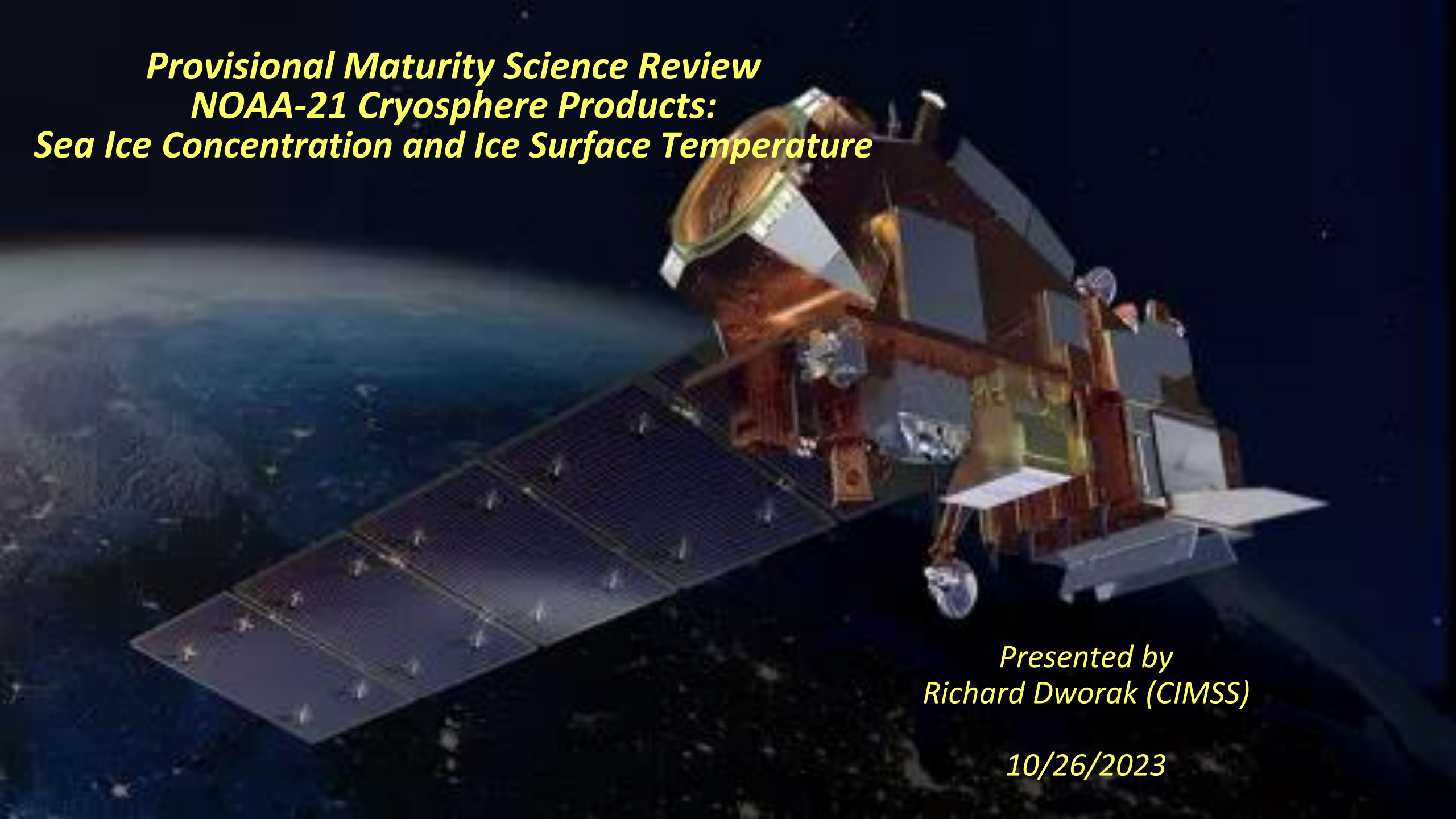


Provisional Maturity Science Review NOAA-21 Cryosphere Products: Sea Ice Concentration and Ice Surface Temperature

Presented by
Richard Dworak (CIMSS)

10/26/2023

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.

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/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

Ice Product Overview

VIIRS ice products include Ice Surface Temperature (IST), Ice Concentration, Ice Thickness and Age over water surface under clear-sky conditions for both day and night. **This review is only for IST and concentration.**

- 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.

* Sea ice age and thickness product provisional review will be scheduled in a later time due to need of independent measurements/products available in the winter season.

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%	-3 to 3%
Precision (recommended)		25%	8.5 to 23.5%
Uncertainty	248	25%	10.5 to 24%

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	0.3 to 1.2 K
Uncertainty	372	1 K	0.5 to 1.3 K

Processing Environment and Algorithms

- 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.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 (Validation data from May 1 through 10 October 2023 used in analyses.)
  - Starting orbit number: 2436.

