

***Beta Maturity Science Review  
For NOAA-21 Cryosphere Products – Sea  
Ice***



***Presented by  
Yinghui Liu (STAR) and Richard Dworak (CIMSS)***

***08/03/2023***

# 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.

- 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

## 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/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, and project management.
Jeff Key	NOAA/NESDIS	Overall snow and sea ice project management, assistance on analysis and validation

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.

- 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, or other ice. Ice age is therefore related to ice thickness.



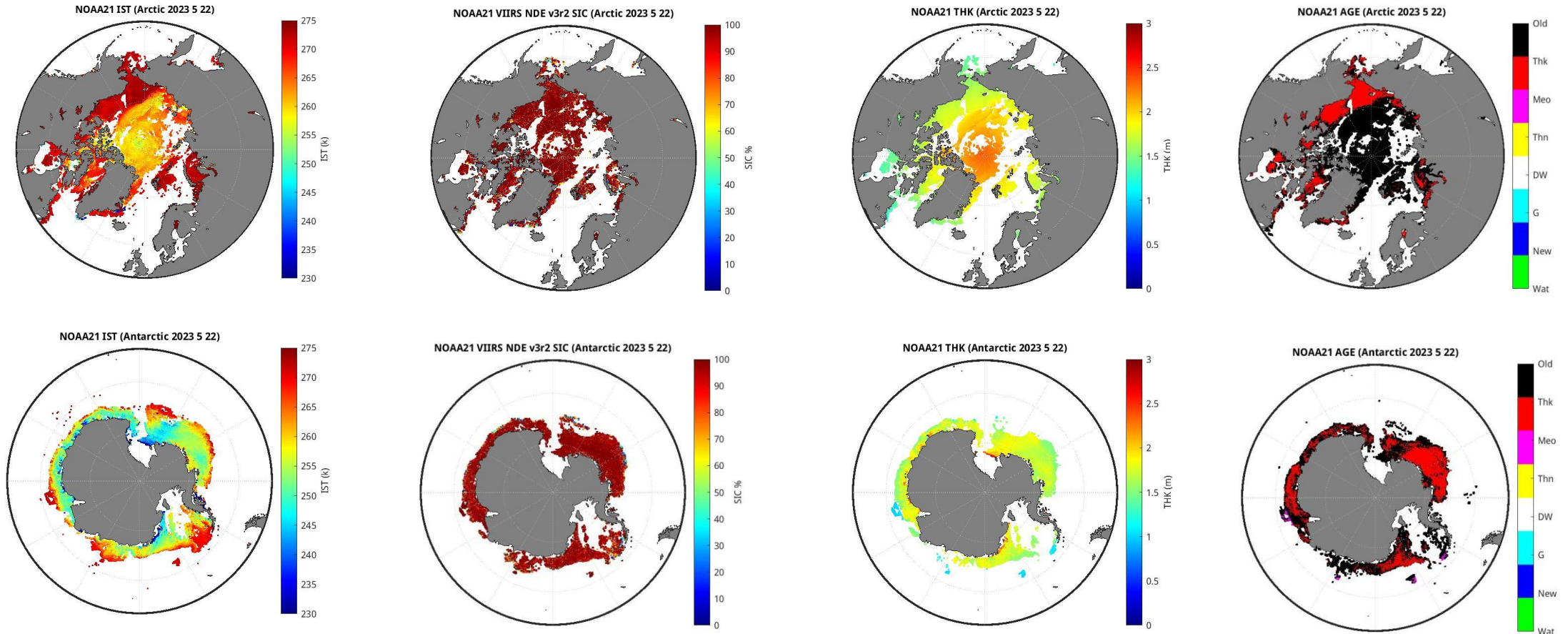
# NOAA-21 Sea Ice Product Examples (NDE I&T v3r2)

Ice Surface Temperature

Ice Concentration

Ice Thickness

Ice Age



Daily composites of sea ice temperature, concentration, thickness, and age on May 22, 2023. Top row is the Arctic; bottom row is the Antarctic.

# Product Overview/Requirements: Sea Ice Concentration

Attribute	DPS	Requirement/Threshold	Performance
Geographic coverage	246	All ice-covered regions of the global ocean	All ice-covered regions of the global ocean
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	246	0 – 100%	0 – 100%
Accuracy (recommended)		10%	-0.2 to -2.6%
Precision (recommended)		25%	10 to 15%
Uncertainty	248	25%	10.5 to 15%

# Product Overview/Requirements: Ice Surface Temperature

Attribute	DPS	Requirement/Threshold	Performance
Geographic coverage	370	All ice-covered regions of the global ocean	All ice-covered regions of the global ocean
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	371	213 - 275 K	213 - 275 K
Accuracy (recommended)		1 K	0.1 to 0.2 K
Precision (recommended)		1.5 K	0.5 to 1.5 K
Uncertainty	372	1 K	0.5 to 1.5 K



# 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 ice, and ice thickness
Accuracy	241	70% probability of correct typing	Near 100% vs N20
Precision		n/a (see GOES-R definition for 2-category variables)	less than one category comp to N20
Uncertainty		70% for ice age probability of correct typing	Near 0 when comp. to N20

# 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
Measurement Range	none	0-6 m
Measurement Accuracy	none	0.16 m
Measurement Precision	none	0.24 m

- Description of processing environment and algorithms used to achieve the maturity stage:
  - Algorithm version: V3R2
  - Algorithm Theoretical Basis Documents
    - [https://www.ospo.noaa.gov/Products/Suites/files/atbd/ATBD\\_IceSurfaceTemperatureIceConcentration\\_v1.0.pdf](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](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 through 31 July 2023.
  - Starting orbit number: 2436.

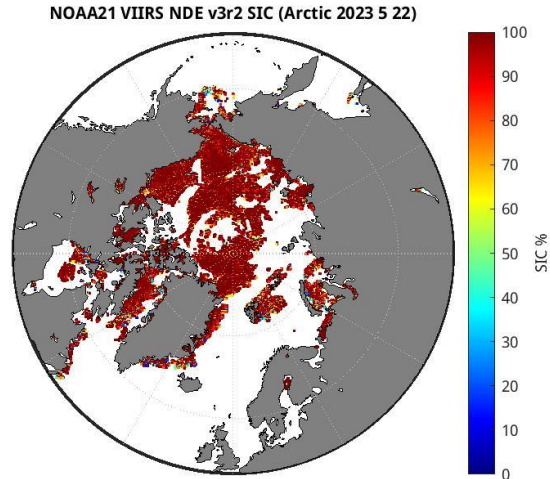
### Algorithm performance evaluation

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

- Inter-sensor comparison
  - Compare with S-NPP and NOAA-20: RMSE 8-10% (SIC), 0.5 to 1.1K (IST), and 0.1m (THK).
  - Validation results: meets requirements
- Validation with independent products
  - Validation data sets: passive microwave AMSR2 SIC, 1 May - 30 June, Arctic and Antarctic
  - Case studies with Landsat, including IST and SIC
  - Validation results: meets requirements
- Long term monitoring readiness: routine comparison to NOAA-20 and AMSR2 SIC

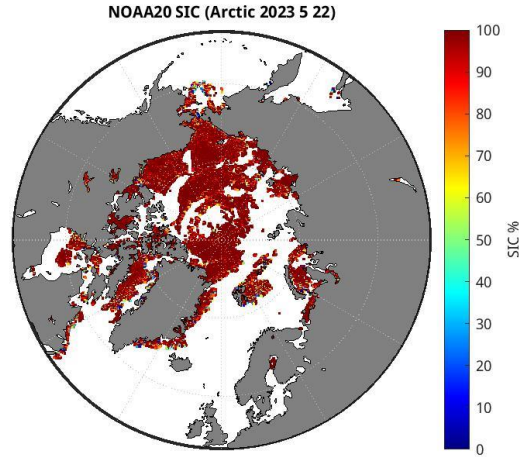
# Sea Ice Concentration: NOAA-21 vs. NOAA-20, Arctic

