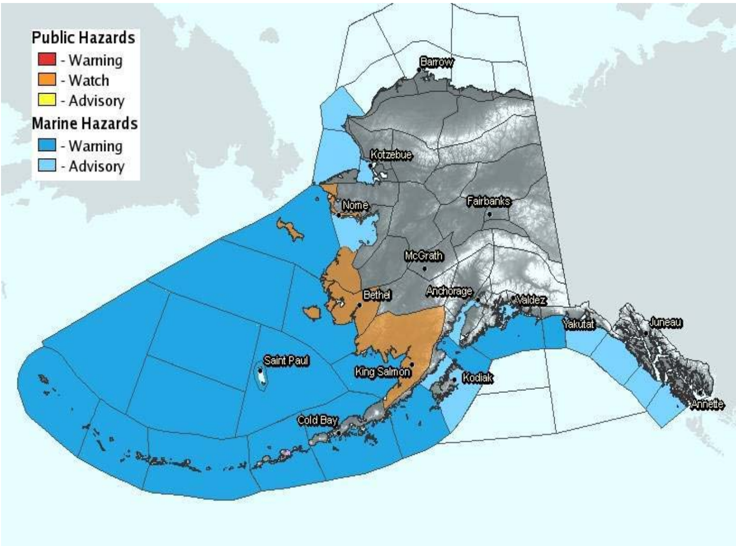
Snow and Ice Product Users (planned)

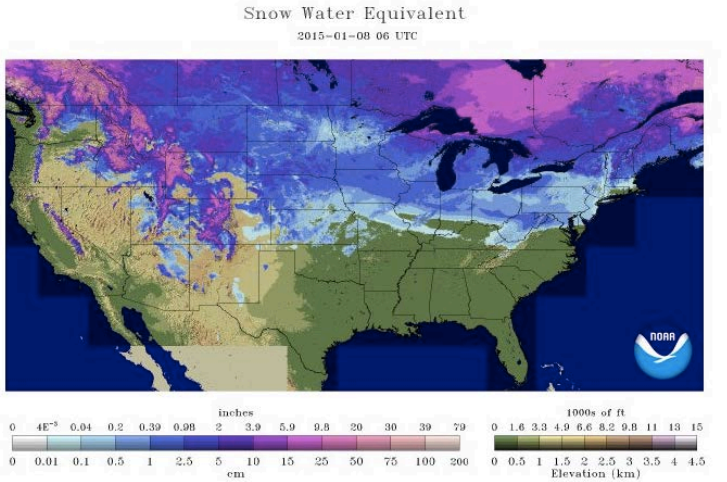
Operational Ice Services

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

Modeling

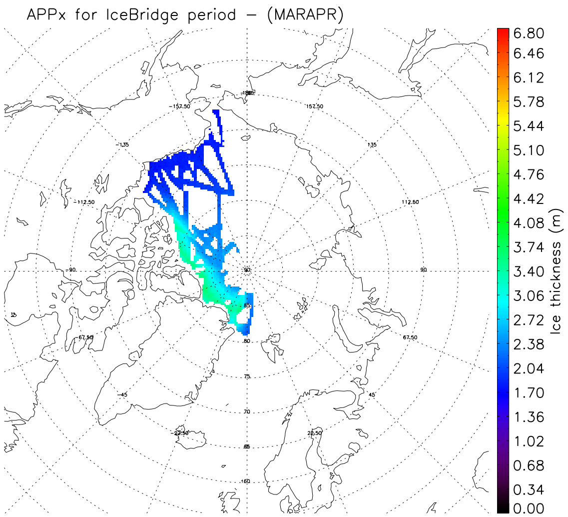
- (Need to set up collaborations and funding) Naval Research Lab, Arctic Cap Nowcast/Forecast System (ACNFS), NCEP
- Universities (Washington, Hamburg)