Evaluation of algorithm performance to specification requirements

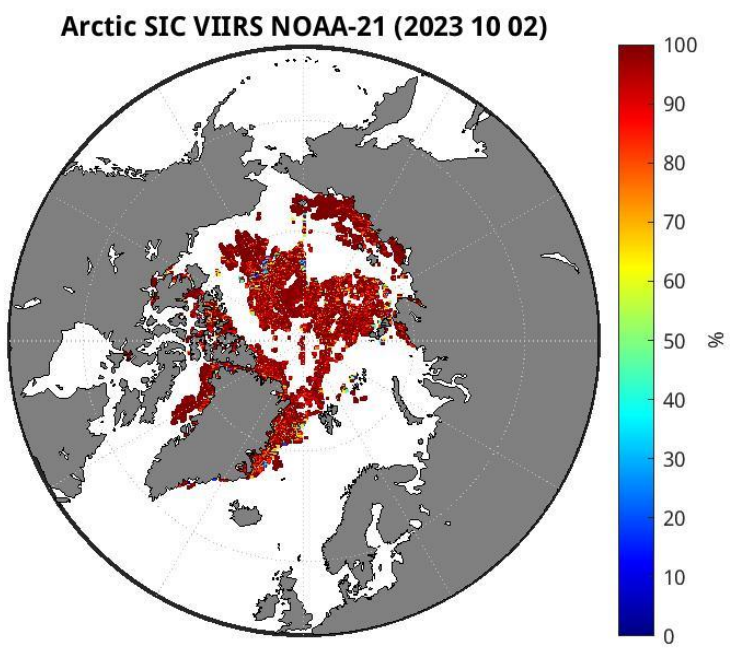
- Algorithm performance evaluation

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

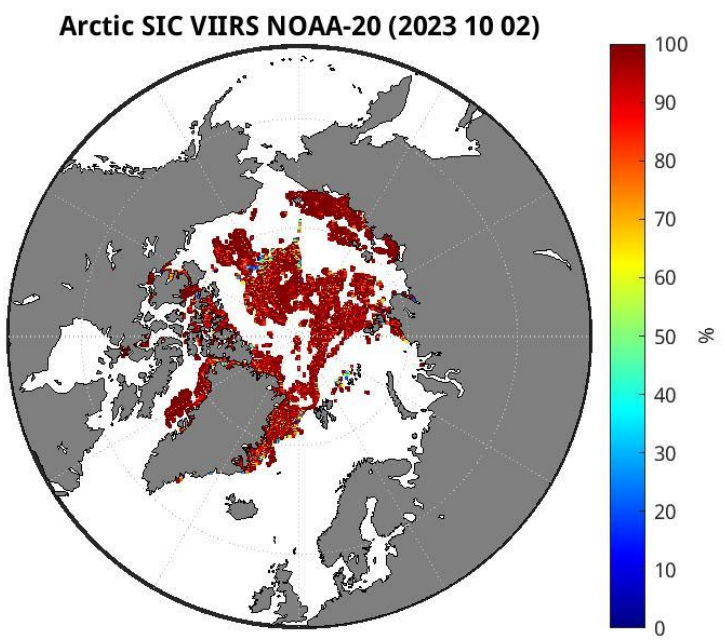
- Inter-sensor comparison
  - Compare with S-NPP and NOAA-20: RMSE 8-10% (SIC) and 0.5 to 1.1K (IST).
  - Validation results: meets requirements
- Validation with independent products
  - Validation data sets: passive microwave AMSR2 SIC, 1 May - 10 October, Arctic and Antarctic
  - Case studies with 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