NOAA-21



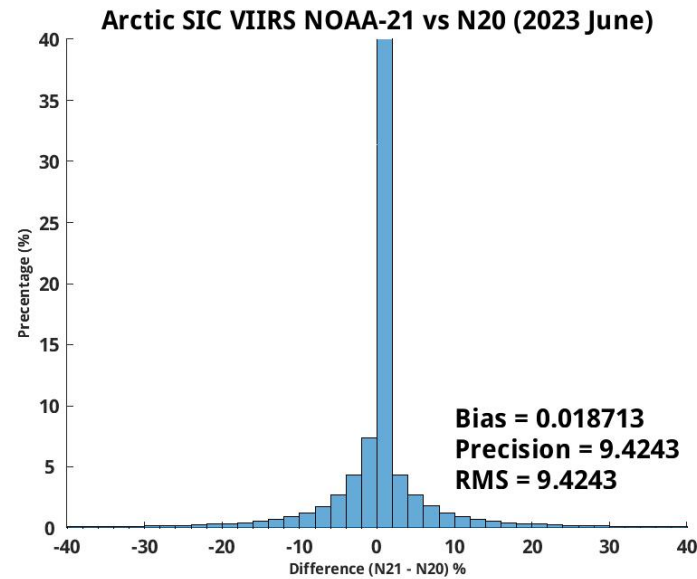
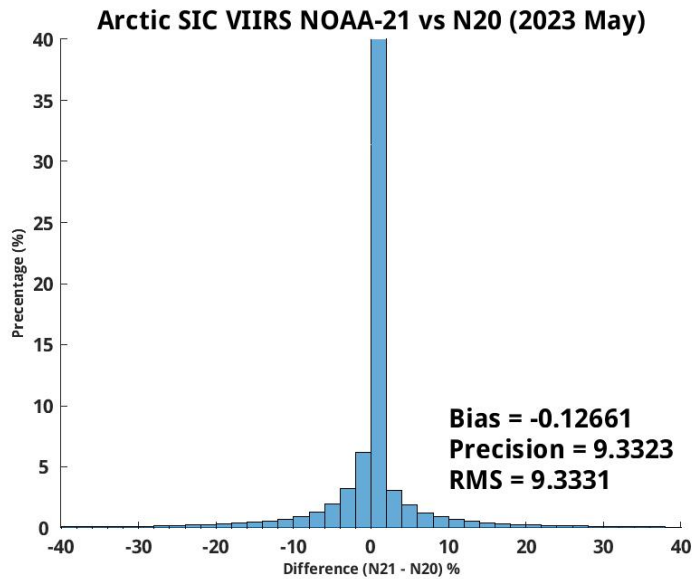
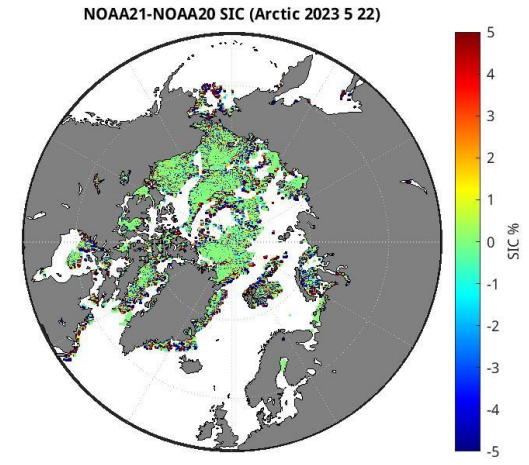
May

NOAA-20



June

NOAA-21 minus NOAA-20

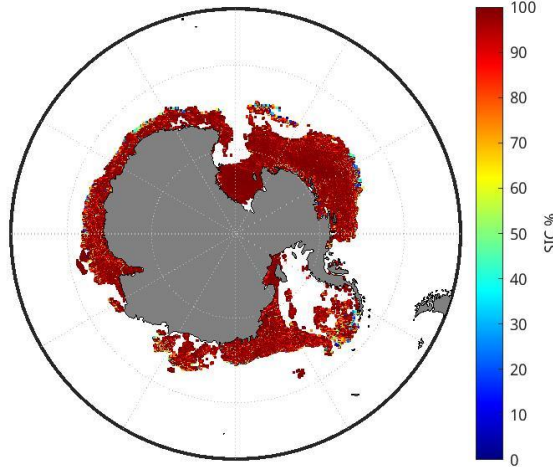


- Top row is the comparison on May 22, 2023
- Histogram by month, May and June 2023

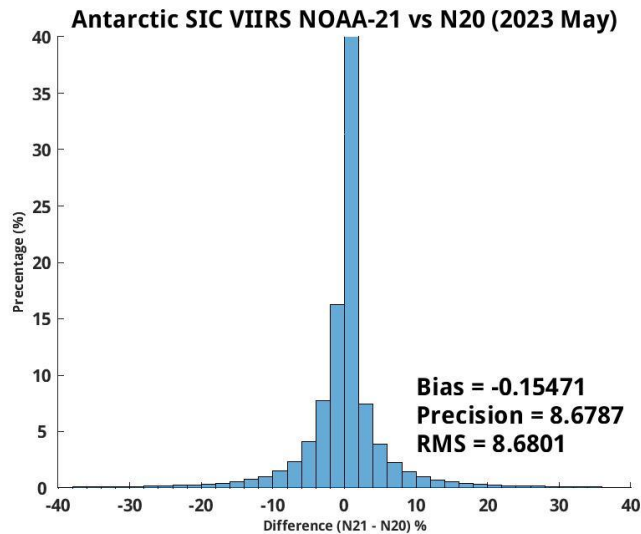
# Sea Ice Concentration: NOAA-21 vs. NOAA-20, **Antarctic**

NOAA-21

NOAA21 VIIRS NDE v3r2 SIC (Antarctic 2023 5 22)

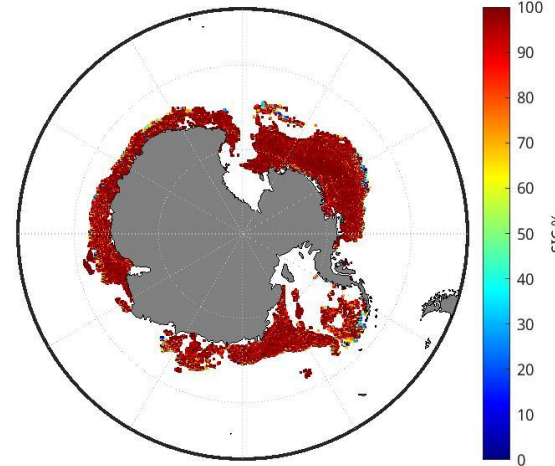


May

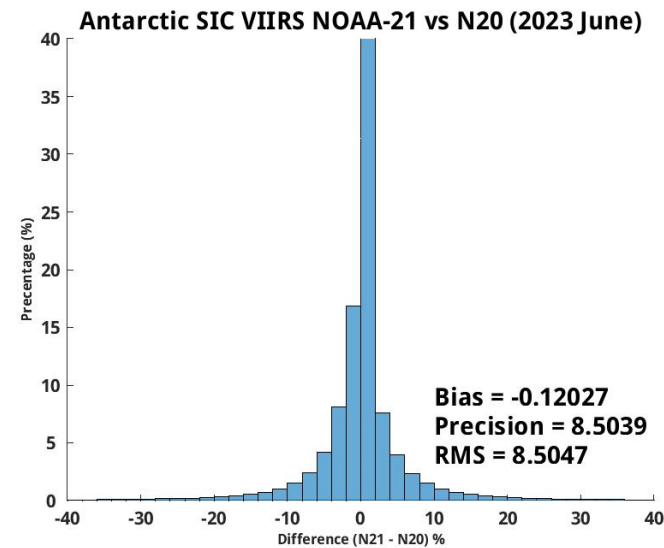


NOAA-20

NOAA20 SIC (Antarctic 2023 5 22)

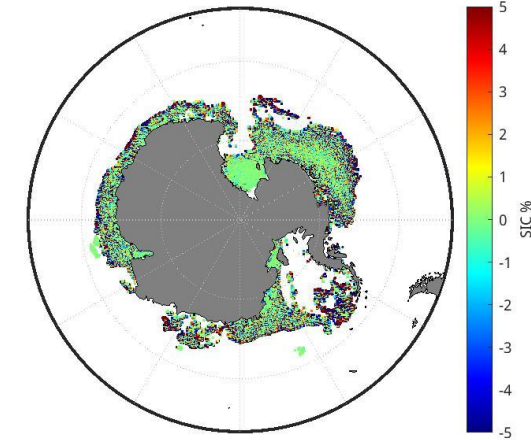


June



NOAA-21 minus NOAA-20

NOAA21-NOAA20 SIC (Antarctic 2023 5 22)



