Provisional Maturity Science Review NOAA-21 Cryosphere Products: Sea Ice Age and Thickness

Presented by Rich Dworak

Questions on algorithm performance directed to Xuanji Wang

01/25/2024

JPSS/GOES-R Data Product Validation Maturity Stages - COMMON DEFINITIONS (Nominal Mission)

1. Beta

- Product is minimally validated, and may still contain significant identified and unidentified errors.
- Information/data from validation efforts can be used to make initial qualitative or very limited quantitative assessments regarding product fitness-for-purpose.
- Documentation of product performance and identified product performance anomalies, including recommended remediation strategies, exists.

2. Provisional

- Product performance has been demonstrated through analysis of a large, but still limited (i.e., not necessarily globally or seasonally representative) number of independent measurements obtained from selected locations, time periods, or field campaign efforts.
- Product analyses are sufficient for qualitative, and limited quantitative, determination of product fitness-for-purpose.
- Documentation of product performance, testing involving product fixes, identified product performance anomalies, including recommended remediation strategies, exists.
- Product is recommended for potential operational use (user decision) and in scientific publications after consulting product status documents.

3. Validated

- Product performance has been demonstrated over a large and wide range of representative conditions (i.e., global, seasonal).
- Comprehensive documentation of product performance exists that includes all known product anomalies and their recommended remediation strategies for a full range of retrieval conditions and severity level.
- Product analyses are sufficient for full qualitative and quantitative determination of product fitness-for-purpose.
- Product is ready for operational use based on documented validation findings and user feedback.
- Product validation, quality assurance, and algorithm stewardship continue through the lifetime of the instrument.

Outline

- Algorithm Cal/Val Team Members
- Product Overview/Requirements
- Evaluation of algorithm performance to specification requirements
  - Algorithm version, processing environment
  - Evaluation of the effect of required algorithm inputs
  - Quality flag analysis/validation
  - Error Budget
- User Feedback
- Downstream Product Feedback
- Risks, Actions, and Mitigations
- Documentation (Science Maturity Checklist)
- Conclusion
- Path Forward

NOAA-21 VIIRS Ice Product Cal/Val Team

Algorithm Cal/Val Team Members

Name	Organization	Major Task
Richard Dworak	CIMSS/UW-Madison	CIMSS project lead. Sea ice product analysis and validation, data processing, and project management.
Hong Zhang	CIMSS/UW-Madison	Sea ice product analysis and validation of NOAA-21 Sea Ice products
Xuanji Wang	CIMSS/UW-Madison	Sea ice thickness and age algorithm development, analysis ,and validation.
Mark Tschudi	CCAR/UC-Boulder	Sea ice product analysis and validation
Yinghui Liu	NOAA/NESDIS	NOAA project lead. Sea ice temperate/concentration algorithm development, analysis, and validation, overall NOAA snow and sea ice project management.
Jeff Key	NOAA/NESDIS	Overall NOAA snow and sea ice project management, assistance on analysis and validation

Ice Product Overview

VIIRS ice products include Ice Surface Temperature, Ice Concentration, Ice Thickness and Age over water surface under clear-sky conditions for both day and night. *Concentration and IST were declared Provisional in October 2023. This review is for thickness/age.*

- Sea Ice Concentration (SIC)
  - Fraction of each pixel covered by ice
- Ice Surface Temperature (IST)
  - Radiating or “skin” temperature of the ice or snow on the ice
- Sea Ice Age and Thickness
  - Ice age is, strictly speaking, the time that has elapsed since the formation of ice on the surface of sea water. For JPSS it is an age category: no ice, new/young ice (0~0.30 m), or other ice (> 0.30 m). Ice age is therefore related to ice thickness.

Product Overview/Requirements: Sea Ice Age

Attribute	DPS	Requirement/Threshold	Performance
Geographic coverage	239	All ice-covered regions of the global ocean and lakes.	All ice-covered regions of the global ocean and lakes
Vertical Coverage		Ice surface	Ice surface
Vertical Cell Size		Ice surface	Ice surface
Horizontal Cell Size		1 km	1 km
Mapping Uncertainty		1 km	1 km
Measurement Range	902	Ice free, New/Young ice, all Other ice	Ice free, New/Young ice, all other ice, and ice thickness
Accuracy	241	70% probability of correct typing	90 to Near 100% vs NOAA-20
Precision		n/a (see GOES-R definition for 2-category variables)	less than one category comp to NOAA-20
Uncertainty		70% for ice age probability of correct typing	0.1 m when comp. to NOAA-20

Requirements: Sea and Lake Ice Thickness

Product performance requirements from JERD Vol. II and L1RD versus observed/validated. ***There is no JPSS requirement for ice thickness.***

Attribute	Threshold	Observed/validated vs Cryosat
Measurement Range	none	0-6 m
Measurement Accuracy	none	0.16 m
Measurement Precision	none	0.24 m ~>80% matching

Processing Environment and Algorithms

- Description of processing environment and algorithms used to achieve the maturity stage:
  - Algorithm version: V3R3, update to Landmask that includes Ice Shelf masking. This update was included in validation results starting on October 24, 2023. (Note: operational V3R3 is OTIM V6.1.)
  - Algorithm Theoretical Basis Documents
    https://www.ospo.noaa.gov/Products/Suites/files/atbd/ATBD_IceSurfaceTemperatureIceConcentration_v1.0.pdf
    https://www.star.nesdis.noaa.gov/jpss/documents/ATBD/ATBD_EPS_Cryosphere_IceThickness_IceAge_v4.0.pdf
  - Version of LUTs used (SIC, IST, see documentation above)
  - Processing Environment
    Production site: NCCF (as provided in the product file attributes)
    Production environment: UAT (as provided in the product file attributes)
  - Effective date: May 1, 2023.
  - Starting orbit number: 2436.

Evaluation of algorithm performance to specification requirements

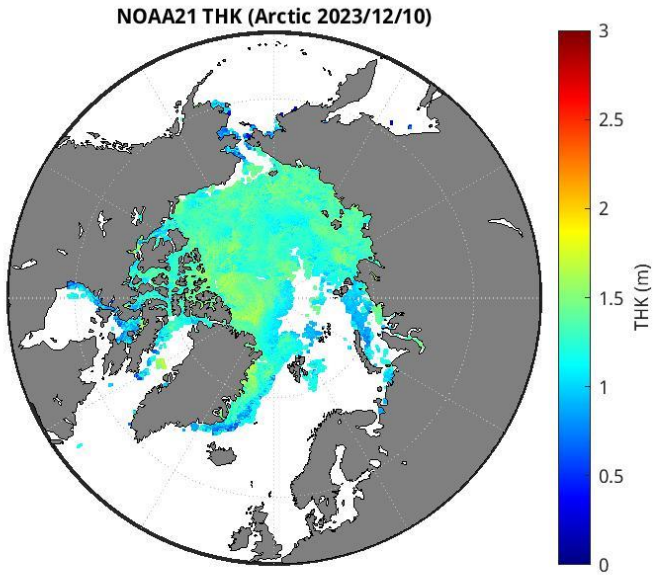
Algorithm performance evaluation

Validation strategies / methods: root mean squared error (RMSE, same as uncertainty with bias considered), standard deviation of difference (precision), and bias (accuracy).

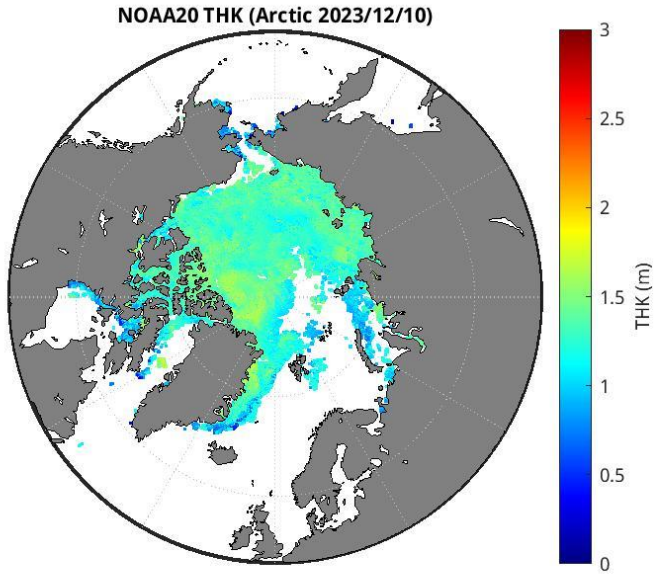
- Inter-sensor comparison
  - Compare with S-NPP and NOAA-20: RMSE 0.1m for thickness.
  - Validation results: meets requirements
- Validation with independent products
  - Validation data sets: CryoSat-2/SMOS, October -December 2023, Arctic
  - Case studies with CryoSat-2 and SMOS for THK
  - Validation results: meets requirements
- Long term monitoring readiness: routine comparison to NOAA-20 and CS2SMOS