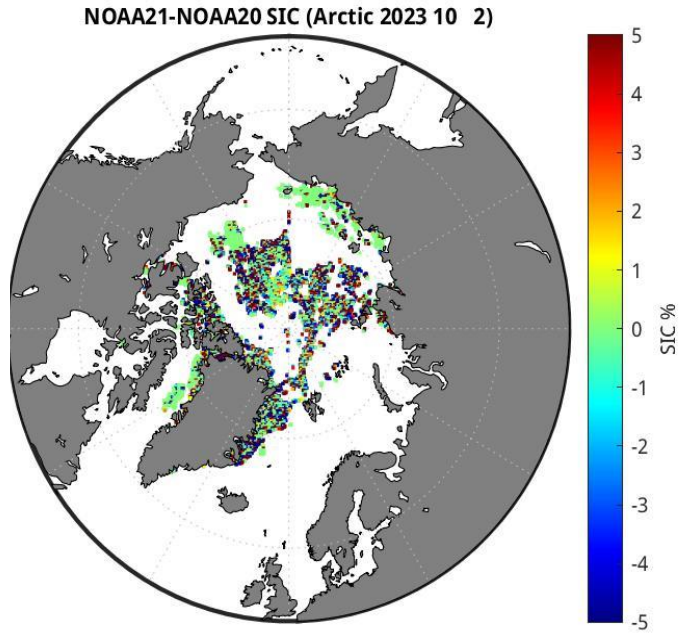
NOAA-21



NOAA-20



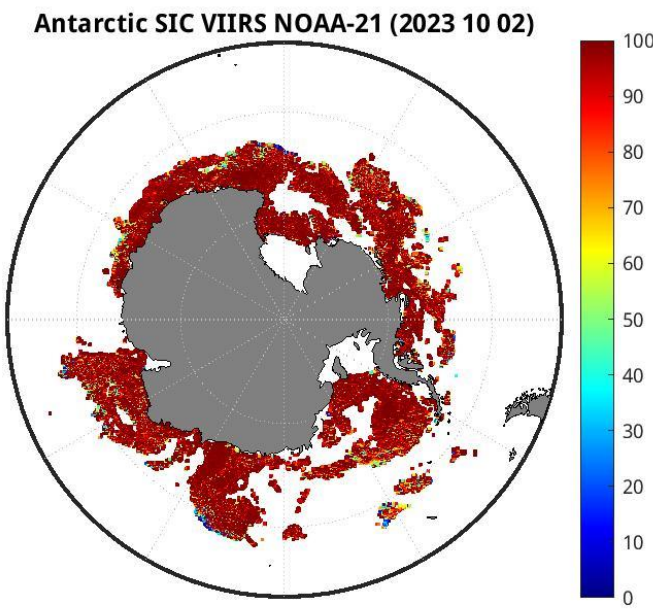
NOAA-21 minus NOAA-20



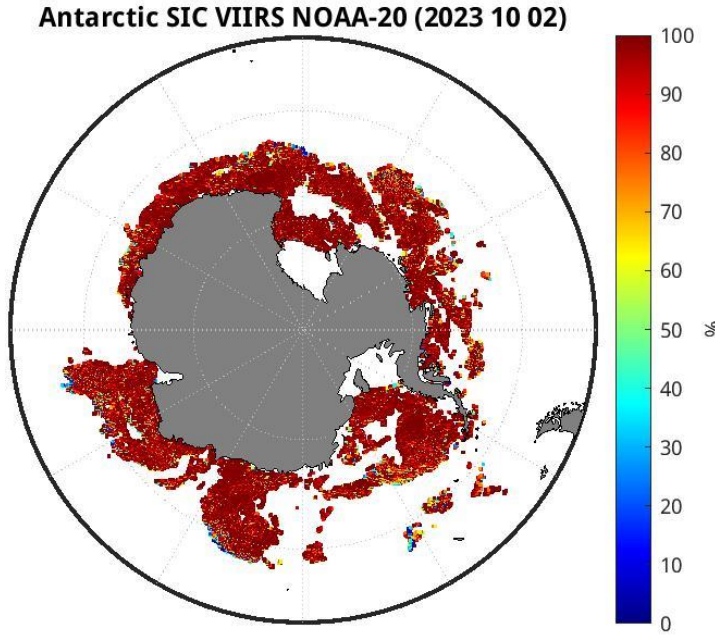
Daily SIC comparison on Oct. 2, 2023

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

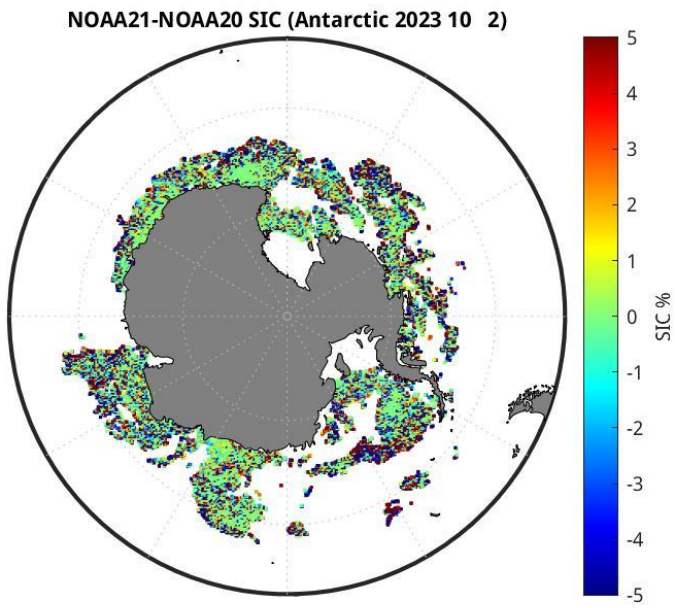
NOAA-21



NOAA-20



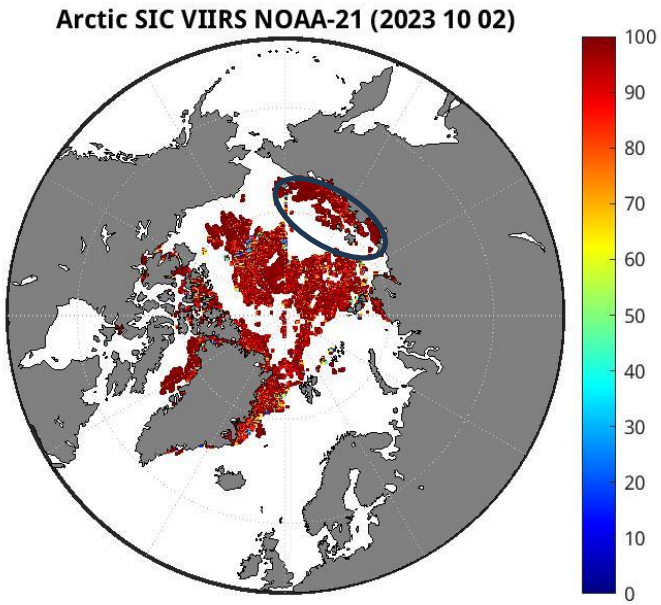
NOAA-21 minus NOAA-20