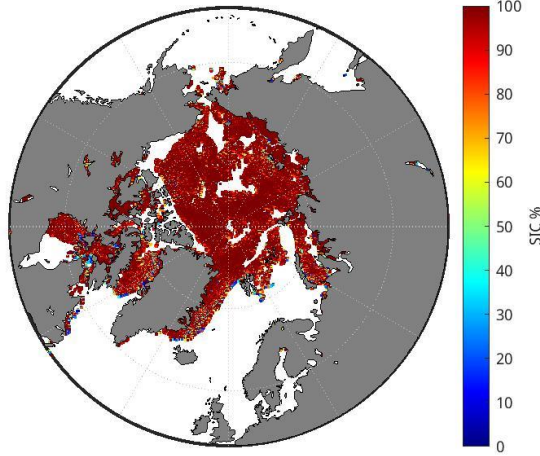
- Top row is the comparison on May 22, 2023
- Histogram by month, May and June 2023



# Sea Ice Concentration: NOAA-21 vs. AMSR2, Arctic

NOAA-21

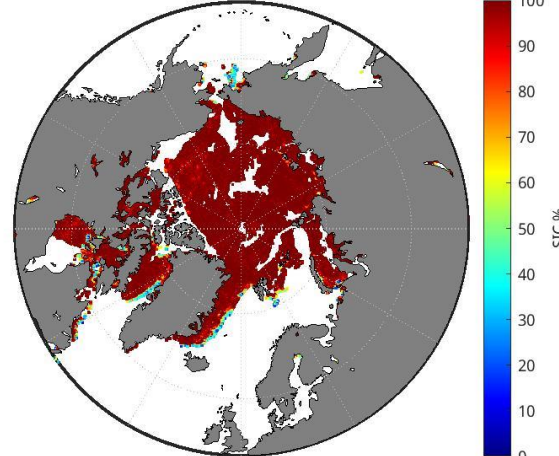
NOAA21 VIIRS NDE v3r2 SIC (Arctic 2023 5 16)



May

AMSR2

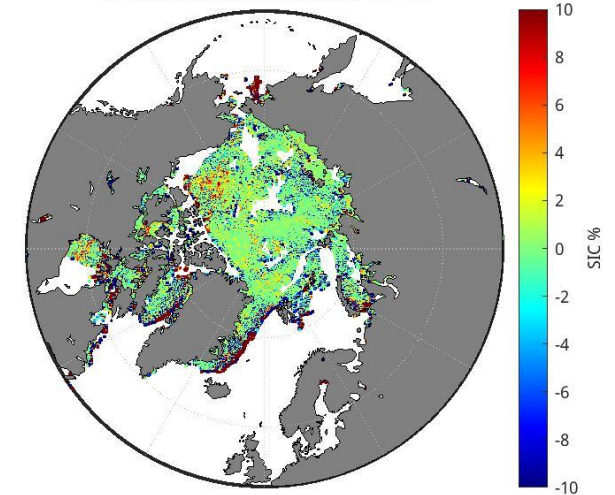
AMSR2 SIC (Arctic 2023 5 16)



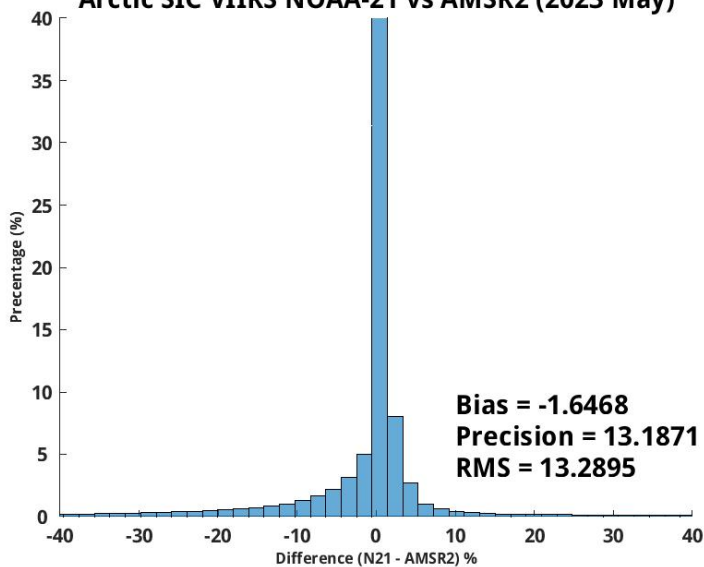
June

NOAA-21 minus AMSR2

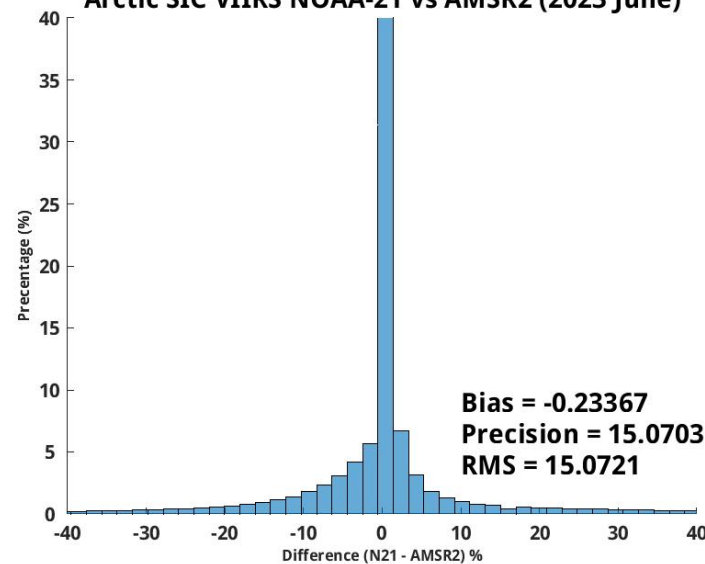
NOAA21-AMSR2 SIC (Arctic 2023 5 16)



Arctic SIC VIIRS NOAA-21 vs AMSR2 (2023 May)



Arctic SIC VIIRS NOAA-21 vs AMSR2 (2023 June)

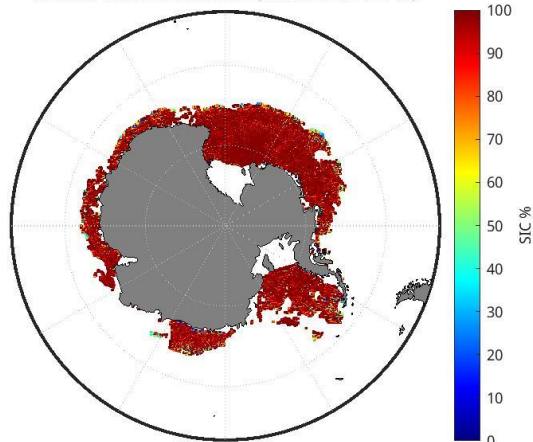


- Top row is the comparison on May 16, 2023
- Histogram by month, May and June 2023

# Sea Ice Concentration: NOAA-21 vs. AMSR2, **Antarctic**

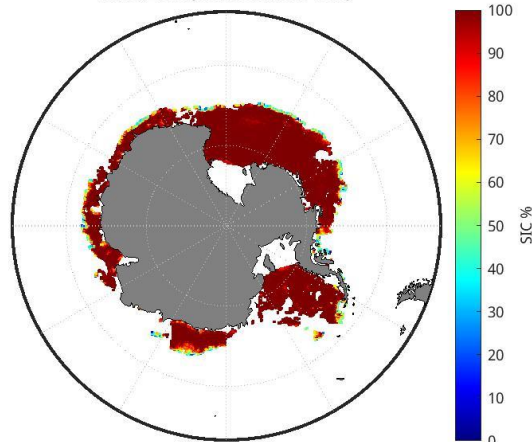
NOAA-21

NOAA21 VIIRS NDE v3r2 SIC (Antarctic 2023 5 16)



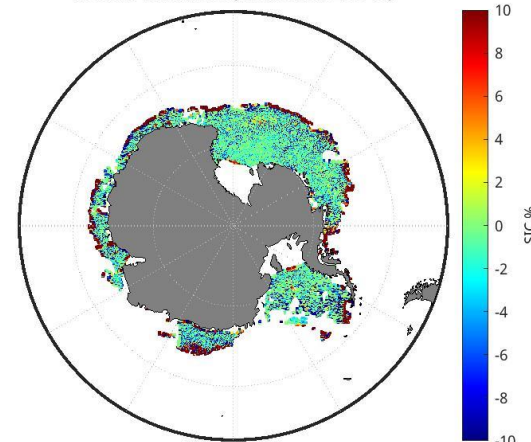
AMSR2

AMSR2 SIC (Antarctic 2023 5 16)