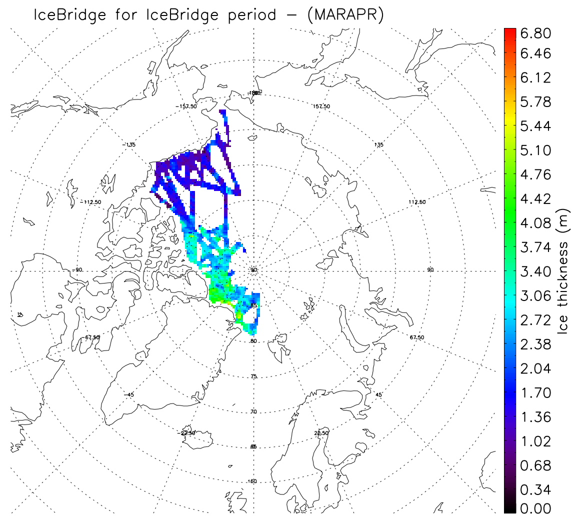


Intercomparison for IceBridge Period, 03/2011 - 04/2013

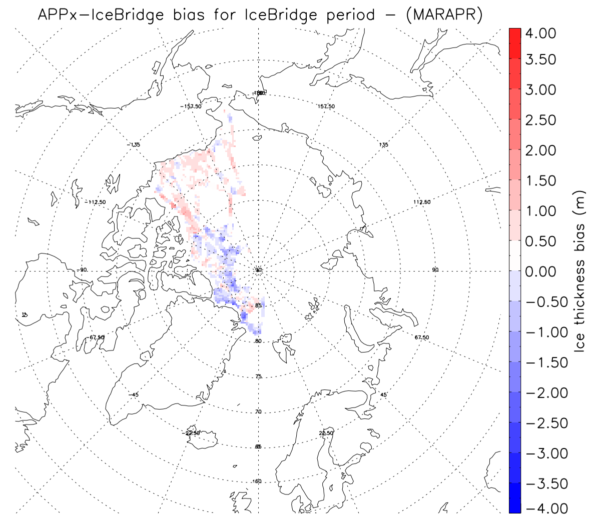
APP-x

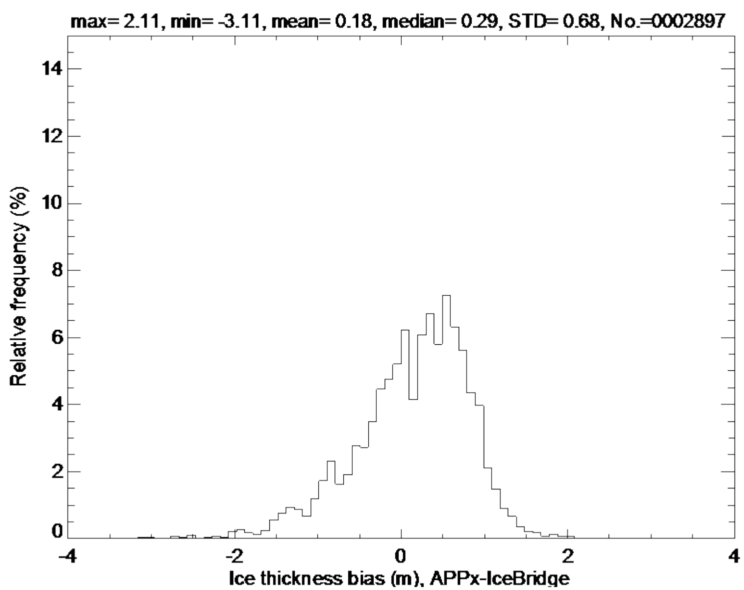


IceBridge



Bias (APP-x minus IceBridge)





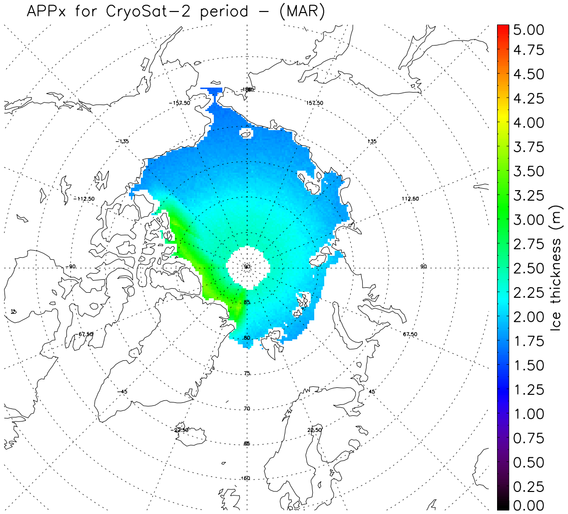
Bias statistics:

mean = 0.18 m
STD = 0.68 m
Median = 0.29 m
Mode = 0.00 m
Skewness = -0.88

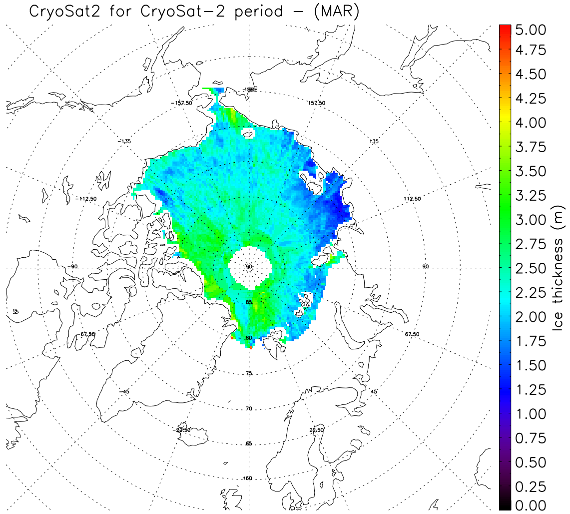
Correlation = 0.70

Intercomparison for CryoSat-2 Period, 01/2011 - 03/2013

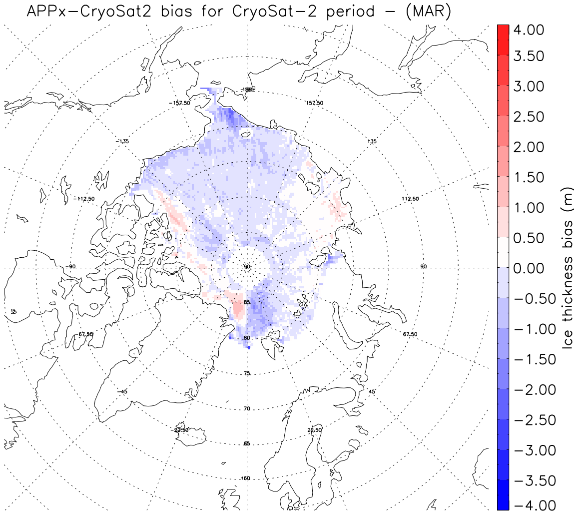
APP-x

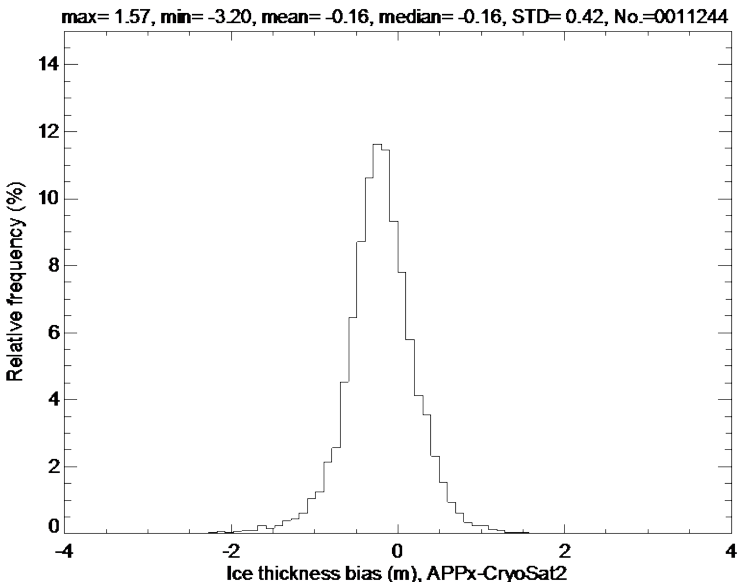


CryoSat-2



Bias (APP-x minus CryoSat-2)





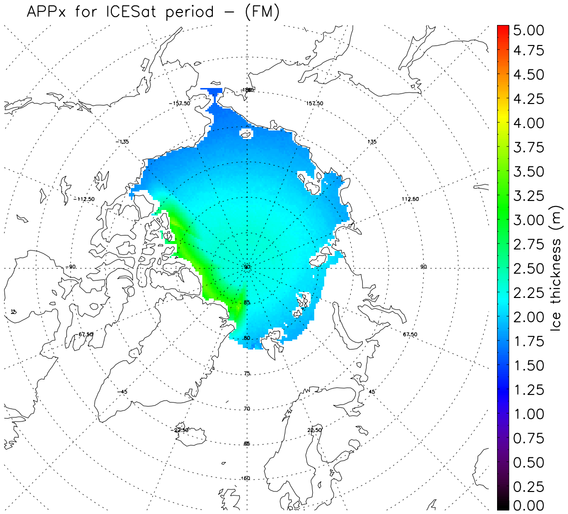
Bias statistics:

mean = -0.19 m
STD = 0.57 m
Median = -0.16 m
Mode = 0.00 m
Skewness = -0.90

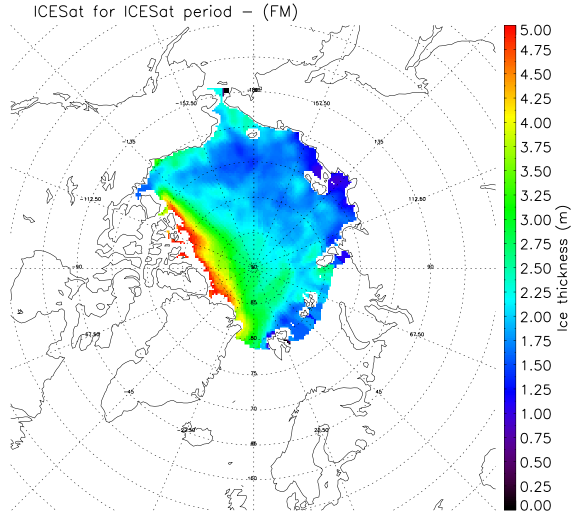
Correlation = 0.66

Intercomparison for ICESat Period, 09/2003 - 03/2008

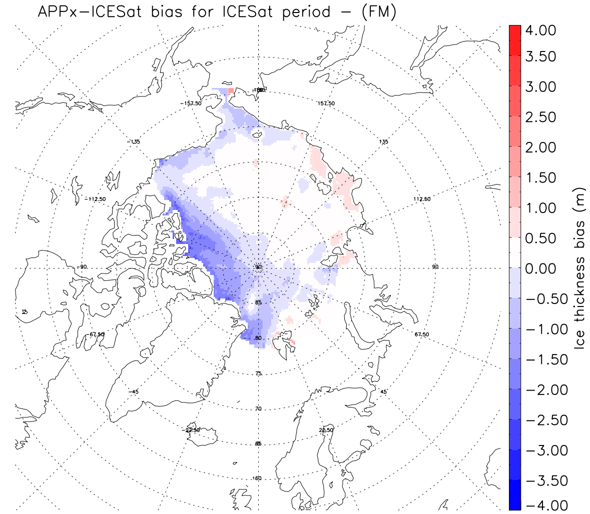
APP-x

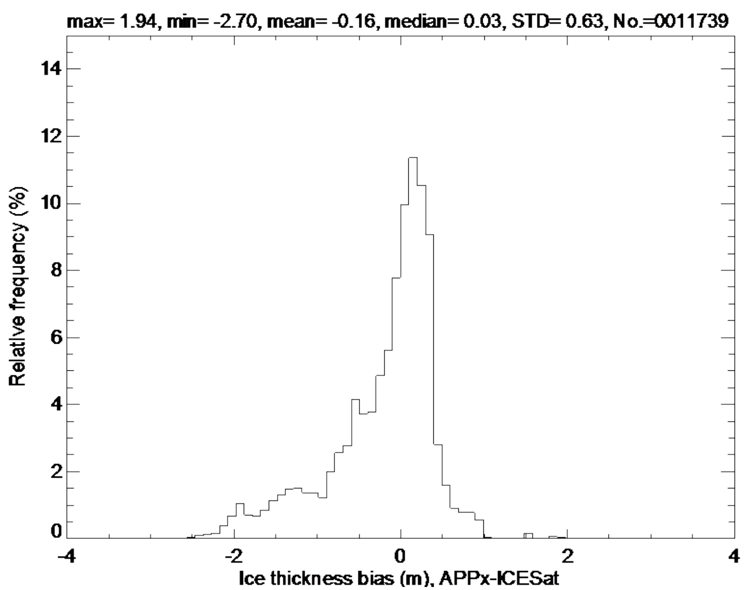


ICESat



Bias (APP-x minus ICESat)