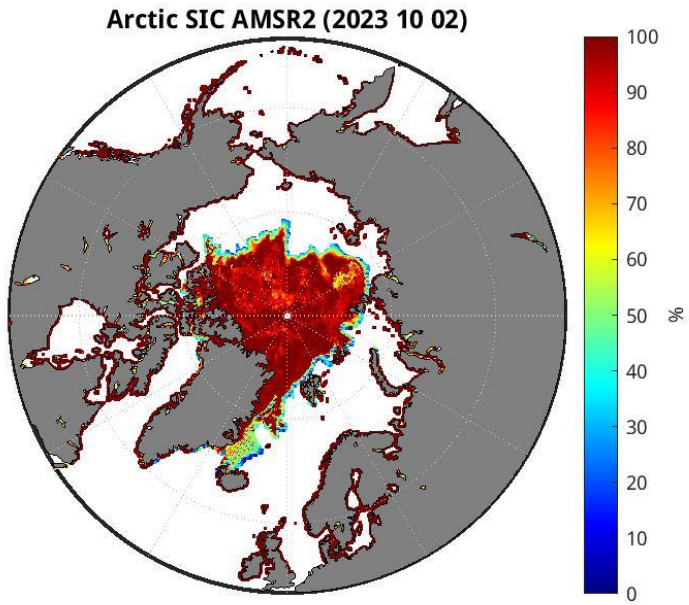
Daily SIC comparison on Oct. 2, 2023

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

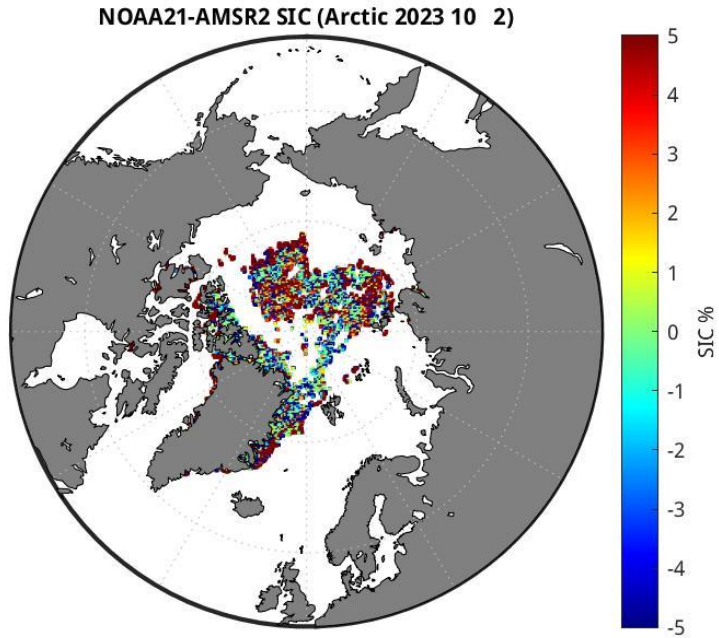
NOAA-21



AMSR2



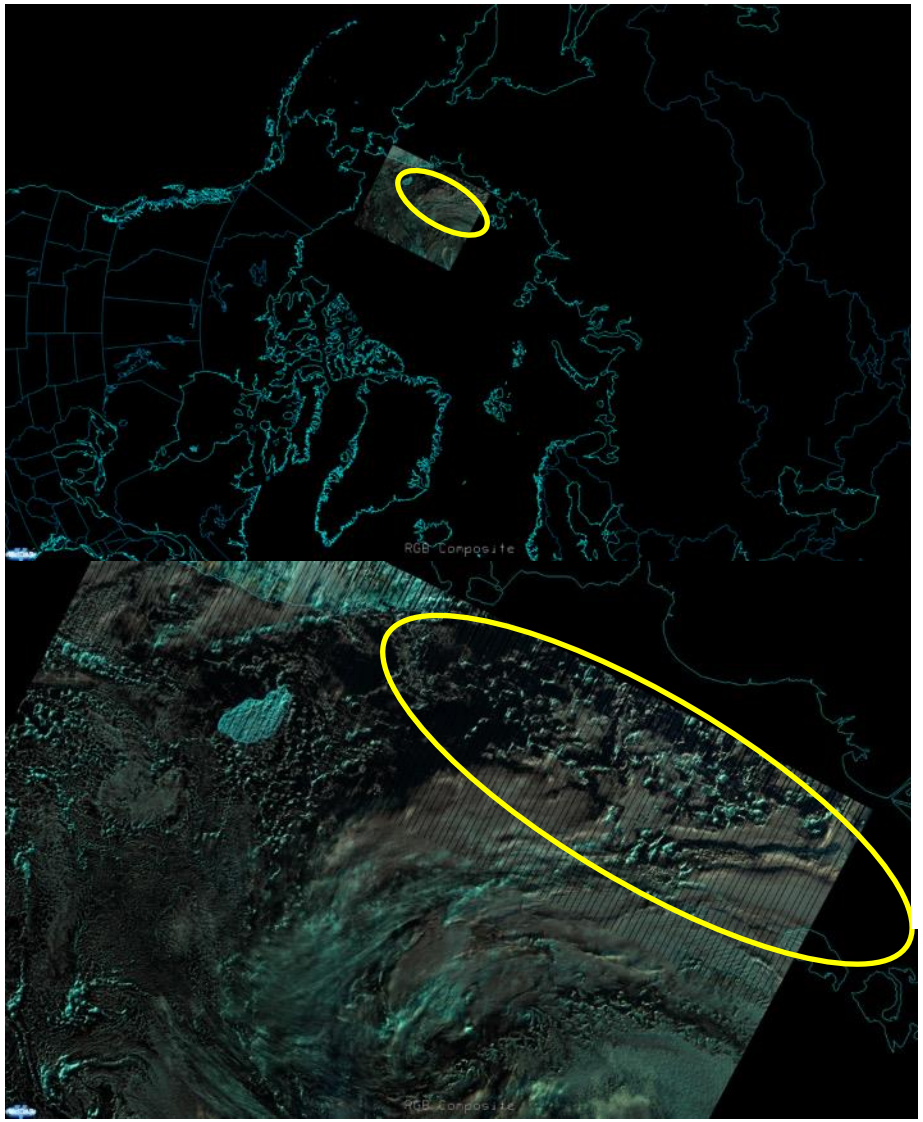
NOAA-21 minus AMSR2



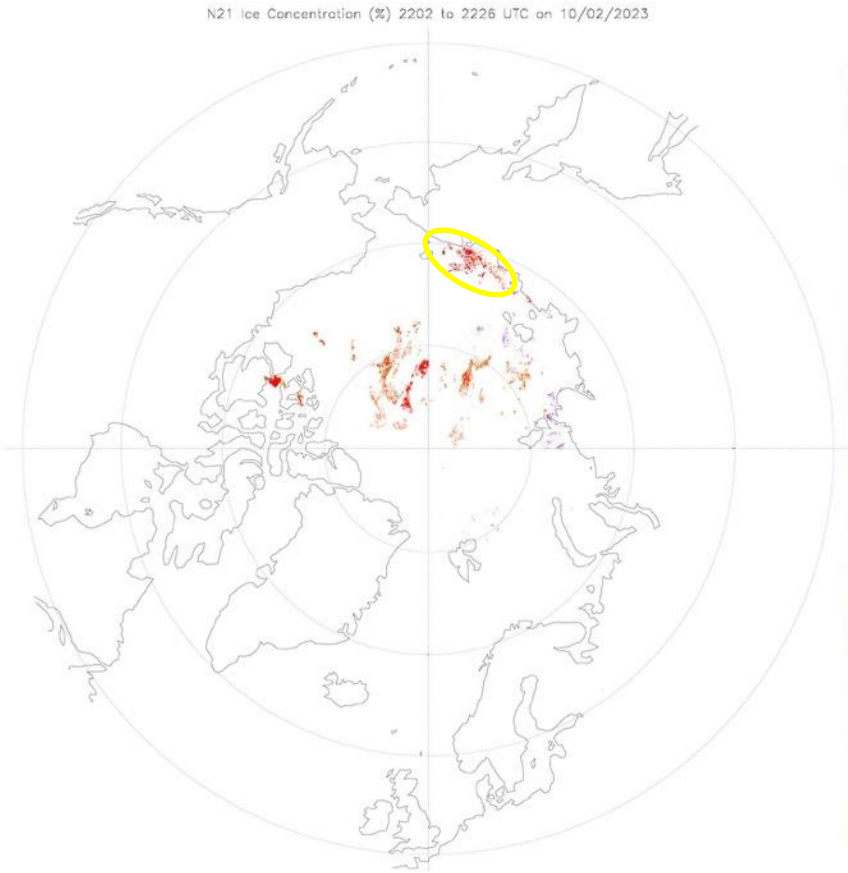
Daily SIC comparison on Oct. 2, 2023

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