Sea Ice Thickness/Age v3r3: NOAA 21 vs. NOAA20 Arctic

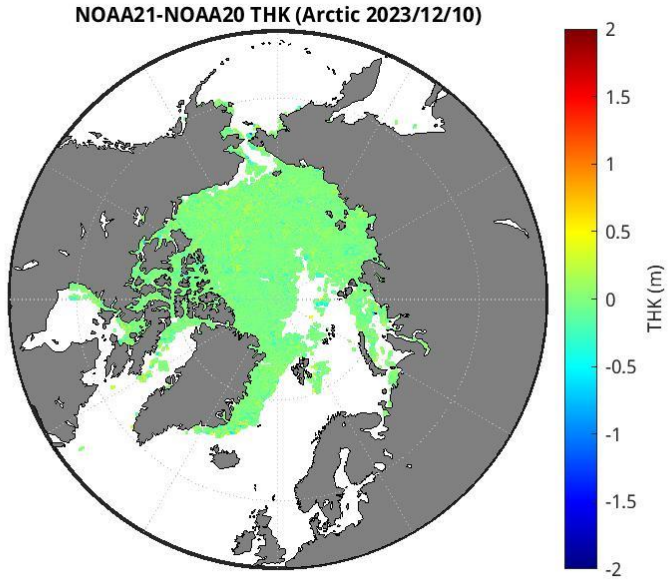
NOAA21



NOAA20



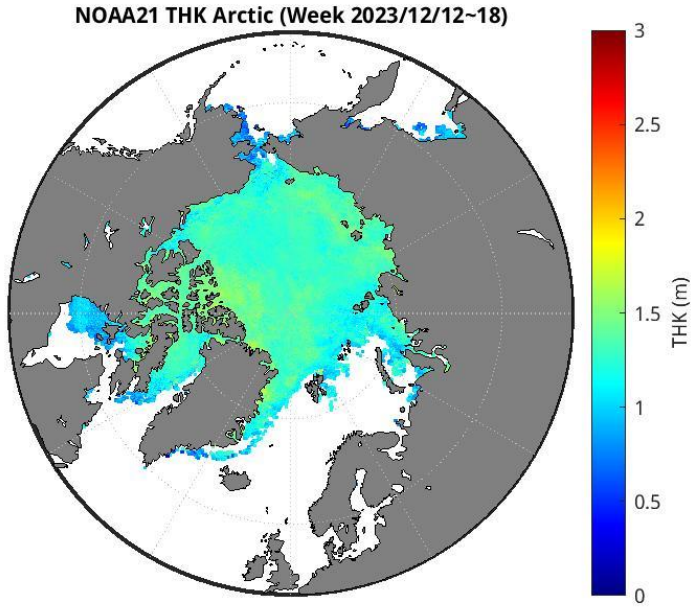
NOAA21- NOAA20 Difference



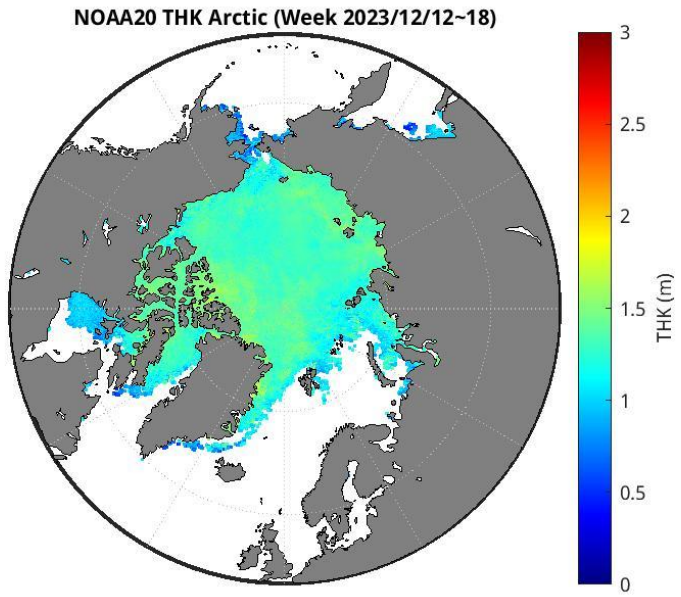
Daily composites comparison of Dec. 10, 2023, NOAA-21 matches well with NOAA-20 overall.

Sea Ice Thickness/Age v3r3: NOAA 21 vs. NOAA20 Arctic

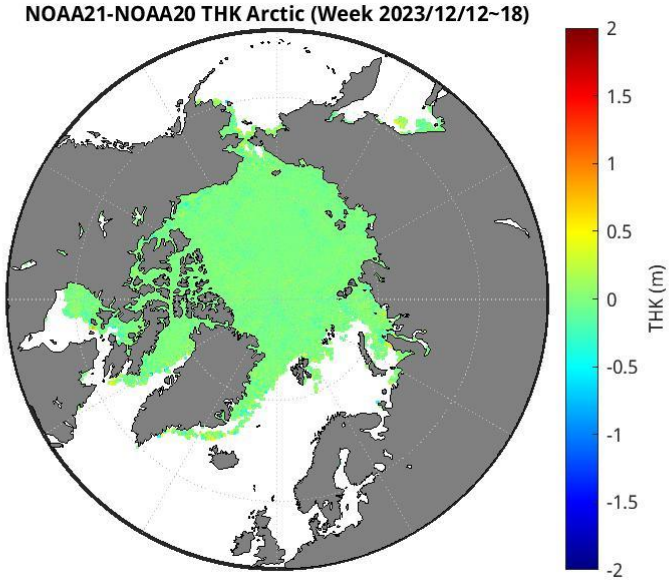
NOAA21



NOAA20



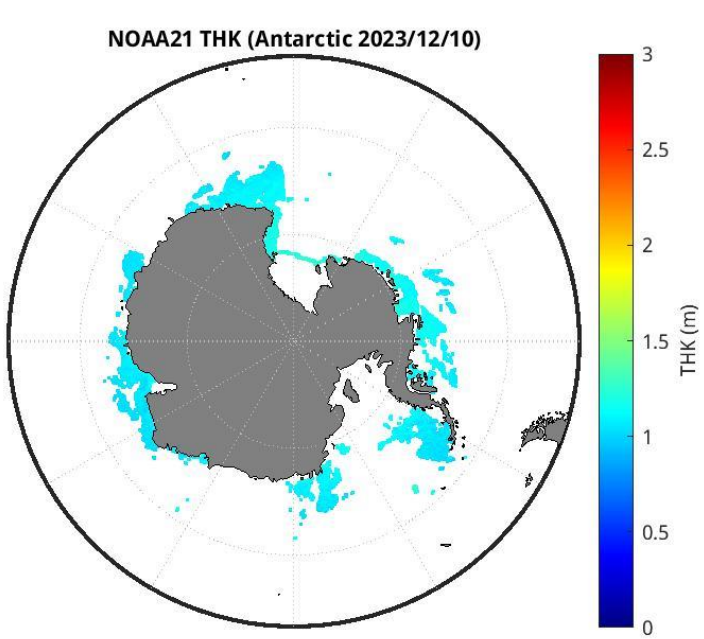
NOAA21- NOAA20 Difference



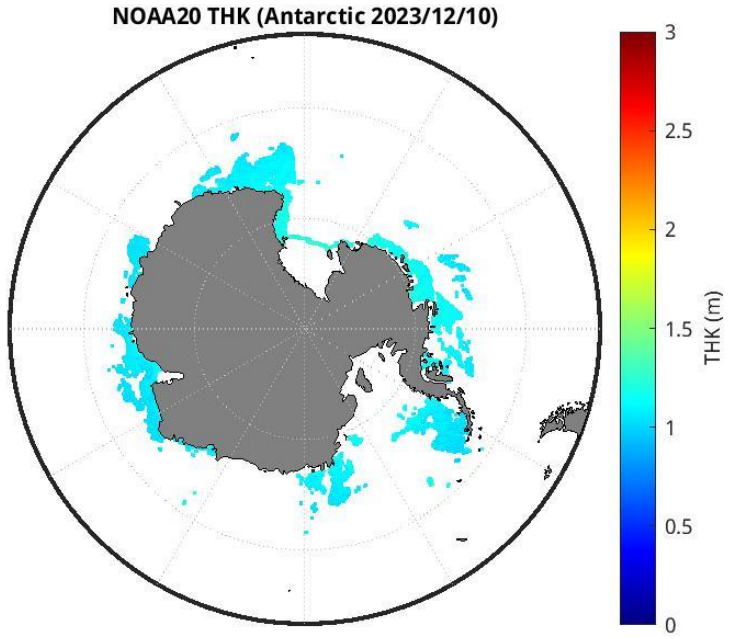
Weekly composites comparison of Dec. 12-18, 2023, NOAA-21 matches well with NOAA-20 overall.