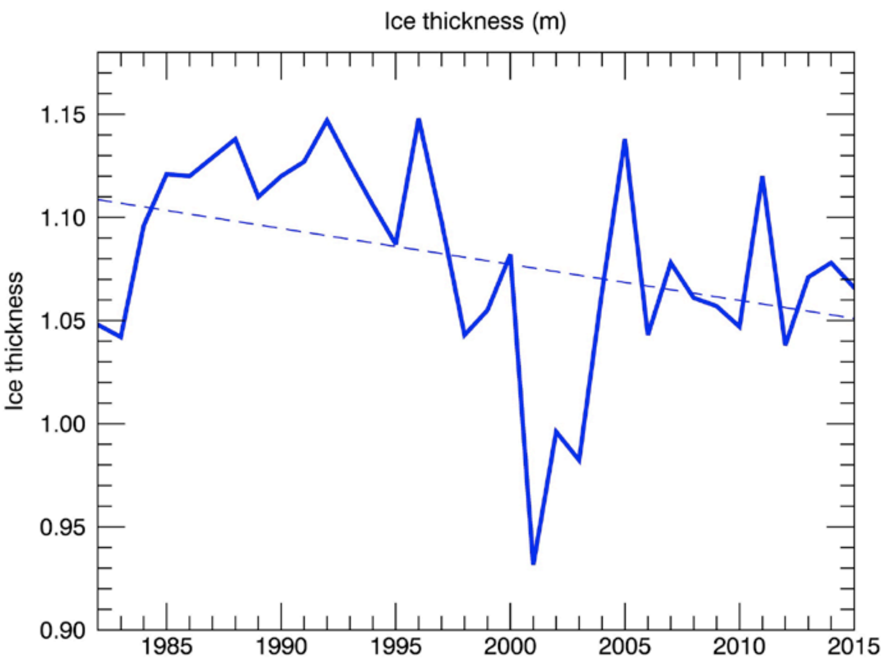
Bias statistics:

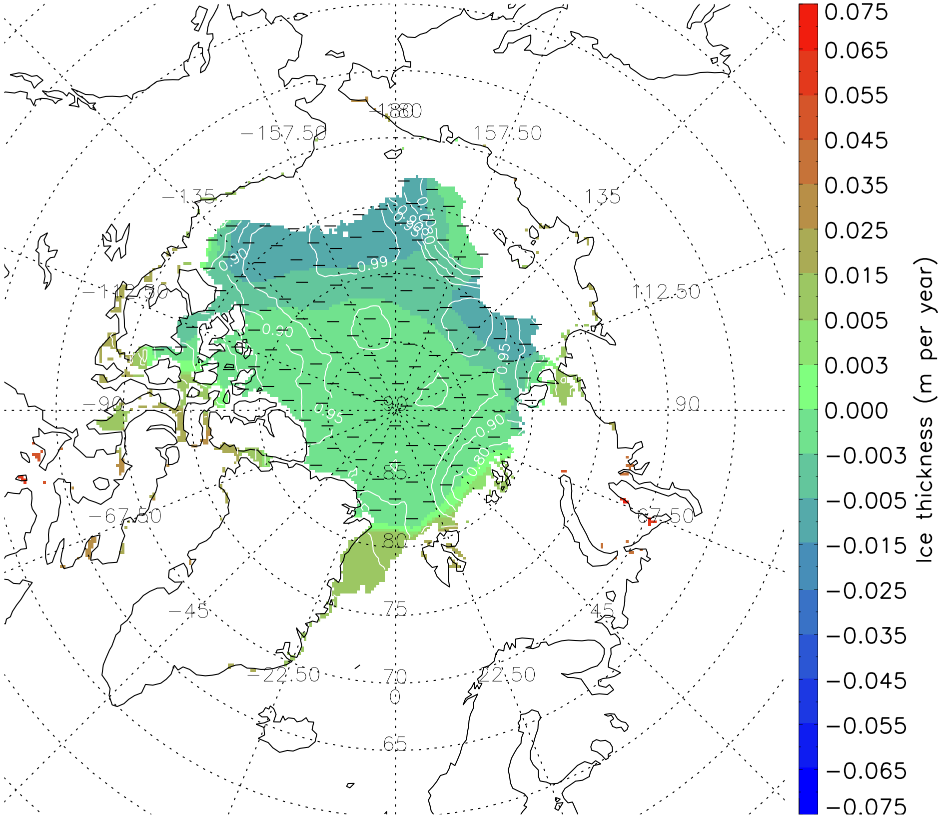
mean = -0.16 m
STD = 0.63 m
Median = 0.06 m
Mode = 0.00 m
Skewness = -1.13

Correlation = 0.71

Arctic Sea Ice Thickness Trend in September, 1982-2015

OTIM retrieved Arctic sea ice thickness trend in September with the APP-x data, 1982-2015.