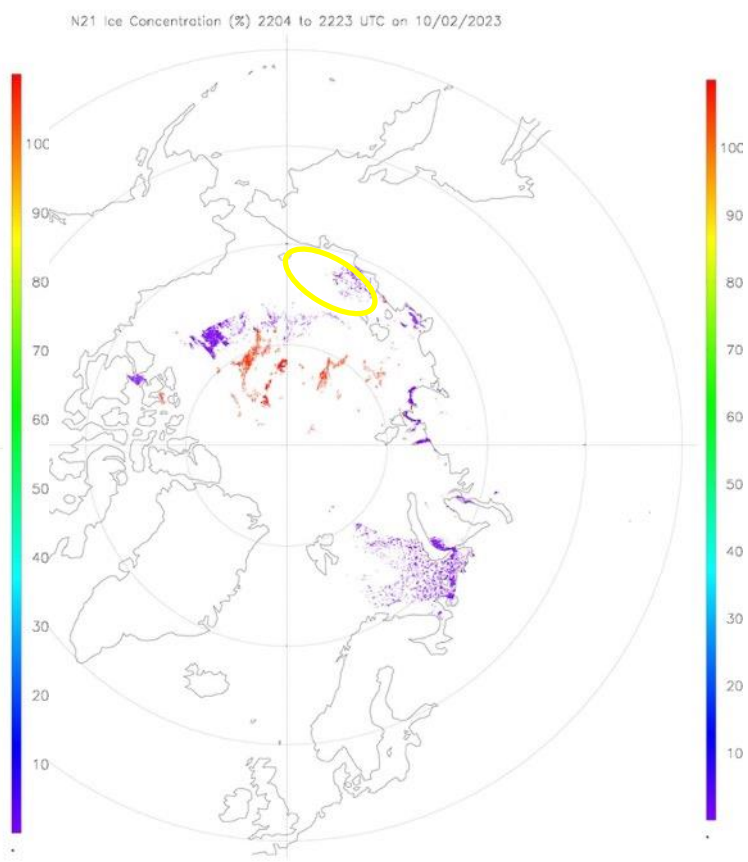
RGB



Operations



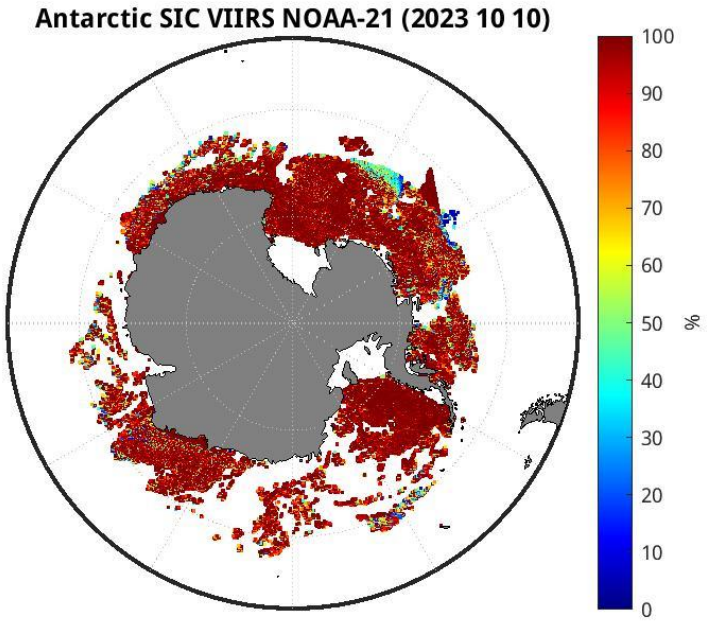
CIMSS



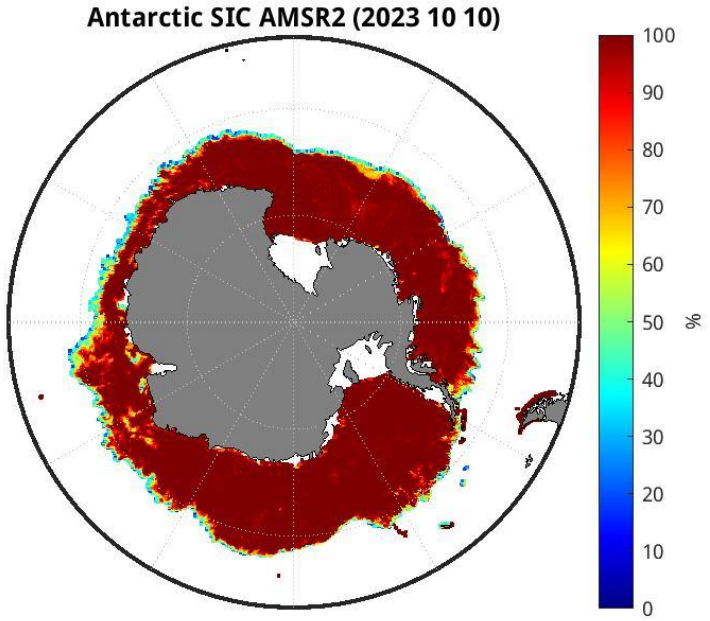
UW-CIMSS uses JRR-CloudMask_v3r2_n21* with Confident Clear setting (Cloud Probability of ≤10%) for solar zenith angles from 80 to 95 degrees. That removes MOST false ice features. ASSISTT should check to make sure that their settings match.