Sea Ice Thickness/Age v3r3: NOAA 21 vs. NOAA20 Antarctic

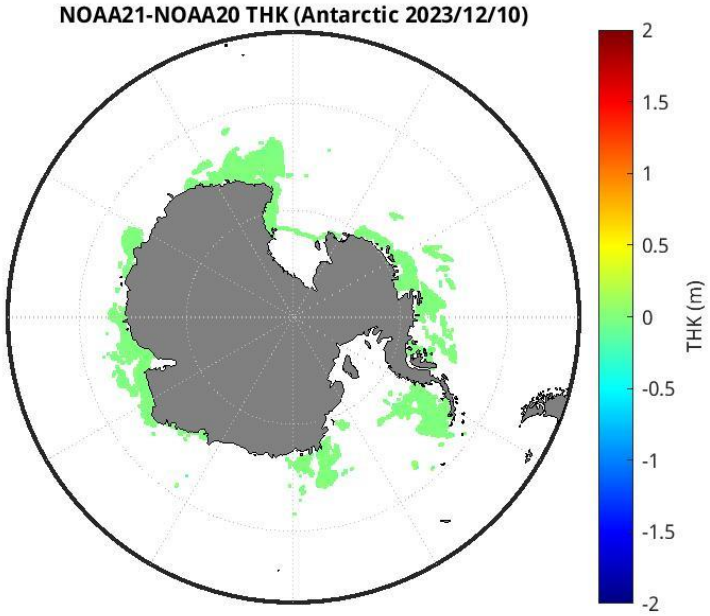
NOAA21



NOAA20



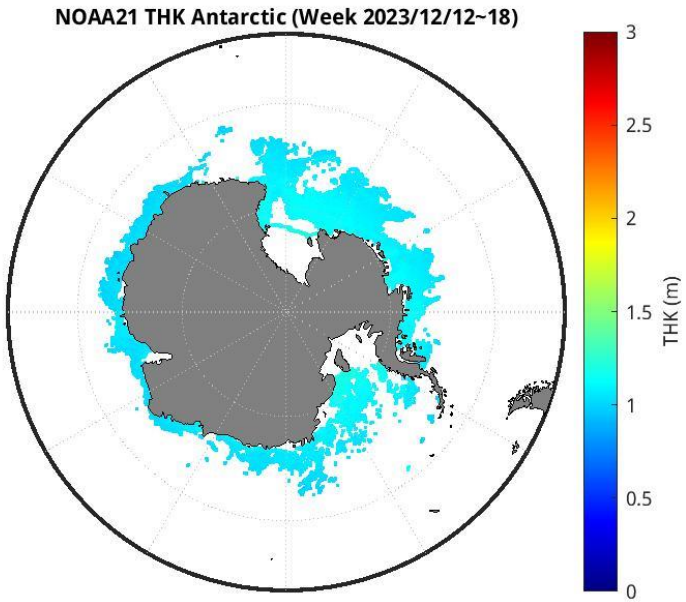
NOAA21- NOAA20 Difference



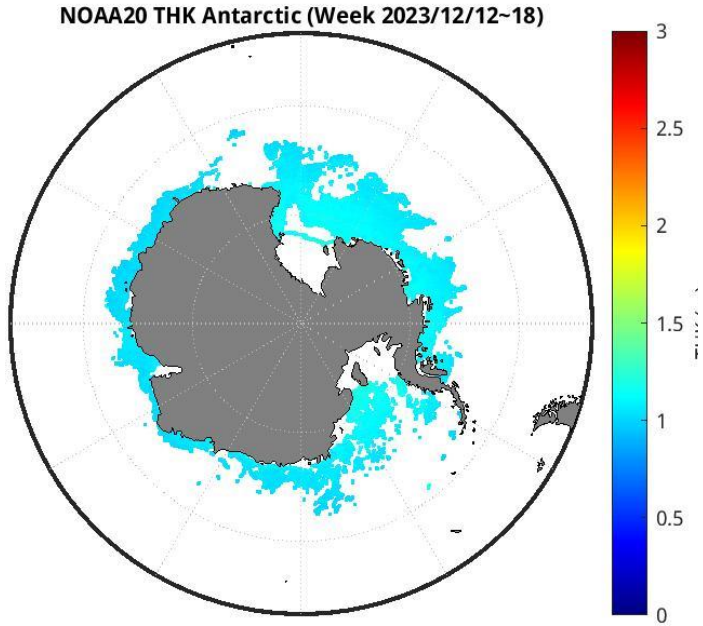
Daily composites comparison of Dec. 10, 2023, NOAA-21 matches well with NOAA-20 overall.

Sea Ice Thickness/Age v3r3: NOAA 21 vs. NOAA20 Antarctic

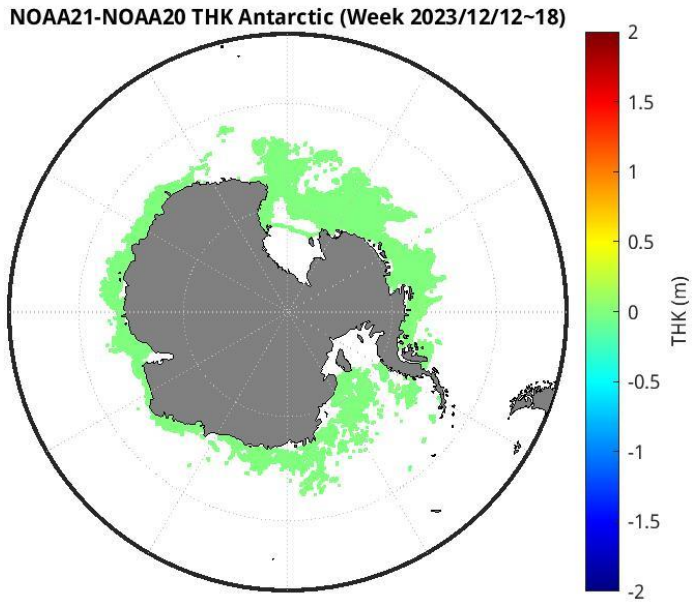
NOAA21



NOAA20



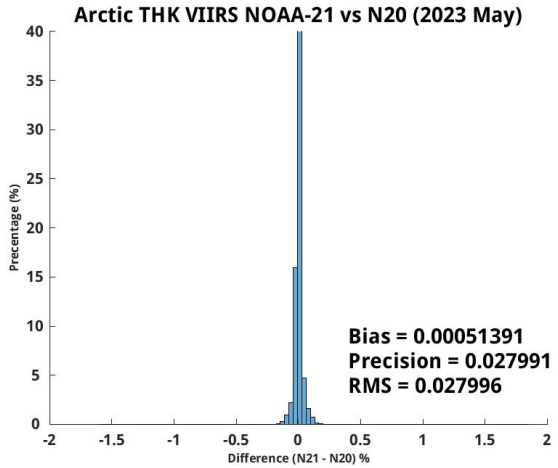
NOAA21- NOAA20 Difference

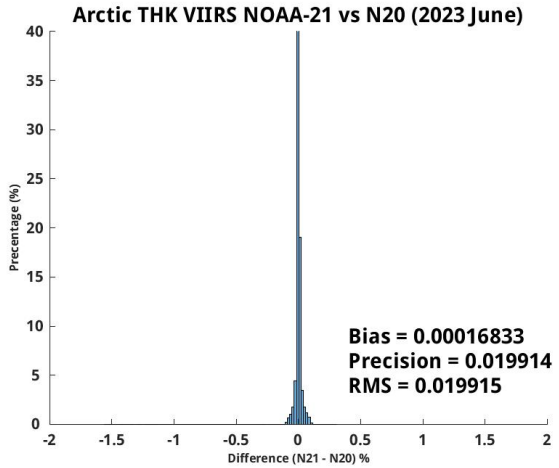


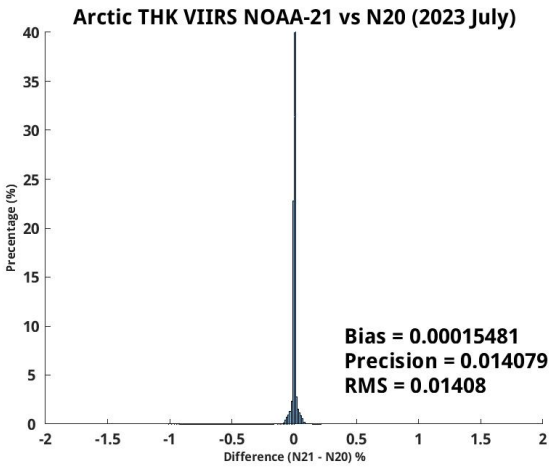
Weekly composites comparison of Dec. 12-18, 2023, NOAA-21 matches well with NOAA-20 overall.