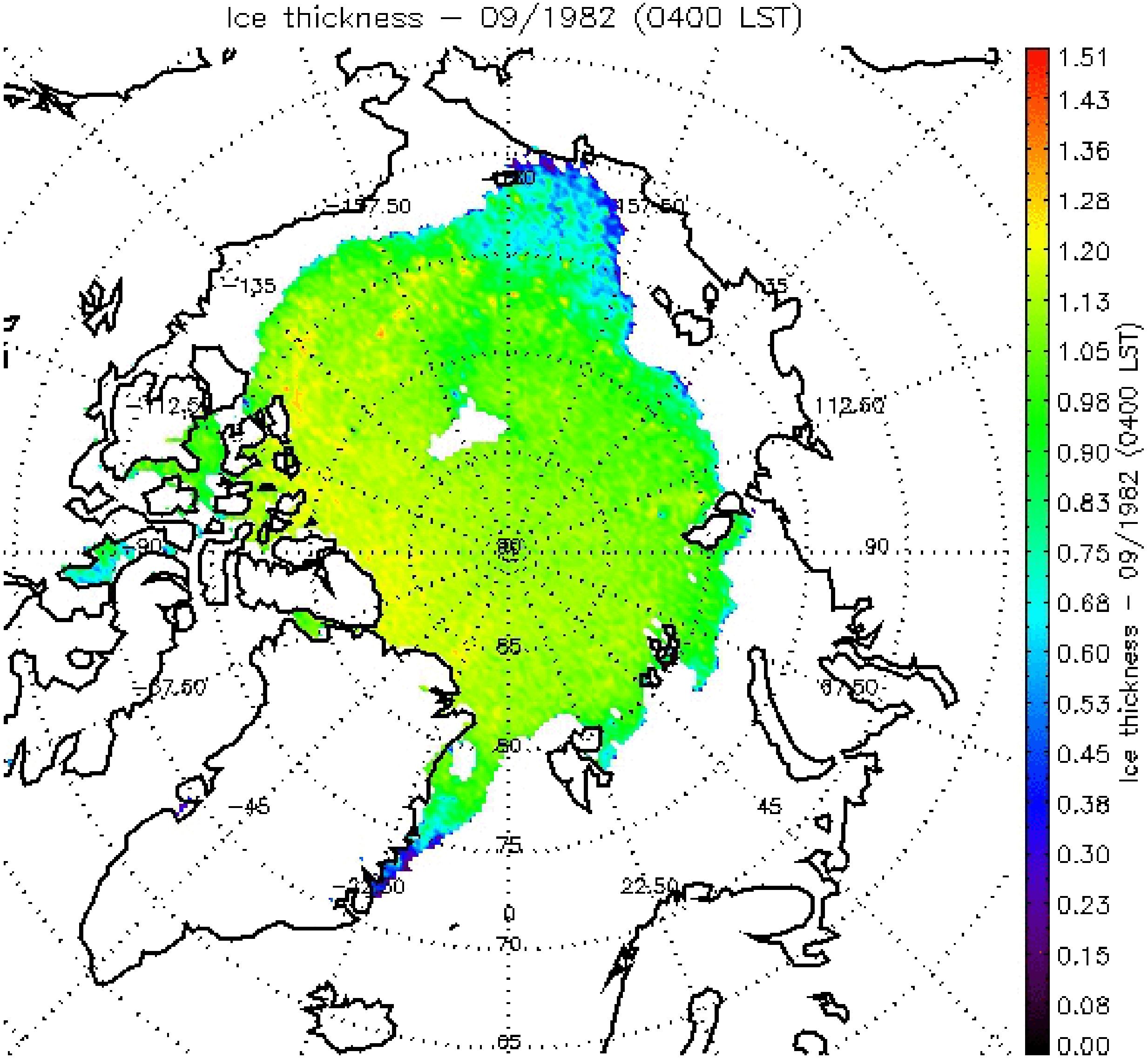




Trend : -1.74 ± 0.81 cm per decade for the Arctic ocean north of 60°N.