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

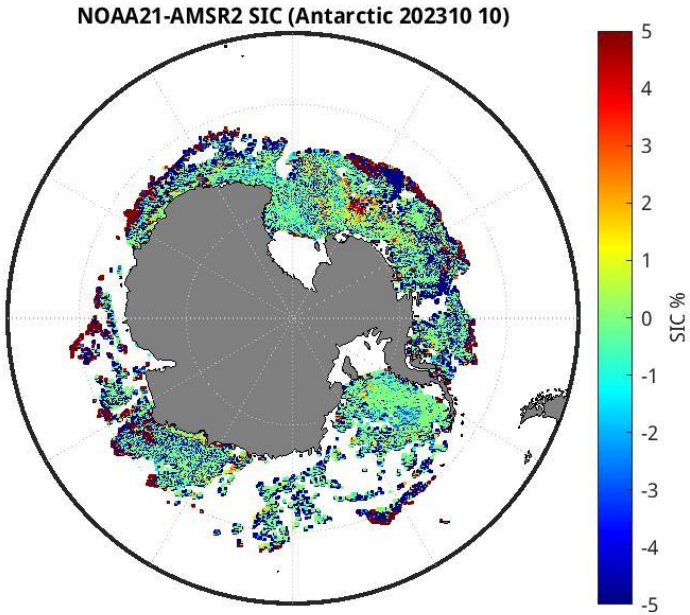
NOAA-21



AMSR2

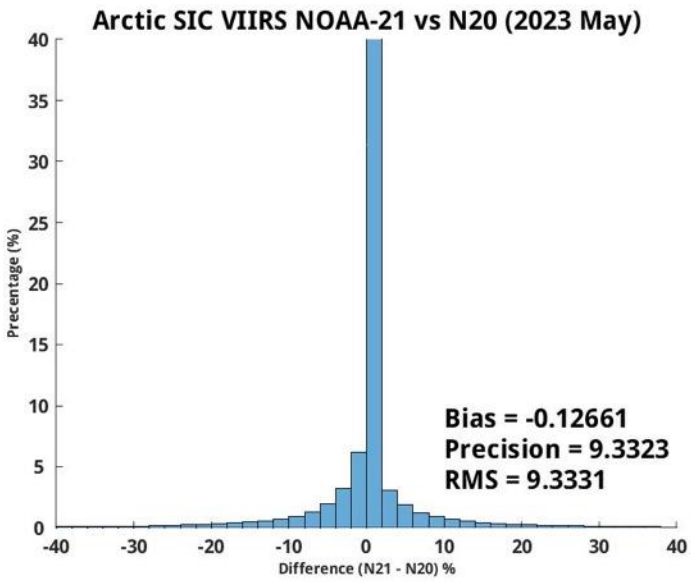


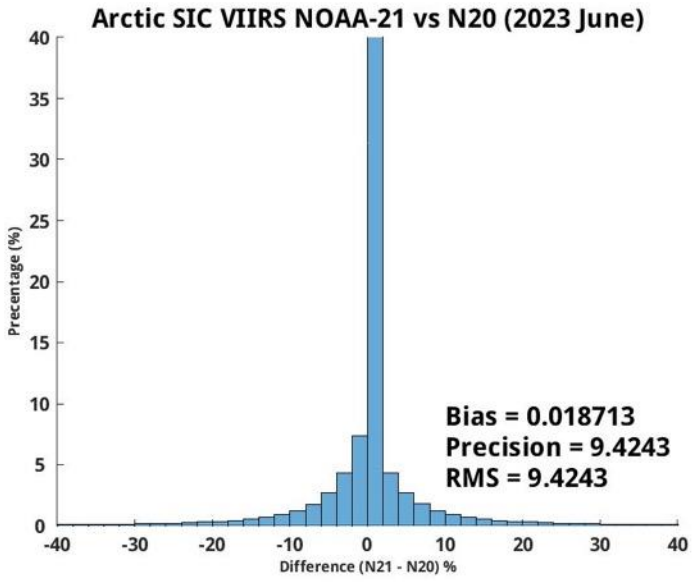
NOAA-21 minus AMSR2

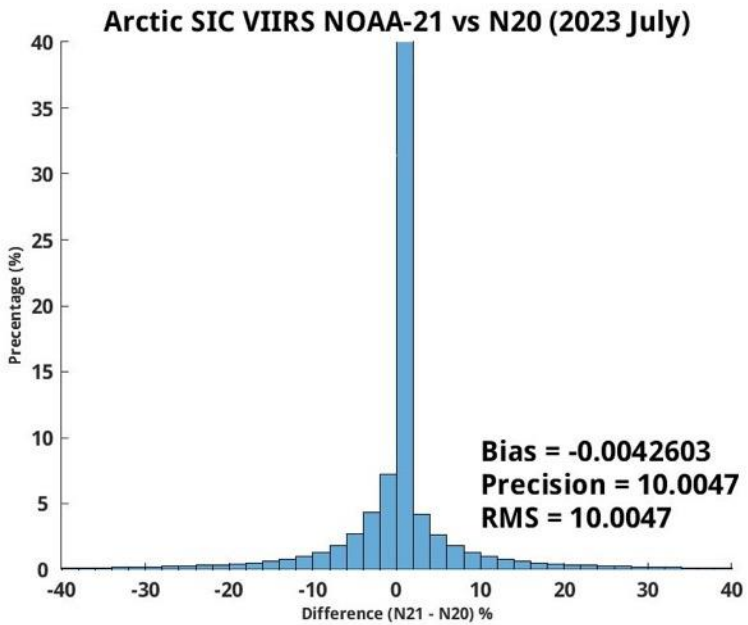


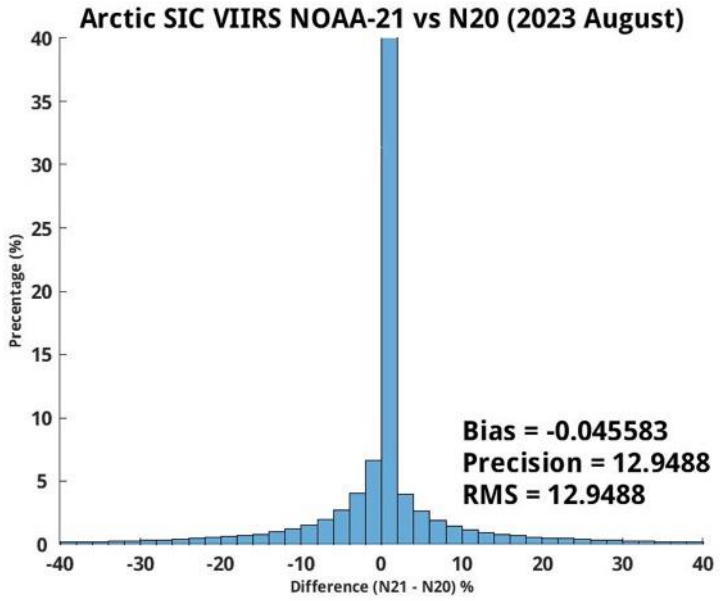
Daily SIC comparison on Oct. 10, 2023

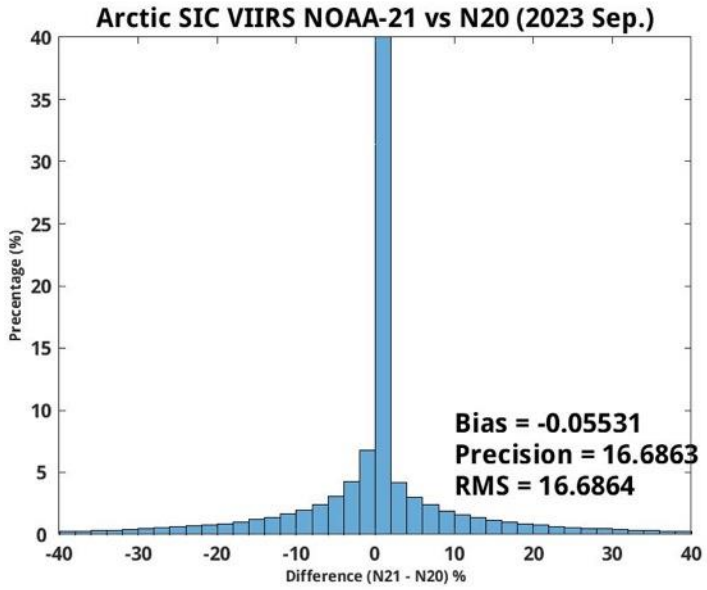
Sea Ice Concentration: NOAA-21 **vs.** NOAA-20, **Arctic**