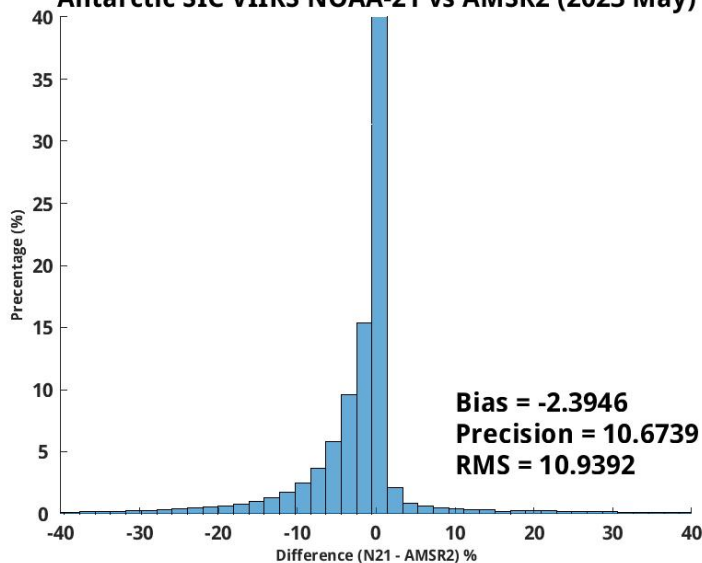
NOAA-21 minus AMSR2

NOAA21-AMSR2 SIC (Antarctic 2023 5 16)



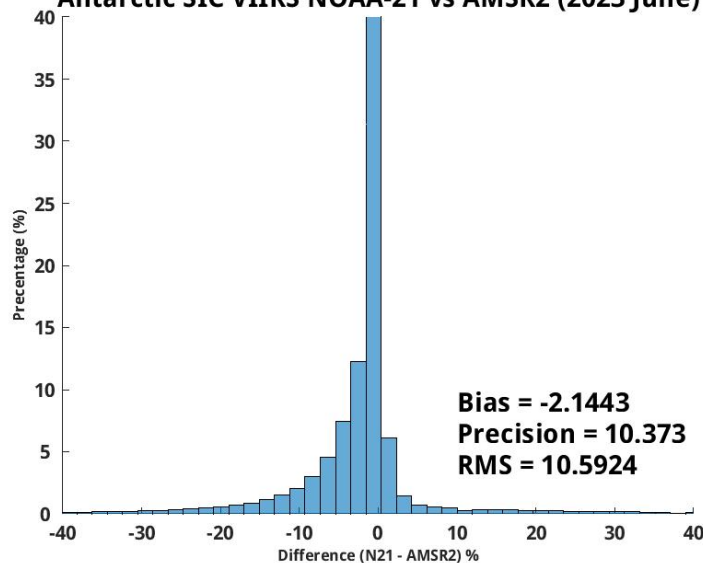
May

Antarctic SIC VIIRS NOAA-21 vs AMSR2 (2023 May)



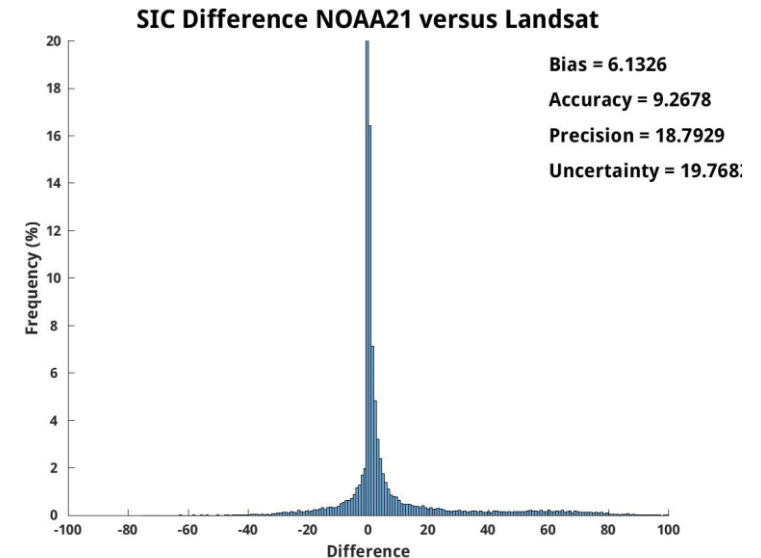
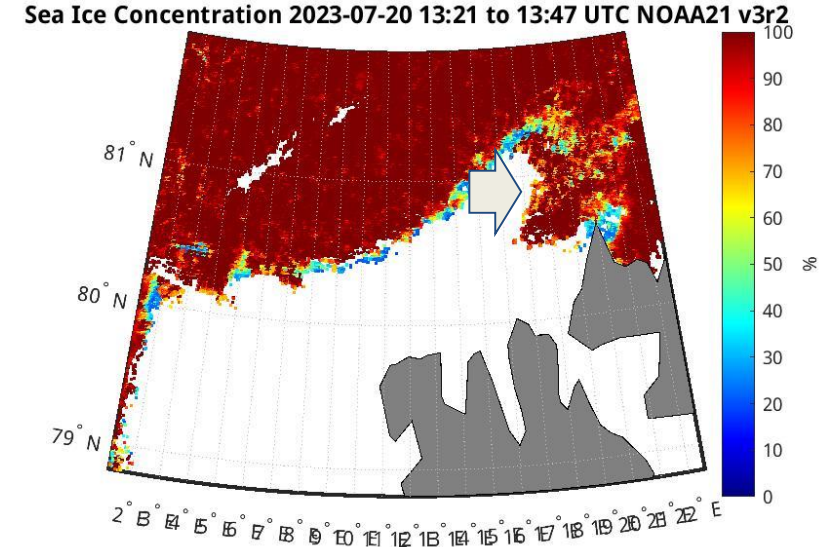
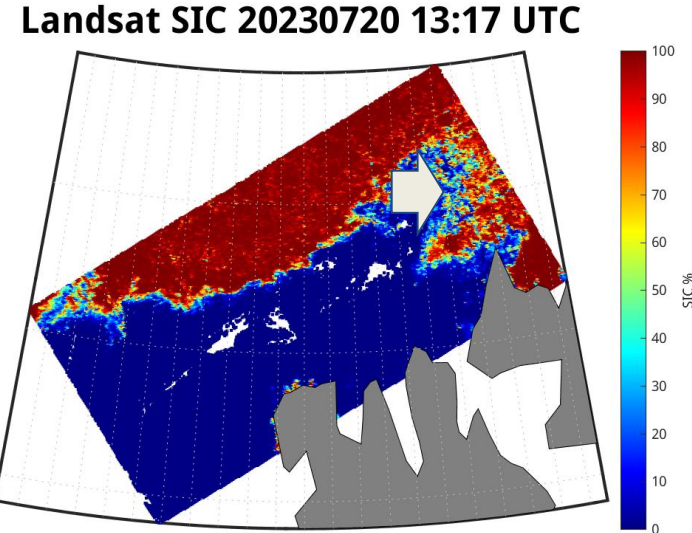
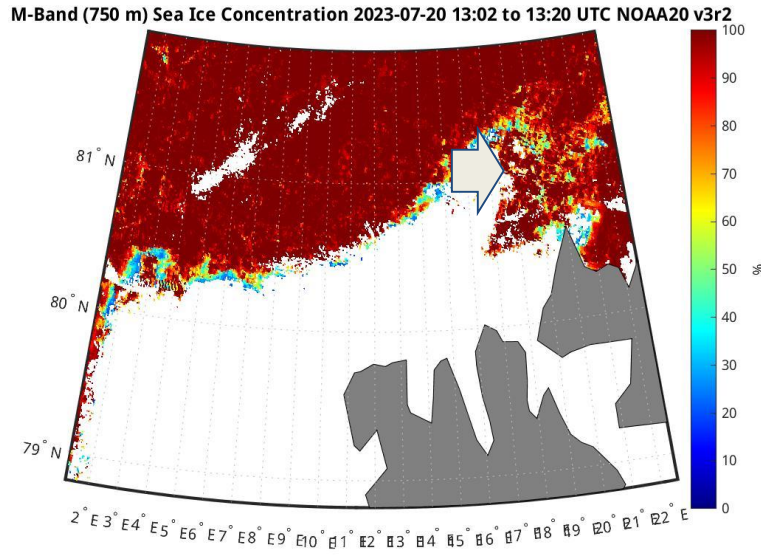
June