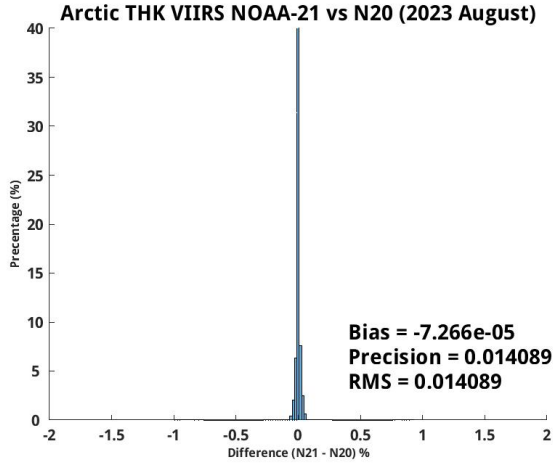
Sea Ice Thickness v3r2: NOAA-21 vs. NOAA-20, Arctic

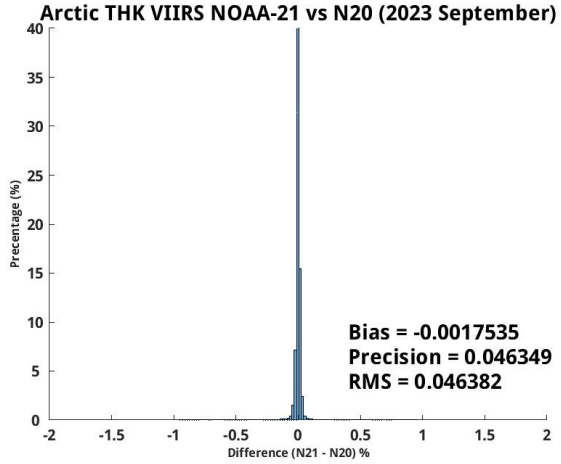
Histogram by month from May to October 2023

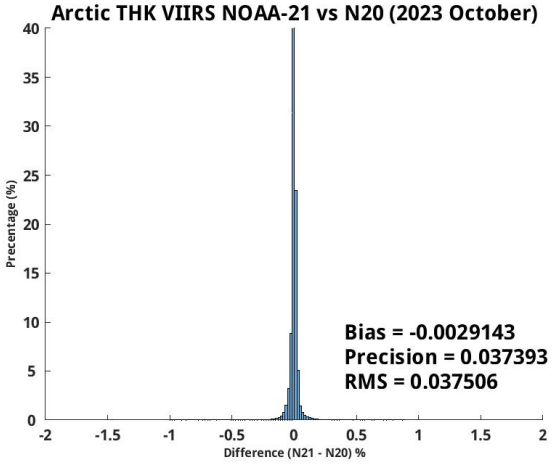






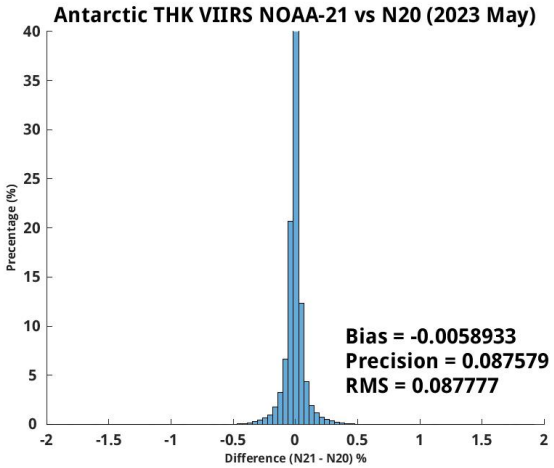


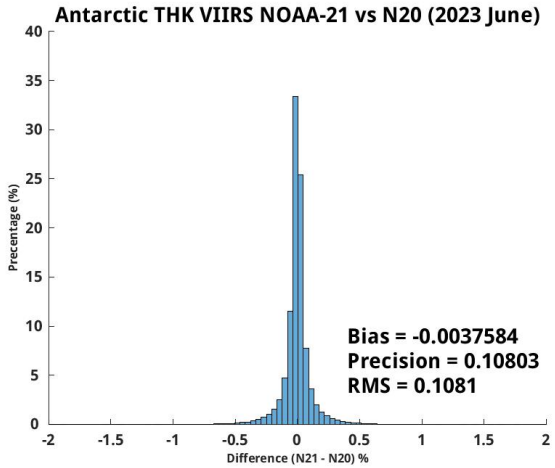


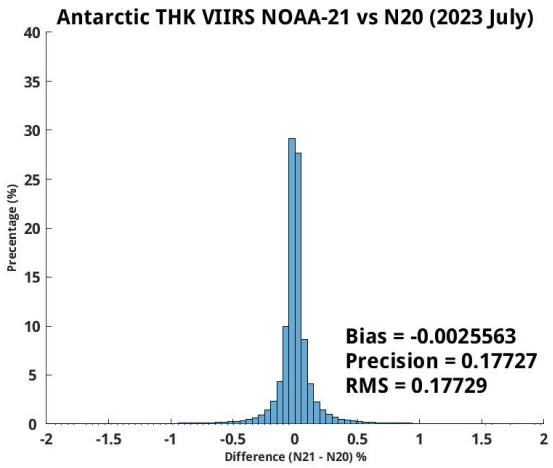


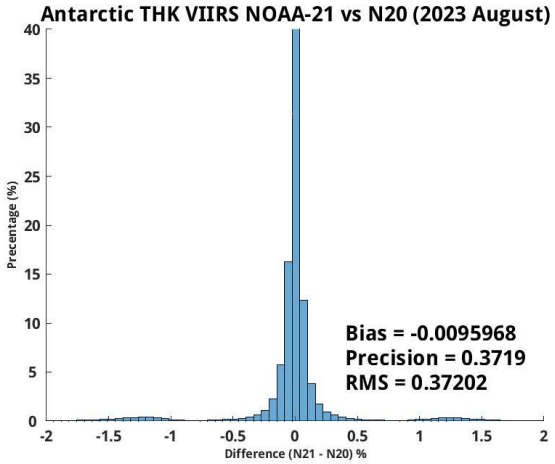
Sea Ice Thickness v3r2: NOAA-21 vs. NOAA-20, Antarctic

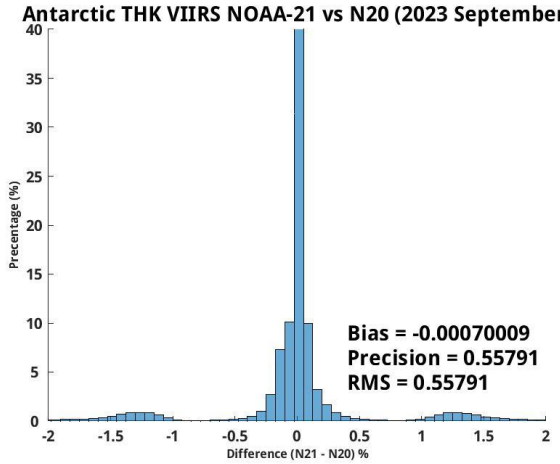
Histogram by month from May to October 2023