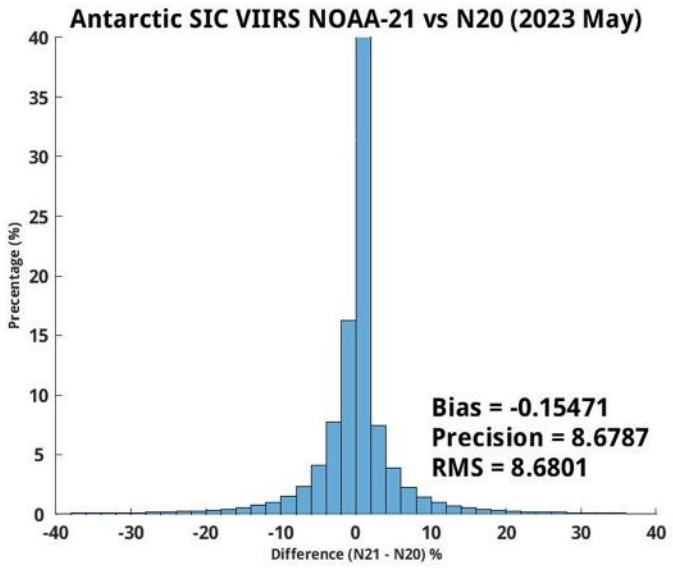


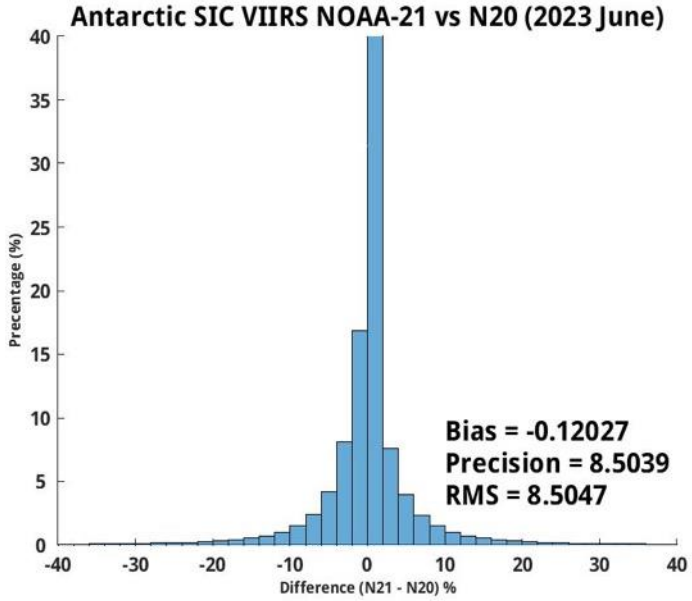


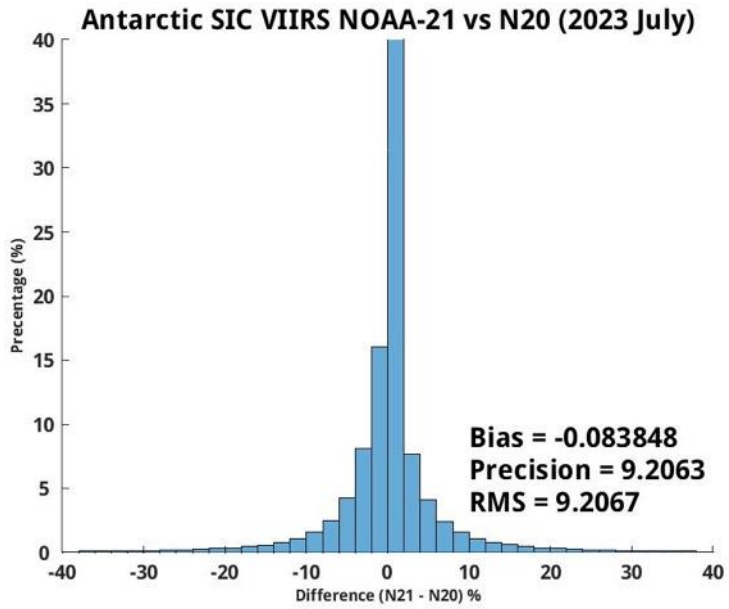


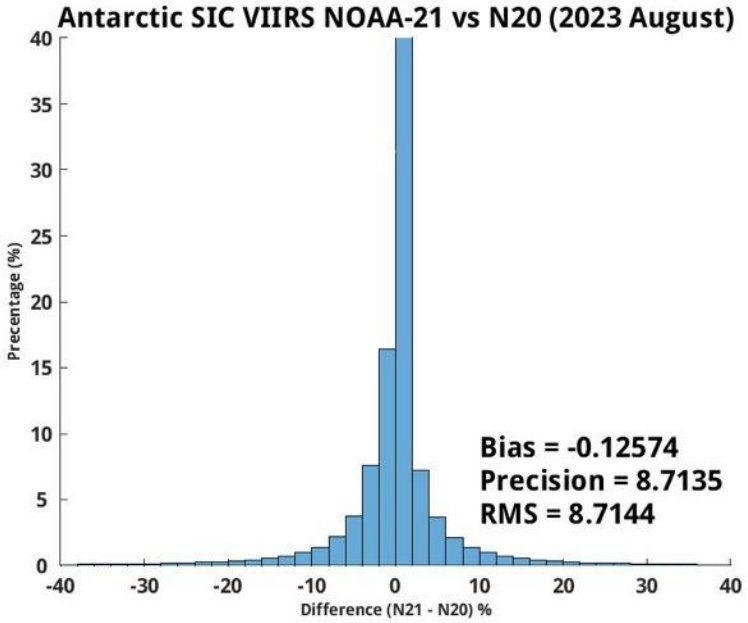
Histogram by month, from May to September 2023

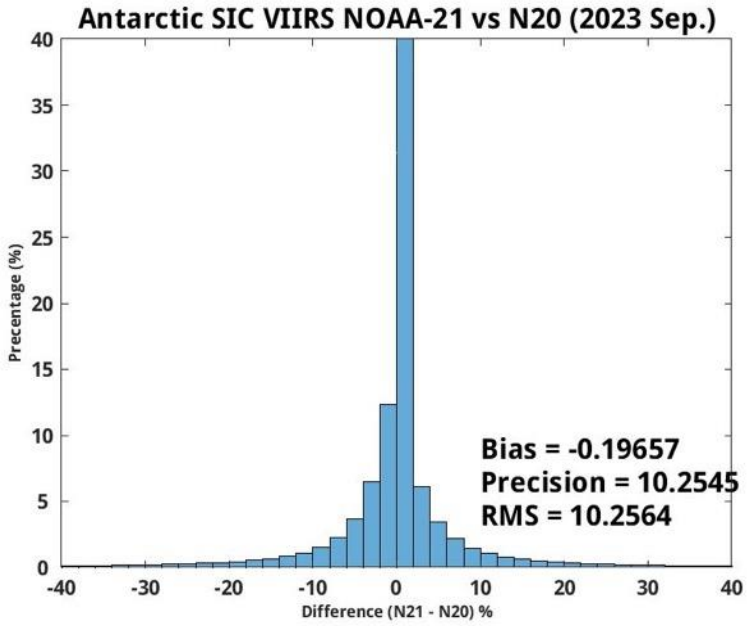
Sea Ice Concentration: NOAA-21 **vs.** NOAA-20, **Antarctic**