Antarctic SIC VIIRS NOAA-21 vs AMSR2 (2023 June)



- Top row is the comparison on May 16, 2023
- Histogram by month, May and June 2023

## Near Svalbard on 23 July, 2023 13-14 UTC



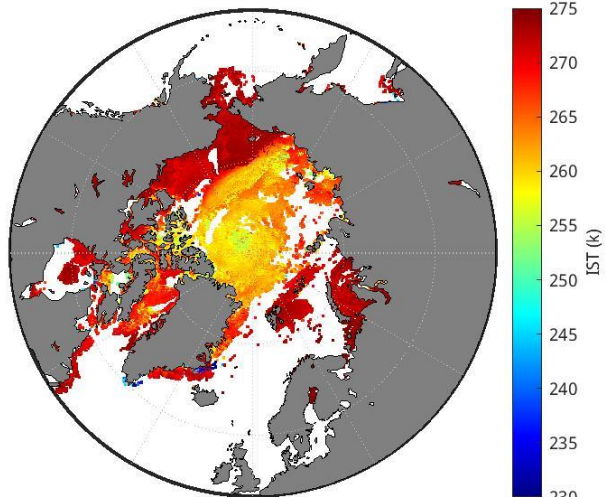
- NDE N20/21 SIC does a good job capturing sea ice edge and pack ice to the north.
- Positive bias in NDE N20/21 SIC in Marginal Ice Zone (MIZ) to the northeast (see arrow).
- Missing SIC=0 in NDE. Instead we see only SIC=missing value.
- A solution to these remaining issues are being investigated.
- **Statistical results show accuracy, precision and uncertainty all meet requirements for this case.**



# Ice Surface Temperature: NOAA-21 vs. NOAA-20, Arctic

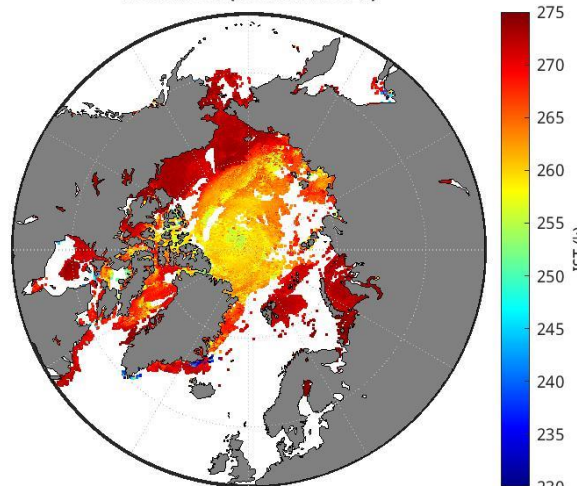
NOAA-21

NOAA21 IST (Arctic 2023 5 22)



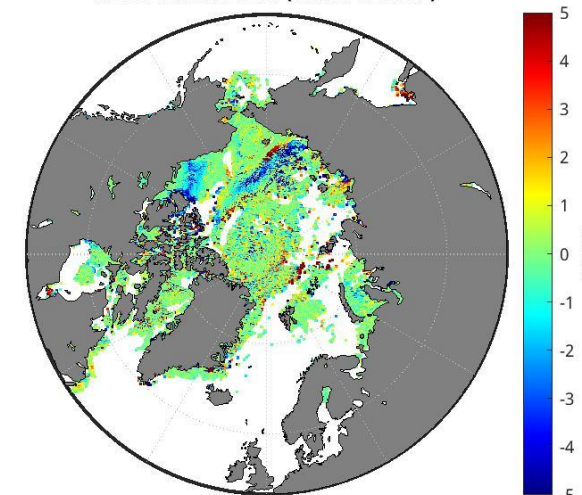
NOAA-20

NOAA20 IST (Arctic 2023 5 22)



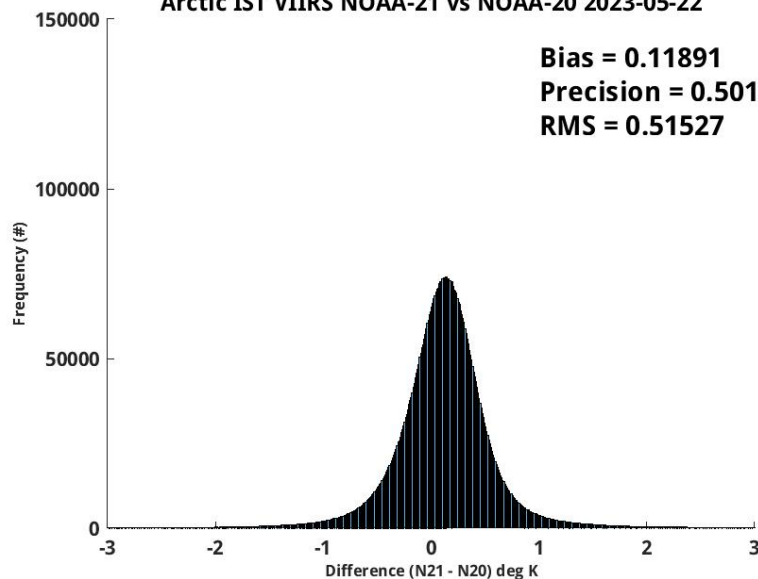
NOAA-21 minus NOAA-20

NOAA21-NOAA20 IST (Arctic 2023 5 22)



Arctic IST VIIRS NOAA-21 vs NOAA-20 2023-05-22

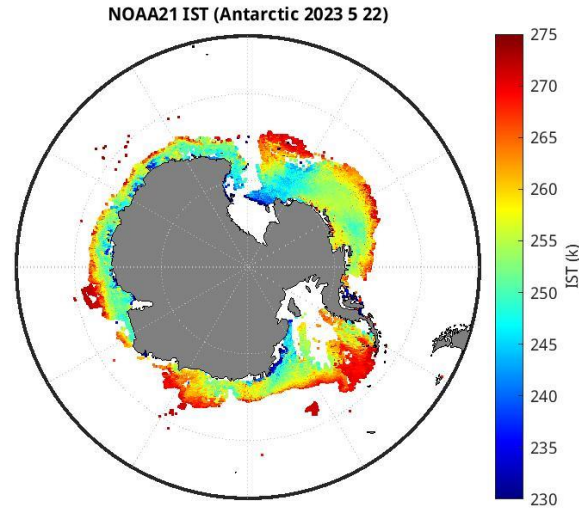
**Bias = 0.11891**  
**Precision = 0.50136**  
**RMS = 0.51527**



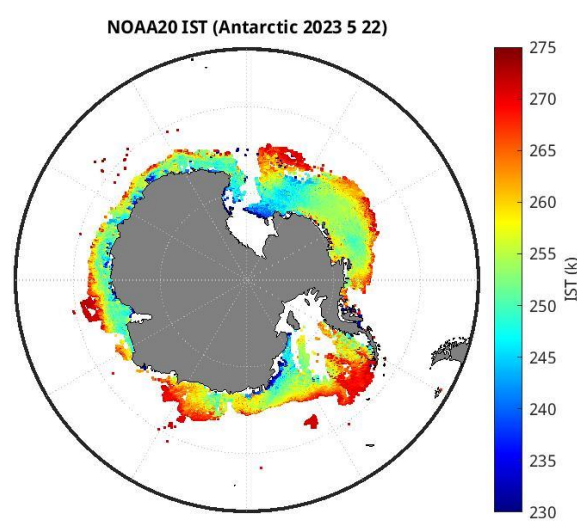
Comparison of May 22, 2023, statistical mean ice surface temperature was done with individual overpasses within one hour.