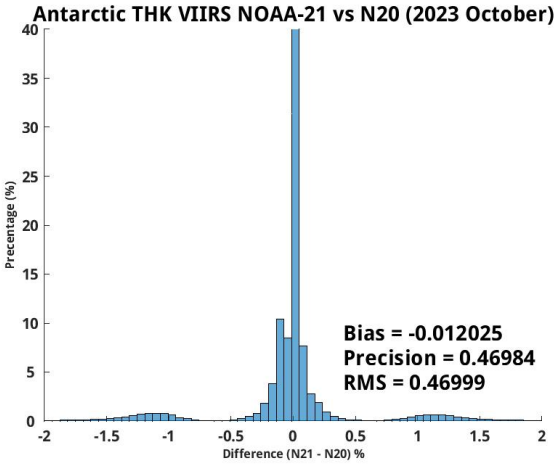




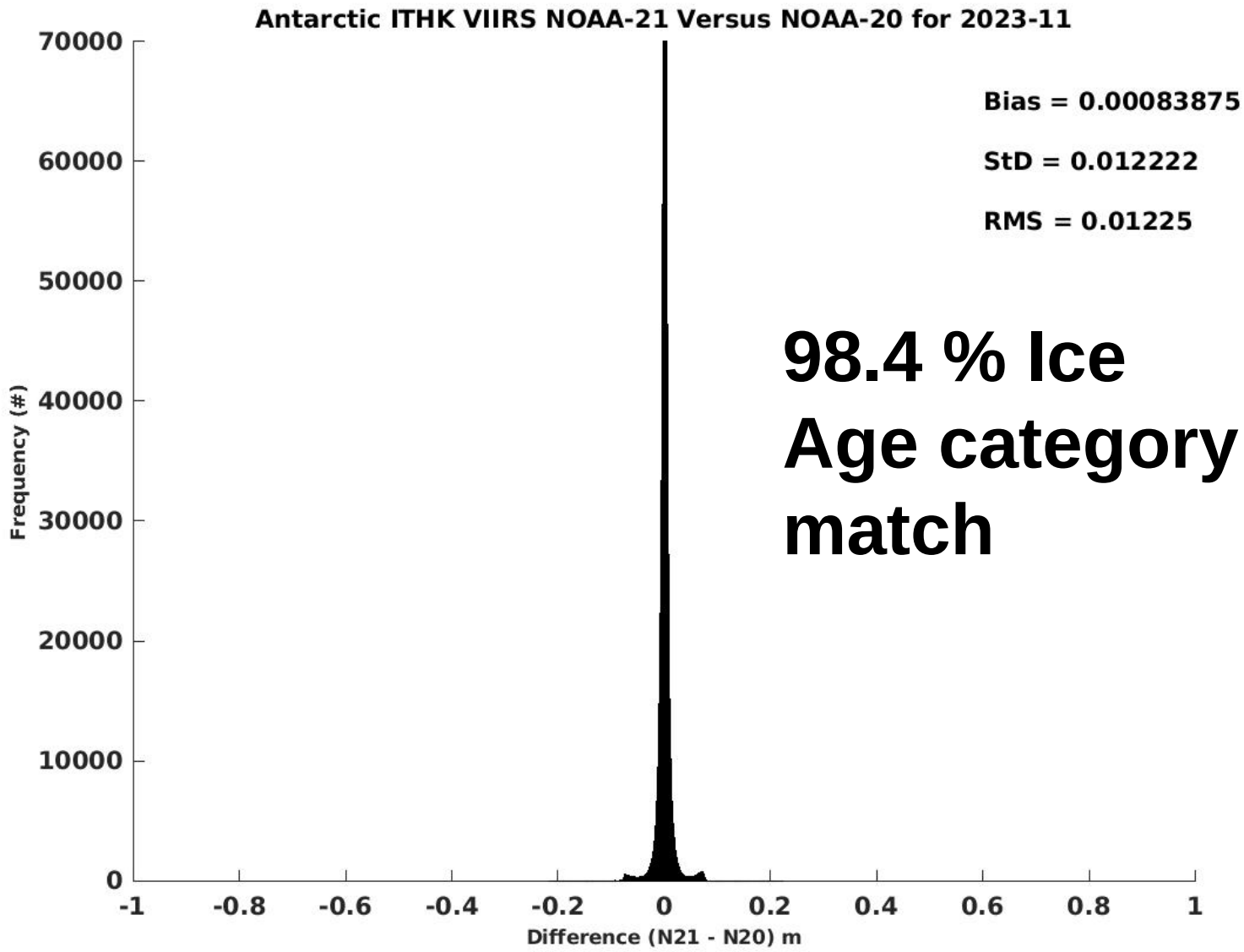






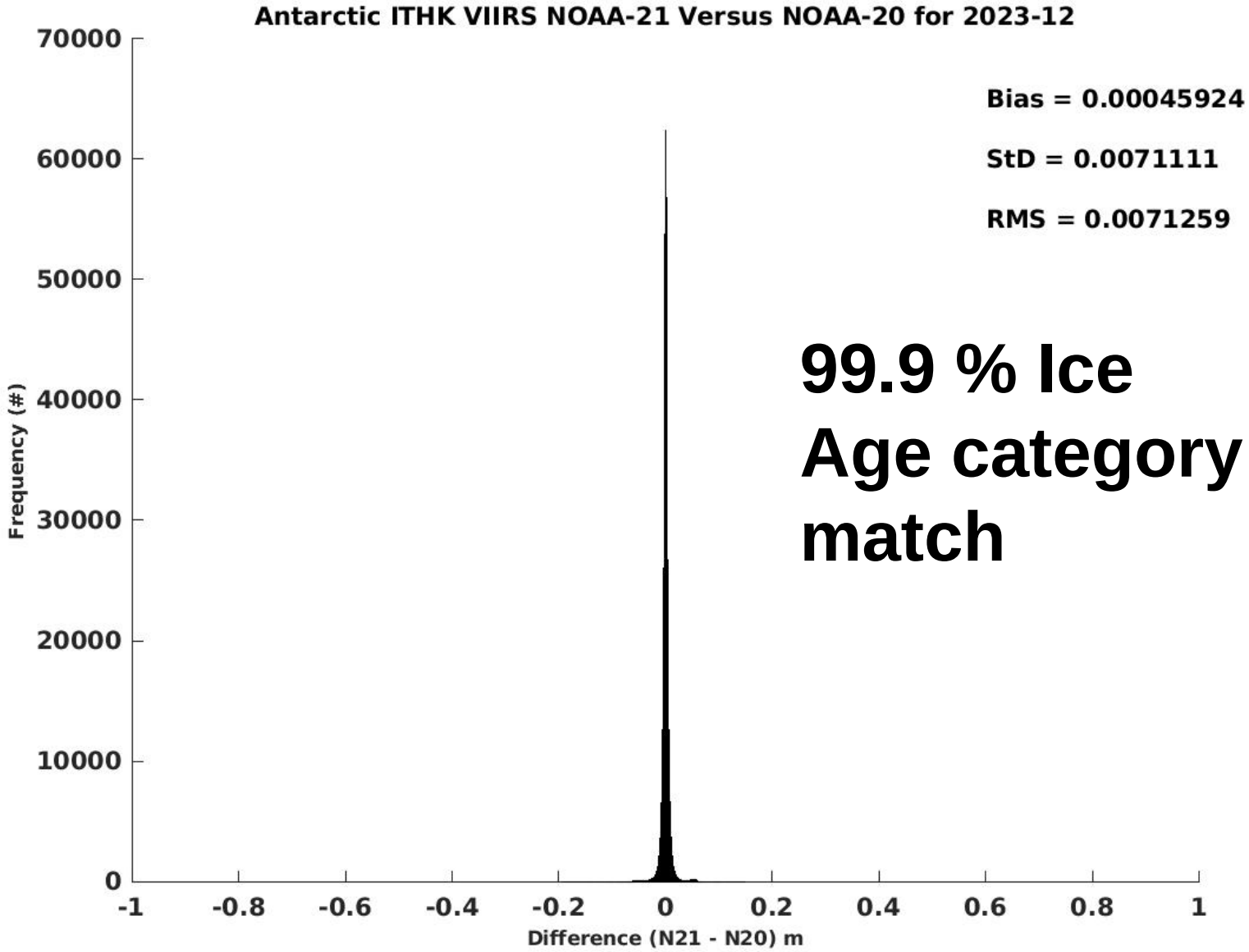


Sea Ice Thickness v3r3: NOAA-21 vs. NOAA-20, Antarctic, November 2023



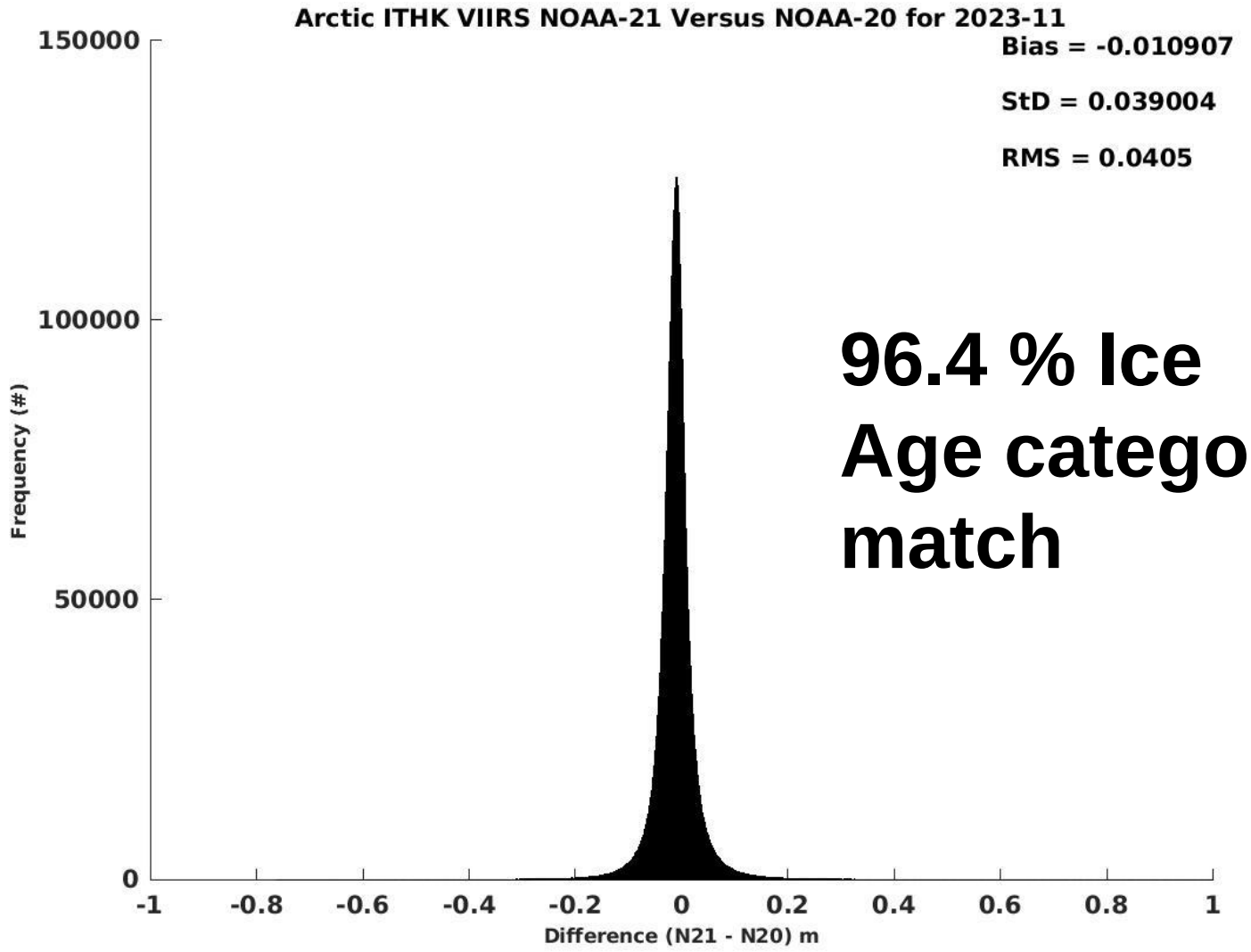
98.4 % Ice Age category match

Sea Ice Thickness v3r3: NOAA-21 vs. NOAA-20, Antarctic, December 2023



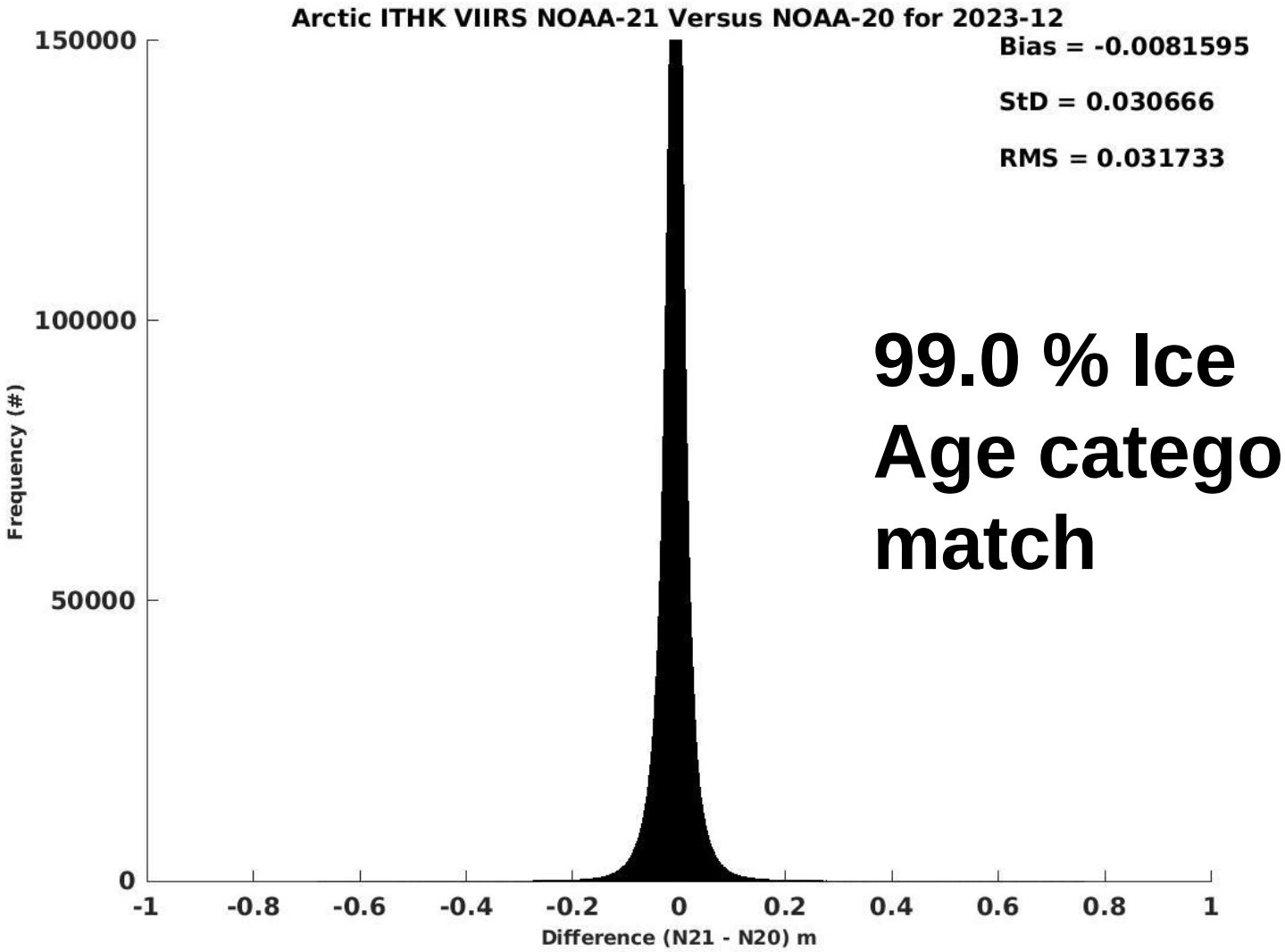
99.9 % Ice Age category match

Sea Ice Thickness v3r3: NOAA-21 vs. NOAA-20, Arctic, November 2023