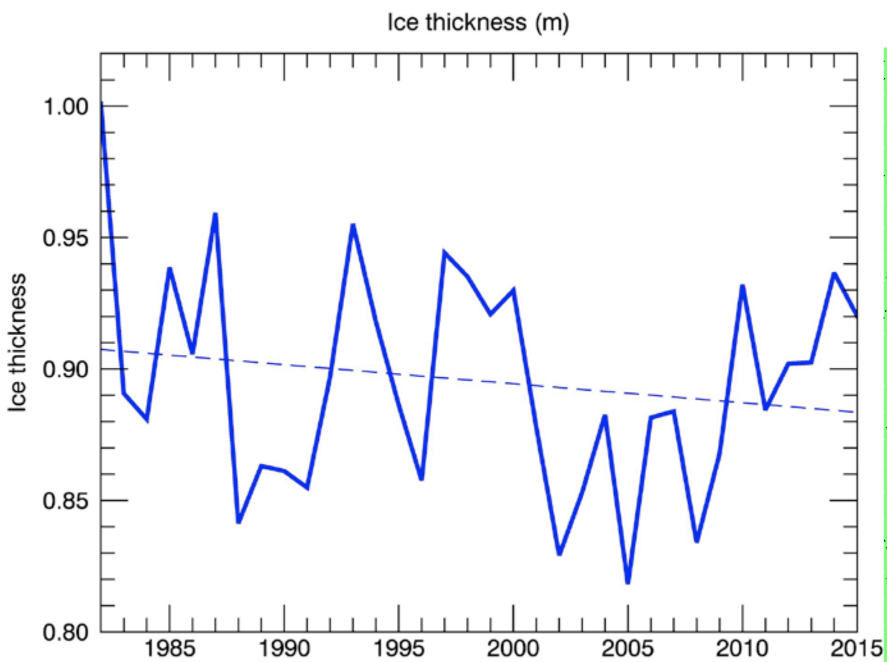
(Statistical Significance level = 0.96)

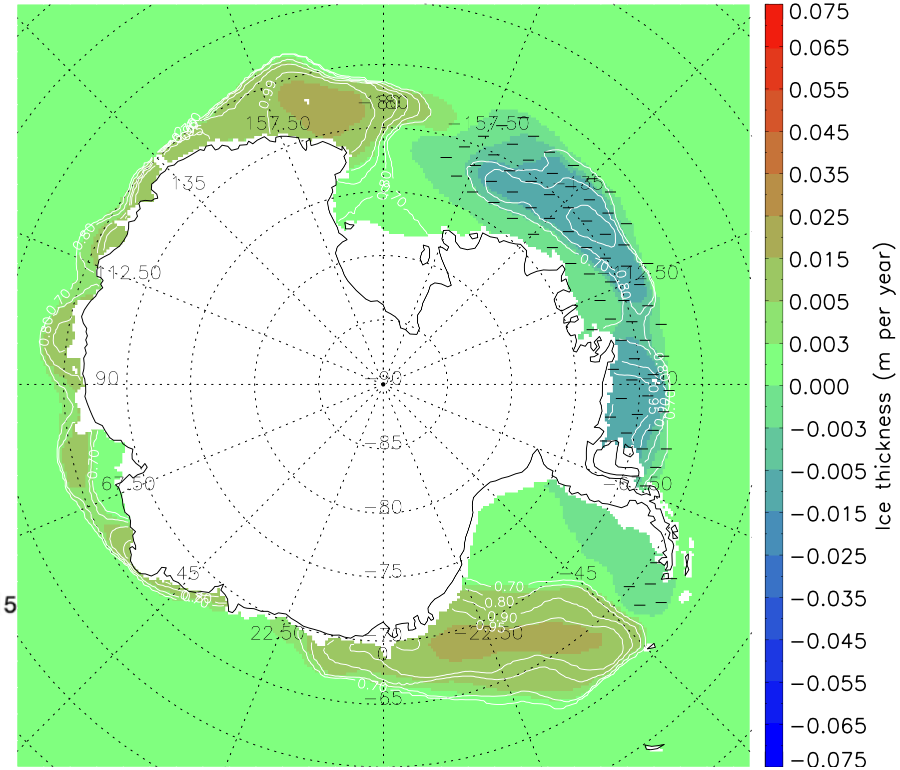
Arctic Sea Ice Thickness Trend in September, 1982-2015
(Movie Clip)



Antarctic Sea Ice Thickness Trend in April, 1982-2015

OTIM retrieved Antarctic sea ice thickness trend in April with the APP-x data, 1982-2015.





Trend : -0.72 ± 0.73 cm per decade for the Antarctic ocean south of 60^{o}S.
(Statistical Significance level = 0.67)

Antarctic Sea Ice Thickness Trend in April, 1982-2015
(Movie Clip)