# Ice Surface Temperature: NOAA-21 vs. NOAA-20, **Antarctic**

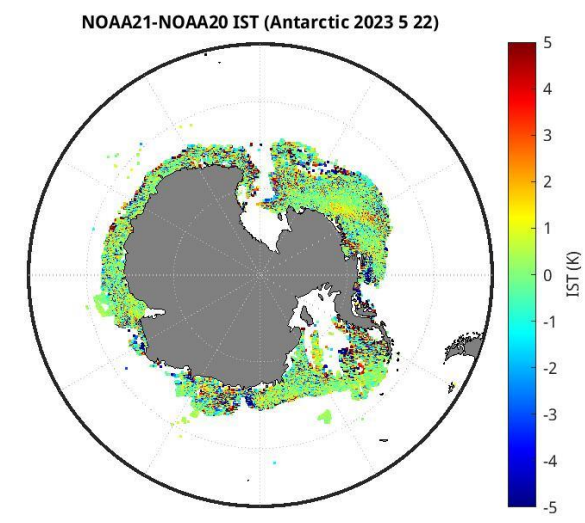
NOAA-21



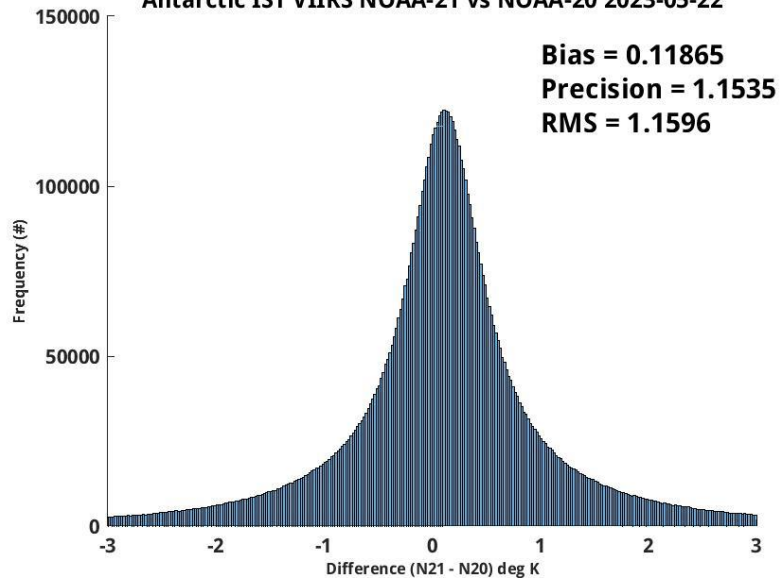
NOAA-20



NOAA-21 minus NOAA-20



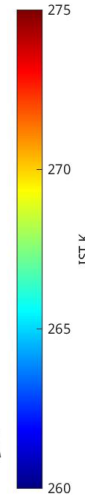
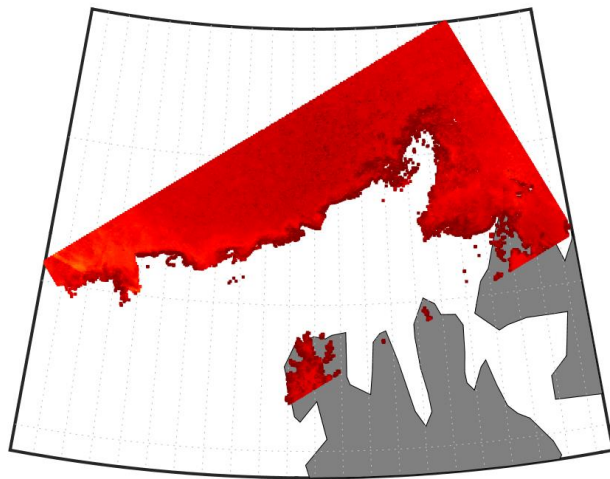
Antarctic IST VIIRS NOAA-21 vs NOAA-20 2023-05-22



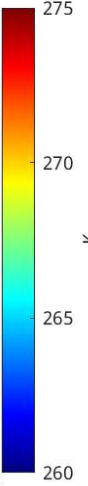
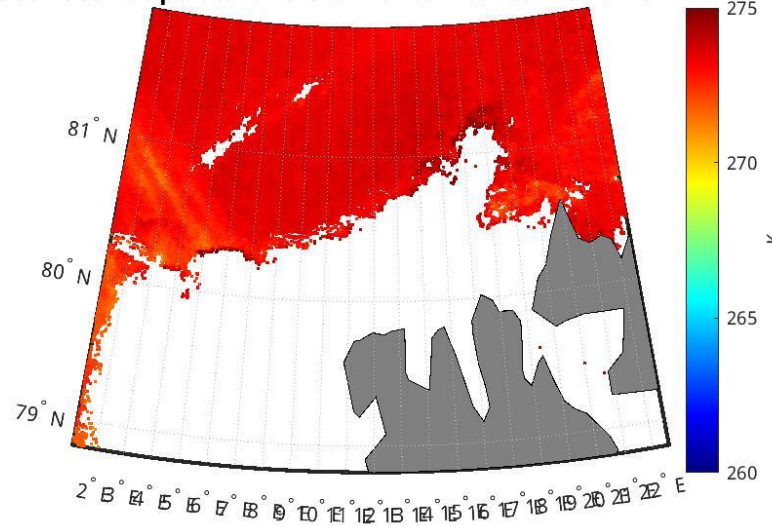
Comparison of May 22, 2023, statistical mean ice surface temperature was done with individual overpasses within one hour.

## Near Svalbard on 23 July, 2023 13-14 UTC

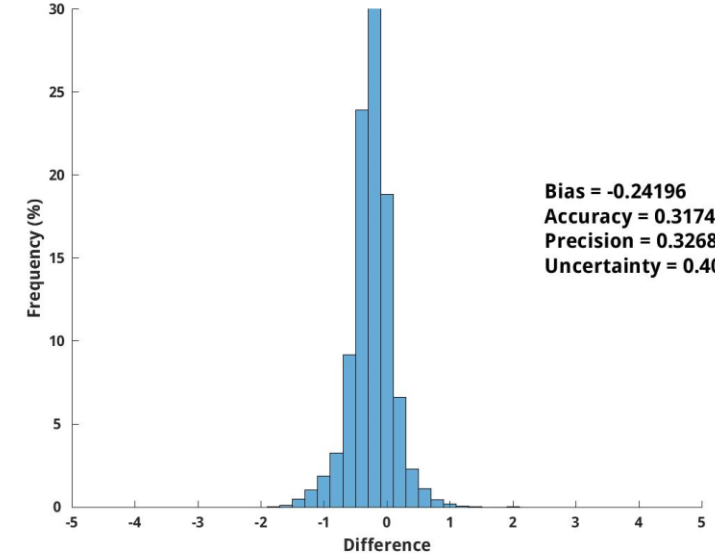
Landsat IST 2023-07-20 13:17 UTC



Ice Surface Temperature 2023-07-20 13:21 to 13:47 UTC NOAA21 v3r2



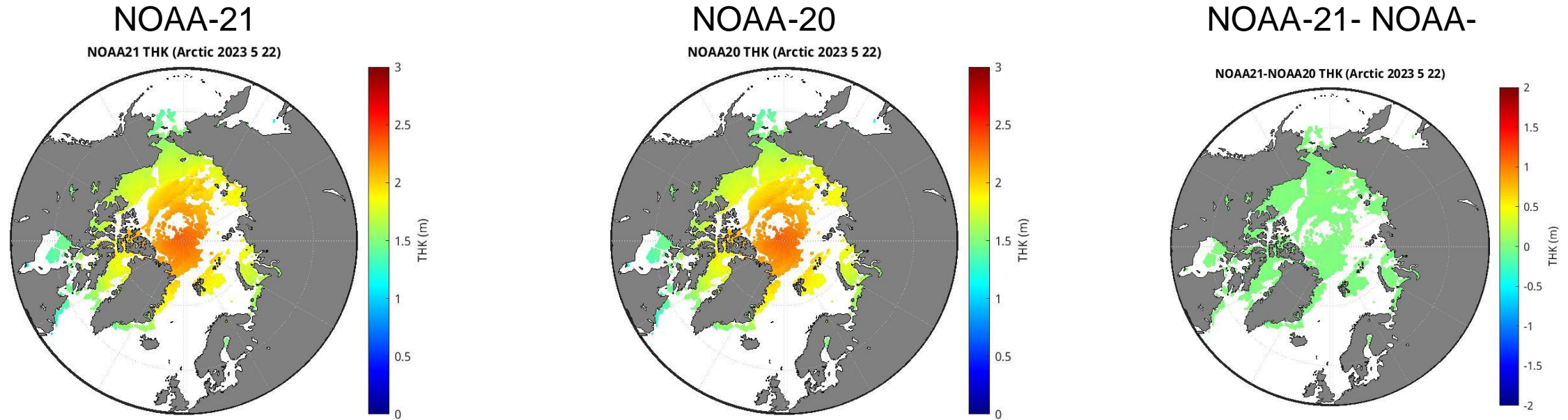
IST Difference NOAA21 versus Landsat



- NDE N21 IST agrees well with Landsat in the warm temperature range (270-275 K)
- Accuracy, Precision and Uncertainty are all well within requirements for this case (**0.32** < 1 K, **0.33** < 1.5 K and **0.41** < 1 K, respectively)
- Caveat being that the range is limited to melting and near melt temperatures (270-275 K)
- More cases to be analyzed over a wider range of temperature ranges.