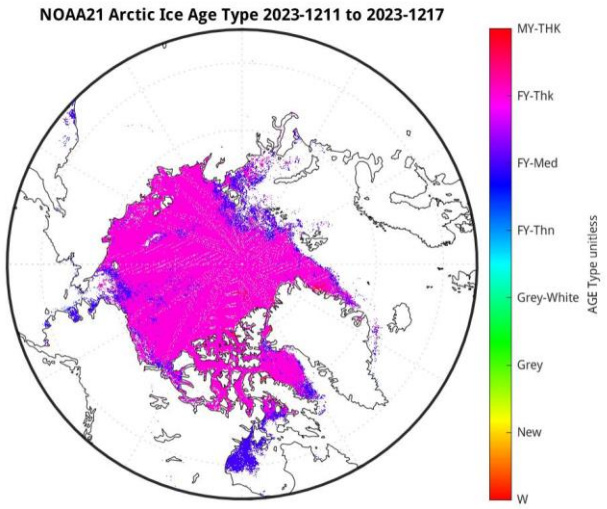
96.4 % Ice Age category match

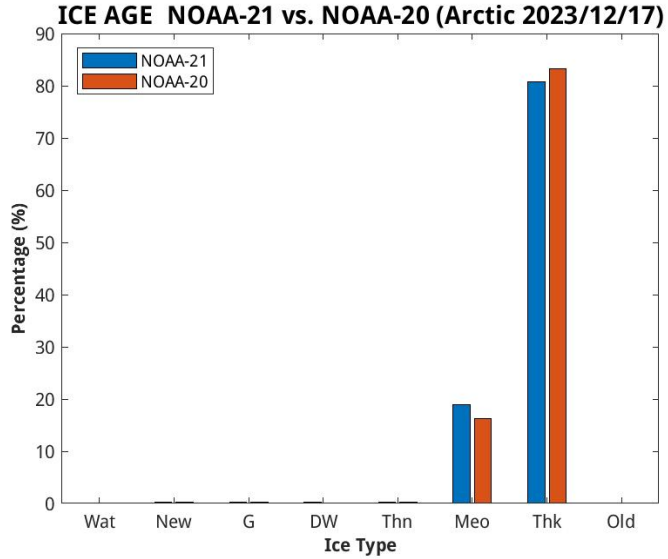
Sea Ice Thickness v3r3: NOAA-21 vs. NOAA-20, Arctic, December 2023

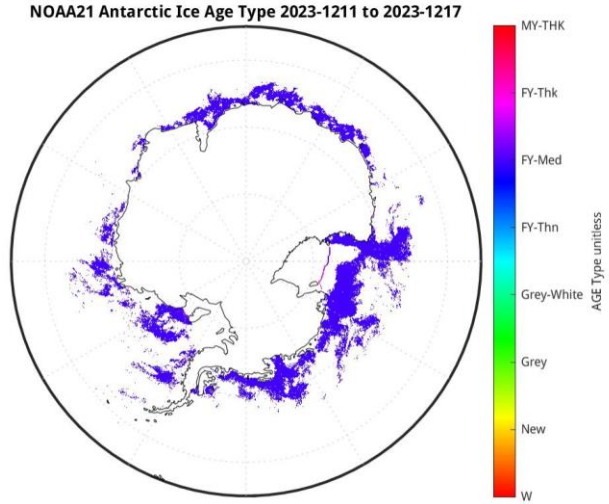


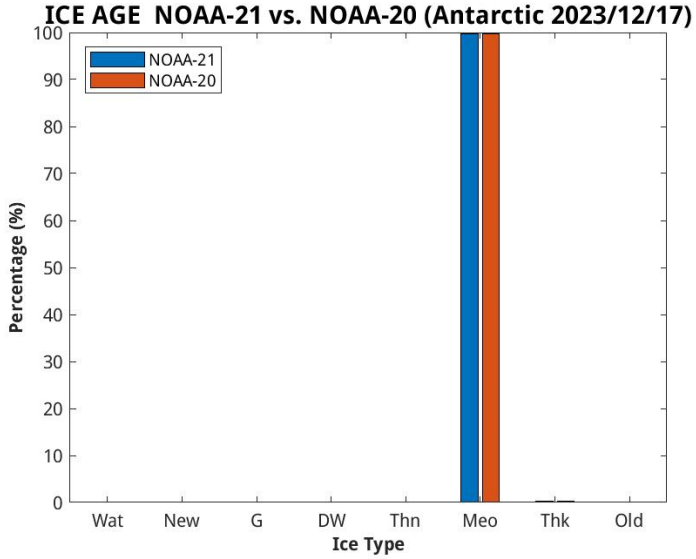
99.0 % Ice Age category match

Sea Ice Age v3r3 Comparison NOAA-21 versus NOAA-20









- **NDE NOAA-21 Ice Age types agrees well with NOAA-20.**
- **>95% of correct typing for NOAA-21 in terms of NOAA-20 ice age.**

Sea Ice Age: NOAA-21 vs CS2SMOS, Arctic (OTIM v6.1=OPSv3r3)

October 2023

Date (Oct. 2023)	TMP	CTP		PCT
		0 ~ 0.30 m	>= 0.30 m	
10/15-21/23	4685	0	4199	90%
10/16-22/23	3669	0	3366	92%
10/17-23/23	2529	0	2383	94%
10/18-24/23	1033	0	992	96%
10/19-25/23	1617	0	1272	79%
10/20-26/23	3225	0	2632	82%
10/21-27/23	4352	0	3485	80%
10/22-28/23	5404	0	4150	77%
10/23-29/23	6593	0	5122	78%
10/24-30/23	7857	0	6114	78%
10/25-31/23	8826	0	6814	77%
10/26-11/01/23	9657	0	7432	77%
10/27-11/02/23	10272	0	7775	76%
10/28-11/03/23	10479	0	7975	76%
10/29-11/04/23	10477	0	8220	79%
10/31-11/06/23	11391	0	8987	79%
Average				**82%**

CTP: Correctly Typed Pixels for NOAA-21 in terms of CS2SMOS
TMP: Total Matched Pixels
PCT: Probability of Correct Typing

November 2023

Date (Nov. 2023)	TMP	CTP		PCT
		0 ~ 0.30 m	>= 0.30 m	
11/01-07/23	11511	0	9278	81%
11/02-08/23	11843	0	9653	82%
11/03-09/23	12301	0	10093	82%
11/04-10/23	12564	0	10393	83%
11/06-12/23	13004	0	10888	84%
11/07-13/23	13099	0	11071	85%
11/08-14/23	13214	0	11239	85%
11/09-15/23	13422	3	11536	85%
11/10-16/23	13575	3	11695	86%
11/11-17/23	13667	3	11855	87%
11/12-18/23	13778	3	11923	87%
11/13-19/23	13785	3	11983	87%
11/14-20/23	13777	0	11899	86%
11/15-21/23	13599	4	11921	88%
11/16-22/23	13865	0	12098	87%
11/17-23/23	14011	2	12175	87%
11/18-24/23	14036	3	12216	87%
11/19-25/23	14017	4	12183	87%
11/27-12/03/23	14138	8	12295	87%
11/28-12/04/23	13804	4	12215	89%
11/29-12/05/23	13905	5	12221	88%
11/30-12/06/23	13853	7	12208	88%
Average				**86%**

December 2023

Date (Dec. 2023)	TMP	CTP		PCT
		0 ~ 0.30 m	>= 0.30 m	
12/02-08/23	14749	10	12740	87%
12/03-09/23	14732	4	12867	87%
12/04-1023	14749	2	13007	88%
12/05-11/23	15133	0	13263	88%
12/06-12/23	15251	0	13404	88%
12/07-13/23	15453	0	13400	87%
12/08-14/23	15725	1	13521	86%
12/09-15/23	15010	1	13557	86%
12/10-16/23	15874	0	13600	86%
12/11-17/23	15881	0	13795	87%
12/12-18/23	15602	0	13775	88%
12/13-19/23	15693	0	13862	88%
12/14-20/23	15793	0	13961	88%
12/15-21/23	15924	0	13950	88%
12/16-22/23	16466	0	14478	88%
12/17-23/23	16798	0	14791	88%
12/18-24/23	17073	0	15074	88%
12/19-25/23	17330	0	15385	89%
12/20-26/23	17528	0	15529	89%
12/21-27/23	17637	0	15731	89%
12/22-28/23	17694	0	15800	89%
12/23-29/23	17804	0	15852	89%
12/24-30/23	17755	0	15858	89%
12/25-31/23	17747	0	15720	89%
12/26-01/24	17708	0	15693	89%
Average				**88%**

Sea Ice Age: NOAA-21 vs CS2SMOS, Arctic (OTIM v6.4 CIMSS)

November 2023

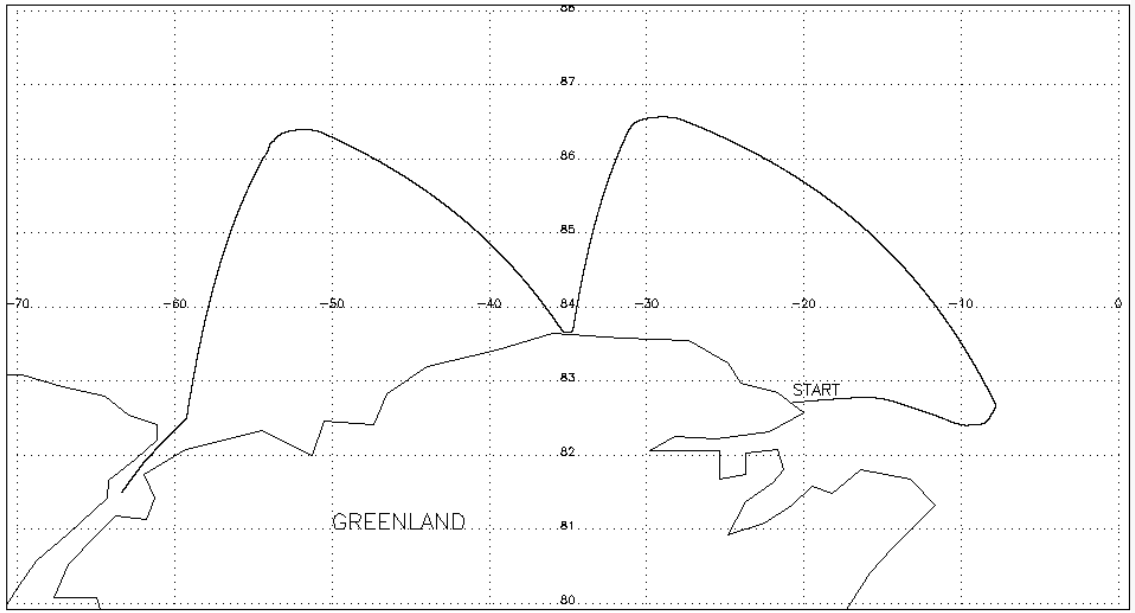
Date (Nov. 2023)	TMP	CTP		PCT
		0 ~ 0.30 m	>= 0.30 m	
11/20-26/23	13965	614	11465	86%
11/22-28/23	14411	714	11678	86%
11/23-29/23	14745	733	11984	86%
11/24-30/23	14813	654	12110	86%
11/26-12/02/23	14902	600	12264	86%
11/27-12/03/23	15060	785	12109	86%
11/28-12/04/23	15156	761	12185	85%
11/29-12/05/23	15316	773	12160	84%
11/30-12/06/23	15246	738	12189	85%
Average				**86%**

CTP: Correctly Typed Pixels for NOAA-21 in terms of CS2SMOS
TMP: Total Matched Pixels
PCT: Probability of Correct Typing