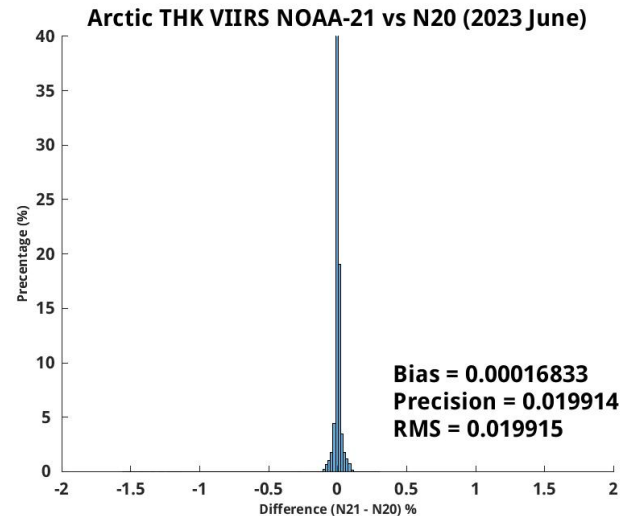
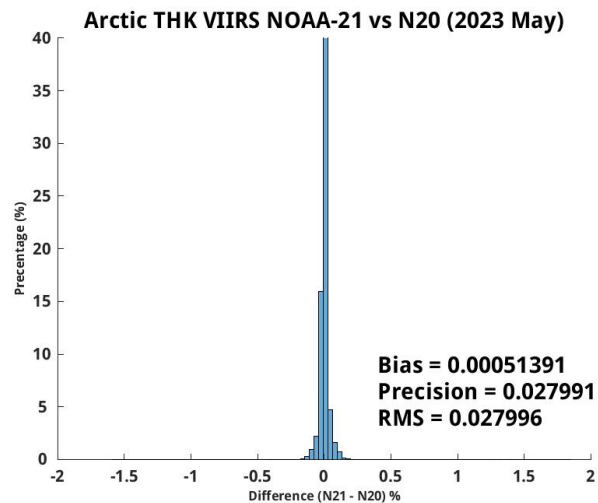


# Sea Ice Thickness/Age: NOAA-21 vs. NOAA-20 Arctic



May

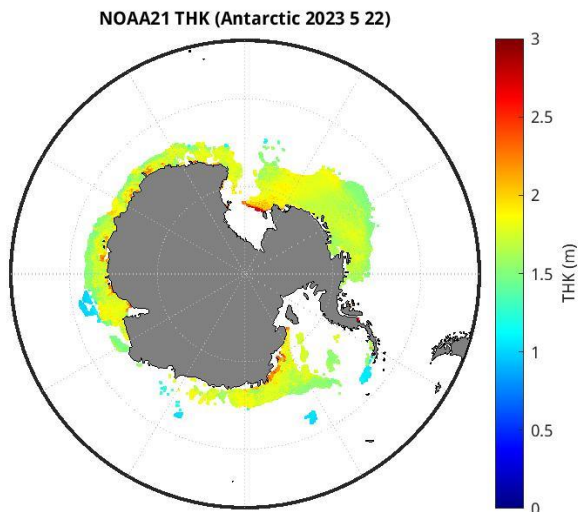
June



- Top row is daily composites comparison of May 22, 2023, NOAA-21 matches well with NOAA-20 overall.
- Histogram by month, May and June 2023

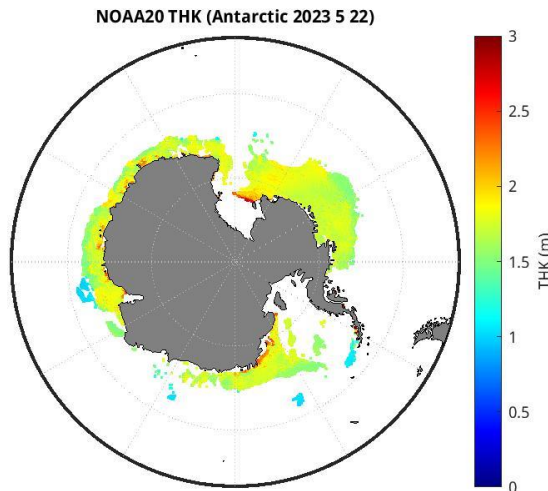
# Sea Ice Thickness/Age: NOAA-21 vs. NOAA-20 Antarctic

NOAA-21



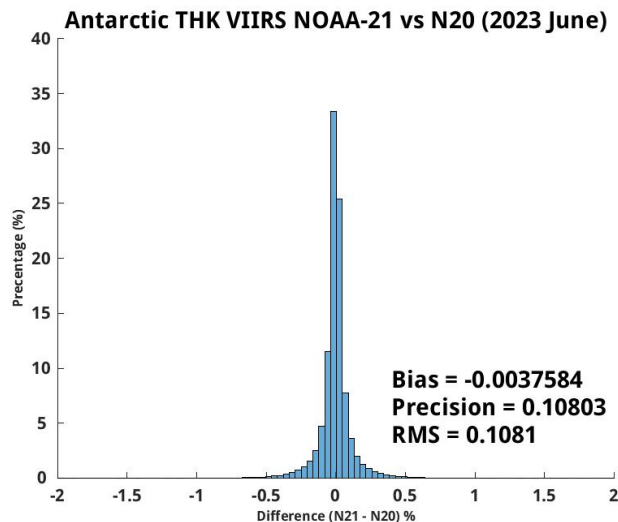
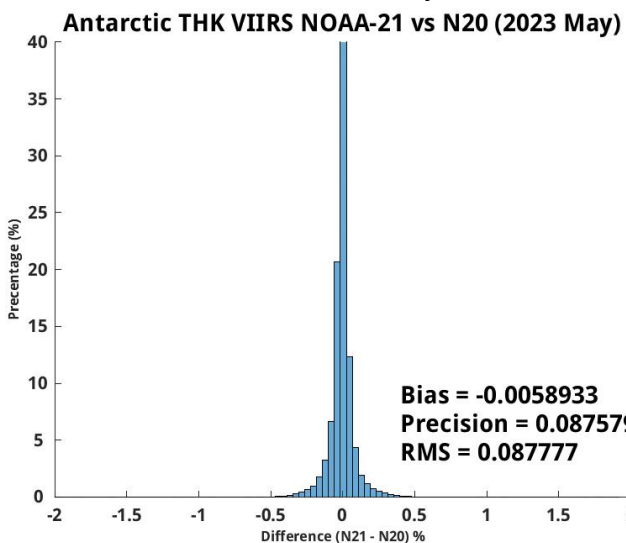
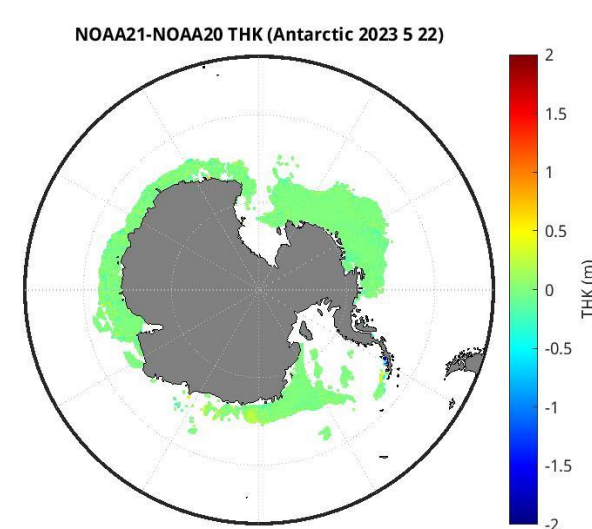
May