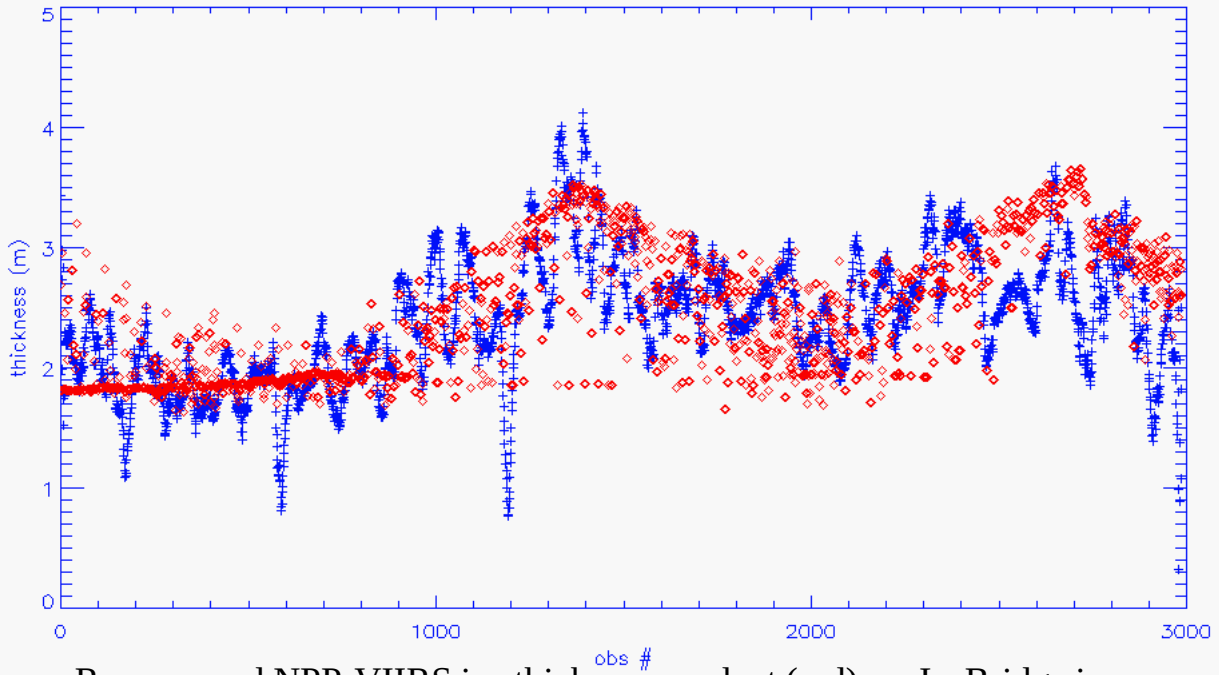
December 2023

Date (Dec. 2023)	TMP	CTP		PCT
		0 ~ 0.30 m	>= 0.30 m	
12/14-20/23	16812	1140	13117	85%
12/15-21/23	17320	1227	13379	84%
12/16-22/23	17649	1182	13602	84%
12/17-23/23	17816	1121	13937	85%
12/18-24/23	18026	1080	14194	85%
12/19-25/23	18113	1006	14467	85%
12/20-26/23	18245	939	14605	85%
12/21-27/23	18161	827	14678	85%
12/22-28/23	17988	783	14674	86%
12/23-29/23	18103	781	14753	86%
12/24-30/23	18010	646	14913	86%
12/25-31/23	18010	638	14866	86%
12/26-01/24	17578	576	14631	87%
Average				**85%**

Sea Ice Thickness Validation: NPP-VIIRS vs IceBridge, Arctic (OTIM v6.4 CIMSS)



IceBridge P-3 aircraft flight track on April 6, 2019. General direction of flight is counterclockwise (START indicates beginning of track).



Reprocessed NPP-VIIRS ice thickness product (red) vs. IceBridge ice thickness measurements (blue) along the April 6, 2019 flight track.

Ice thickness results for IceBridge (OIB) and VIIRS products for the 2 OIB flights.

Flight Date	Mean OIB thickness (m)	Mean VIIRS thickness (m)	OIB Std. Dev. (m)	VIIRS Std. Dev.
April 6, 2019	2.402	2.459	0.526	0.546
April 20, 2019	2.113	2.377	0.563	0.687

Cloud contamination would cause some suspicious sea ice thickness with NPP-VIIRS data.

Evaluation of the effect of required algorithm inputs

- Required Algorithm Inputs
  - Primary Sensor Data: VIIRS M5, M7, M10, M15 and M16
  - Ancillary Data: VIIRS geolocation, Cloud Mask, Land Mask
  - Atmospheric profile data and snow depth data (Thickness/Age, optional).
  - Upstream algorithms: NDE Cloud Mask v3r2
  - LUTs / PCTs: internal LUT for ice /concentration algorithm
- Evaluation of the effect of required algorithm inputs (mainly cloud mask)
  - Study / test cases: 20 July, 2023 north of Svalbard, Norway (78-80 deg N; 8-25 deg W, northeast of Greenland Sea)
  - The effect of the cloud mask depends on conditions: it will mask false ice due to wrong cloud mask.
  - Low sun conditions (solar zenith angle between 86^{o}~93^{o}) will cause larger uncertainties on ice products due to larger uncertainties for cloud masking and surface albedo. Large uncertainty for any ice product under low sun condition.

Quality flag analysis/validation

- Defined Quality Flags
  - Ice Mask
  - Description
  - Value: 0: cloud, 1: visible ice, 2: infrared ice, -1: land, -2: water,others
  - **No issues were found.**
  - **Quality Control Flags for All Ice Products:**

Value & Meaning: 0	0	Good/Optimal retrieval
Value & Meaning: 1	0	Uncertain/Suboptimal retrieval
Value & Meaning: 1	0	Bad/Missing retrieval
Value & Meaning: 1	1	Non-retrieval

Error Budget (Ice Age and and Thickness)

Attribute Analyzed	DPS	Requirement / Threshold	Pre-Launch Performance (N20vs21)	On-orbit Performance			Meet Requirement?	Additional Comments
				NOAA-21	NOAA-20	S-NPP		
Accuracy		70%	0.14 m	<0.006 m	N/A	NA	**YES; YES**	
Precision		n/a	0.12 m	<0.11 m	N/A	N/A	**YES; YES**	
Uncertainty		70%	0.18 m ~ <2 cat	<0.11 m	N/A	N/A	**YES; YES**	
Match				>90%		>90%	**AGE;THK**	**Same as NOAA-20**

User Feedback

Name	Organization	Application	User Feedback - User readiness dates for ingest of data and bringing data to operations
Mike Lawson	NWS AK Sea Ice Program (ASIP)	Ice operations around Alaska	Useful in areas of varying thickness, but no way to actually confirm the data (actual ice thickness). Enough of a gradient in the product to make some general assumptions about the analysis in the area of data. **Doesn't seem to pick up thicknesses less than 1.2 m, we need to know thickness data much less than that**." **>** *Issue with older versions and has been fixed with more recent versions.*
Various	US National Ice Center (USNIC)	Ice operations, global	Training done at the NIC in August; expressed interest in products
Bob Grumbine	NCEP/EMC	Forecast modeling	Concentration has been tested with positive results; thickness will be useful in the future.
Walt Clark	US National Ice Center (USNIC)	Ice operations	The USNIC uses VIIRS Snow Cover and the VIIRS Sea Ice Extent products. "We use the derived VIIRS snow and ice products from all of the polar orbiters available. With the loss of MODIS, we have beefed up some of our VIIRS based products we make available to our analysts. We hope to continue to pull these VIIRS products off all 3 platforms for our composites: SNPP, NOAA-20, and NOAA-21."

Downstream Product Feedback

No VIIRS products use ice products as input.

Algorithm	Product	Downstream Product Feedback - Reports from downstream product teams on the dependencies and impacts

Risks, Actions, and Mitigations

- Provide updates for the status of the risks/actions identified during the previous maturity review(s); add new ones as needed

Identified Risk	Description	Impact	Action/Mitigation and Schedule
Cloud mask	Still some false clear in the Arctic and Antarctic, but improved over v2r0.	Some false ice	Continue to work with cloud team (ongoing)
Identifying Very Thin Ice	Daytime conditions limit algorithms ability to measure very thin ice < 0.25 m	New/Young Cat	Work with ASSIST to update algorithm with more recent version that improve upon known issue. Most recent version submitted in 2022.

Documentation (Check List)

Science Maturity Check List	Yes
ReadMe for Data Product Users	Yes
Algorithm Theoretical Basis Document (ATBD)	Yes
Algorithm Calibration/Validation Plan	Yes
(External/Internal) Users Manual	Yes
System Maintenance Manual (for ESPC products)	Yes
Peer Reviewed Publications (Demonstrates algorithm is independently reviewed)	Yes
Regular Validation Reports (at least annually) (Demonstrates long-term performance of the algorithm)	Yes

Check List - Provisional Maturity-Sea Ice Age and Thickness

Provisional Maturity End State	Assessment
Product performance has been demonstrated through analysis of a large, but still limited (i.e., not necessarily globally or seasonally representative) number of independent measurements obtained from selected locations, time periods, or field campaign efforts.	Yes
Product analyses are sufficient for qualitative, and limited quantitative, determination of product fitness-for-purpose.	Yes
Documentation of product performance, testing involving product fixes, identified product performance anomalies, including recommended remediation strategies, exists	Yes
Product is recommended for potential operational use (user decision) and in scientific publications after consulting product status documents.	Yes

Conclusion – Sea Ice Age and Thickness

- NOAA-21 VIIRS ice age and ice thickness products have been evaluated using a limited set of products from October to December of 2023.
- Calibration/validation with NOAA-20 VIIRS ice age and ice thickness products show all NOAA-21 VIIRS ice age and ice thickness products perform well and meet the product requirements.
- Comparisons to CryoSat-2/SMOS (CS2SMOS) merged ice thickness data show NOAA-21 and CS2SMOS match to each other at 85% or higher rate in terms of ice age classification.
- Only a limited set of data available for evaluation at this time, further comprehensive assessment of the products is needed.
- **The Cryosphere Team recommends that NOAA-21 Ice Age and Ice Thickness products be declared Provisional Maturity.**

Path Forward

- More calibration/validation may reveal the causes of a positive bias in Ice Age and Thickness. Possible adjustments/improvements will be carried out accordingly in the algorithm improvement and maintenance.
  - OTIM v6r1 was submitted to ASSISTT in September, 2022 and has been implemented for the operational product as v3r3.
  - Update to OTIM v6r4 for Sea Ice Age and Thickness algorithm; Local runs at UW-CIMSS have shown removal of positive bias in Thickness/Age for more recent versions.
  - Include ice thickness validation results with Cryosat-2/SMOS when available.
- Continue to work with Cloud Team with focus over the Antarctic.
- Continue evaluation/validation of the product with independent data sets.
- Get ready for Validated Maturity Review.