NOAA-20



June

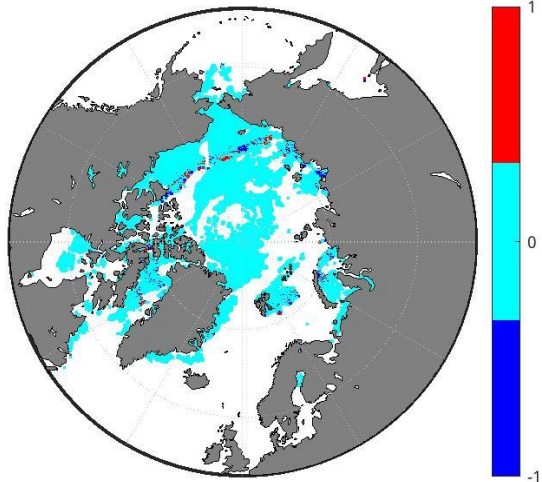
NOAA-21 minus NOAA-20



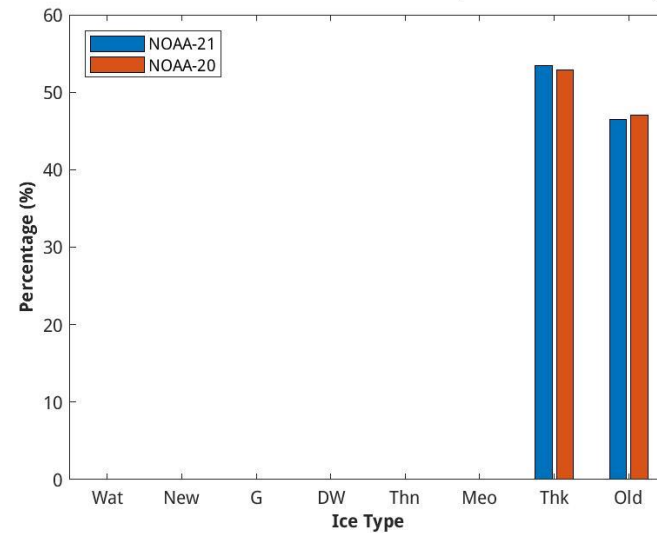
- Top row is daily composites comparison of May 22, 2023, NOAA-21 matches well with NOAA-20 overall.
- Histogram by month, May and June 2023

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

NOAA21-NOAA20 AGE (Arctic 2023 5 22)

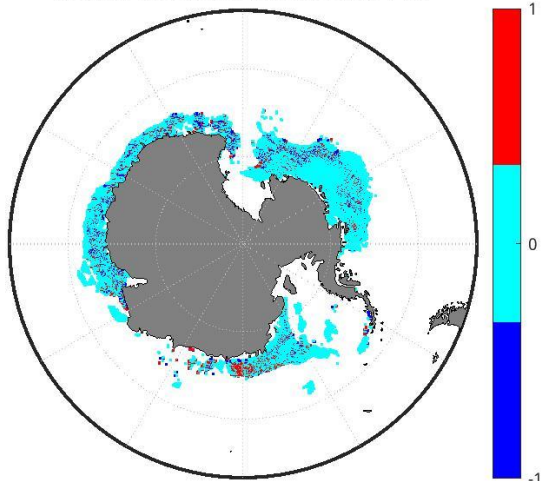


ICE AGE NOAA-21 vs. NOAA-20 (Arctic 2023 5 22)

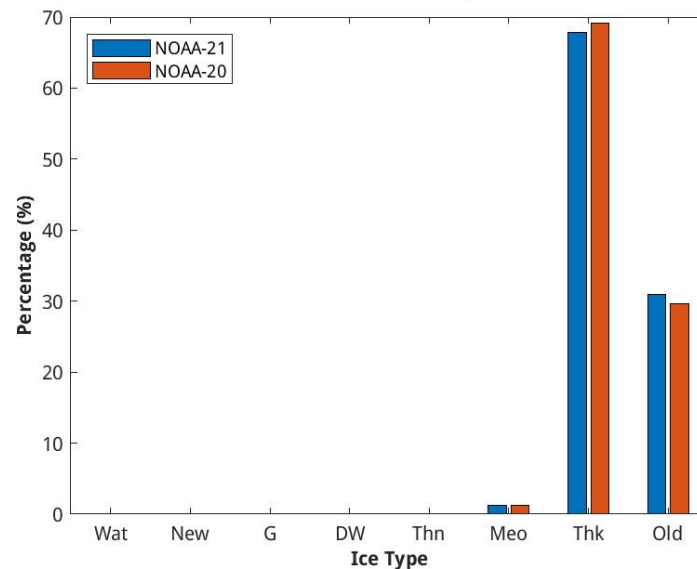


- NDE N21 Ice Age types agrees well to N20.
- >90% of correct typing.
- OTIM v6 increases the frequency of lower categories.

NOAA21-NOAA20 AGE (Antarctic 2023 5 22)



ICE AGE NOAA-21 vs. NOAA-20 (Antarctic 2023 5 22)



- 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: Landsat 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  $86^{\circ}$ ~ $93^{\circ}$ ) 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.

- 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 Concentration and Temperature)

Attribute Analyzed	DPS	Requirement/ Threshold	Pre-Launch Performance (N20vs21)	On-orbit Performance			Meet Requirement?	Additional Comments
				NOAA-21 (Arctic)	NOAA-20 (Arctic)	S-NPP		
Accuracy		10% SIC; 1K IST	-0.1%;-0.18K	-1.6%	-1.6%	N/A	<b>YES; YES</b>	<b>Larger SIC differences found over MIZ.</b>
Precision		25% SIC; 1.5 K IST	3.9%;0.08K	13.1%	12.3%	N/A	<b>YES; YES</b>	<b>Precision found to be 1.1 K over the Antarctic.</b>
Uncertainty		25% SIC; 1 K IST	3.9%;0.2K	13.2%	12.4%	N/A	<b>YES; YES</b>	<b>Larger IST differences were found over the Antarctic.</b>
			SIC; IST	*SIC vs AMSR2	*SIC vs AMSR2		<b>SIC;IST</b>	



# 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	N/A	<b>YES; YES</b>	
Precision		n/a	0.12 m	<0.11 m	N/A	N/A	<b>YES; YES</b>	
Uncertainty		70%	0.18 m ~ <2 cat	<0.11 m	N/A	N/A	<b>YES; YES</b>	
							<b>AGE;THK</b>	

# User Feedback

Name	Organization	Application	<b>User Feedback</b> - User readiness dates for ingest of data and bringing data to operations
Mike Lawson	NWS AK Sea Ice Program (ASIP)	Ice operations around Alaska	Concentration: Very useful. Temperature: Useful for certain analyses. Thickness and Age: Useful in limited circumstances.
Various	National Ice Center (NIC)	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.
Mark Middlebus her	NAVOCEAN	Ice forecasting (modeling)	Concentration improved the accuracy of the ice edge forecast by more than 30%.
Mike Lawson	NWS AK Sea Ice Program (ASIP)	Ice operations around Alaska	Concentration: Very useful. Temperature: Useful for certain analyses. Thickness: Useful in limited circumstances.

*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 Antarctic, in particular, but improved over v2r0.	Some false ice	Continue to work with cloud team (ongoing)

# 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

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



Provisional Maturity End State	Assessment
<p>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.</p>	<p>Yes</p>
<p>Product analyses are sufficient for qualitative, and limited quantitative, determination of product fitness-for-purpose.</p>	<p>Yes</p>
<p>Documentation of product performance, testing involving product fixes, identified product performance anomalies, including recommended remediation strategies, exists</p>	<p>Yes</p>
<p>Product is recommended for potential operational use (user decision) and in scientific publications after consulting product status documents.</p>	<p>Yes</p>

# Check List - Beta Maturity- Sea Ice Age and Thickness

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

- NOAA-21 VIIRS Ice Concentration and Ice Surface Temperature Products have been evaluated using a large but still limited set of products from May to July of 2023.
- Calibration/validation with NOAA-20 VIIRS ice products and independent products show NOAA-21 VIIRS ice concentration and ice surface temperature products perform well and meet the product requirements.
- **The Cryosphere Team recommends that NOAA-21 Ice Concentration and Ice Surface Temperature products be declared Provisional Maturity.**

## 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 May to July 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.
- 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 Beta Maturity.**

# Path Forward

- More calibration/validation may reveal the causes of the found issues, relatively larger uncertainties observed in Marginal Ice Zone Sea Ice Concentration, Ice Surface Temperature precision slightly above specification requirement over the Antarctic, a positive bias in Ice Age and Thickness. Possible adjustments/improvements will be carried out accordingly in the algorithm improvement and maintenance.
  - Adjustments to the ice tie-point algorithm to improve MIZ results.
  - Address the relatively higher IST uncertainty over the Antarctic.
  - Update to OTIM v6.4 for Sea Ice Age and Thickness algorithm; Local runs at UW-CIMSS have shown removal of positive bias in Thickness/Age.
  - Include ice thickness validation results with Cryosat-2 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 Provisional Maturity Review.