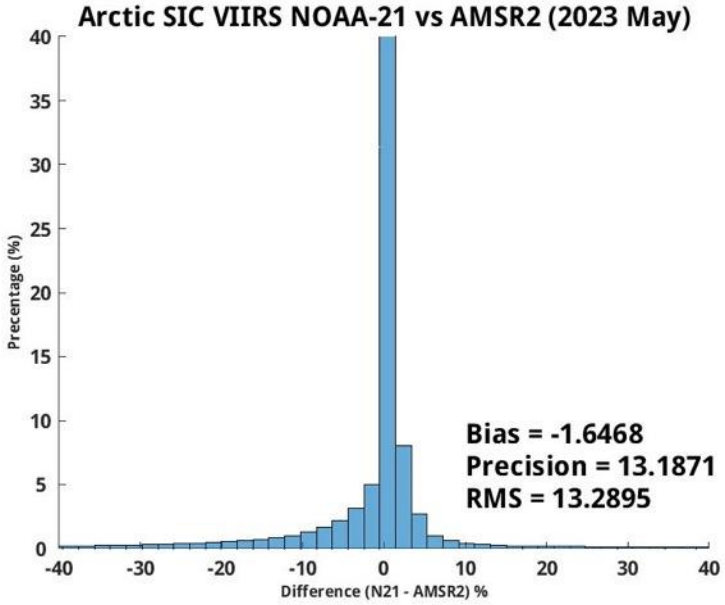


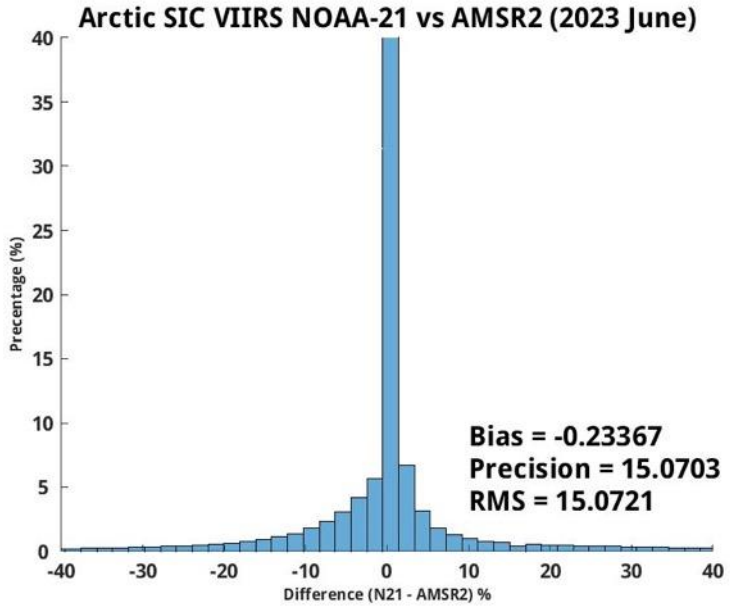


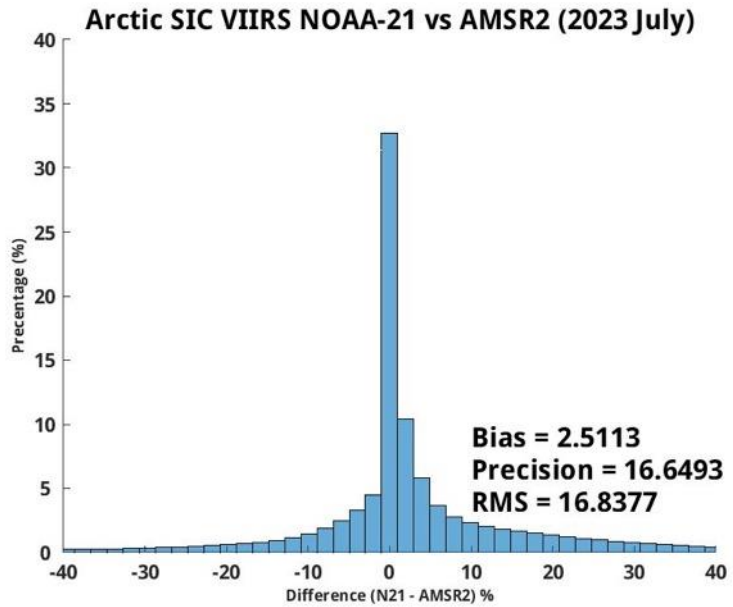


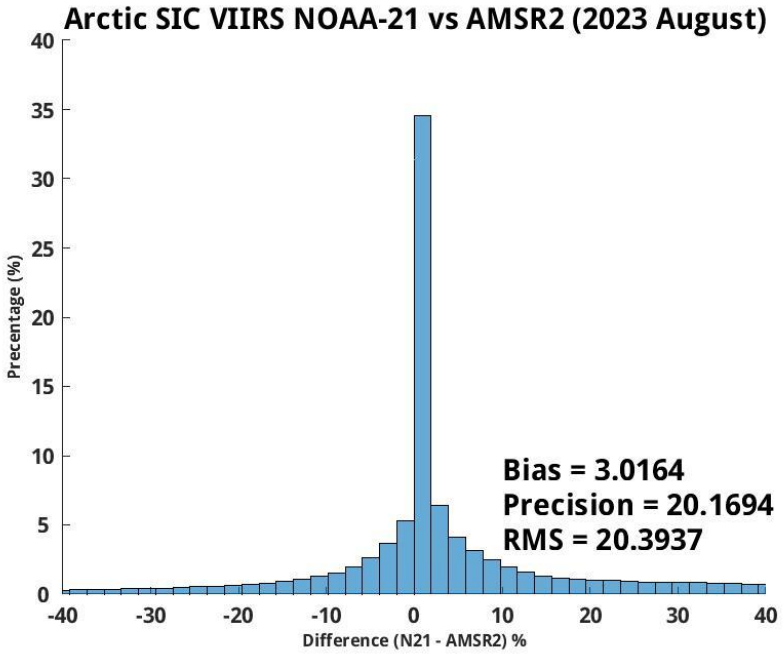
Histogram by month, from May to September 2023

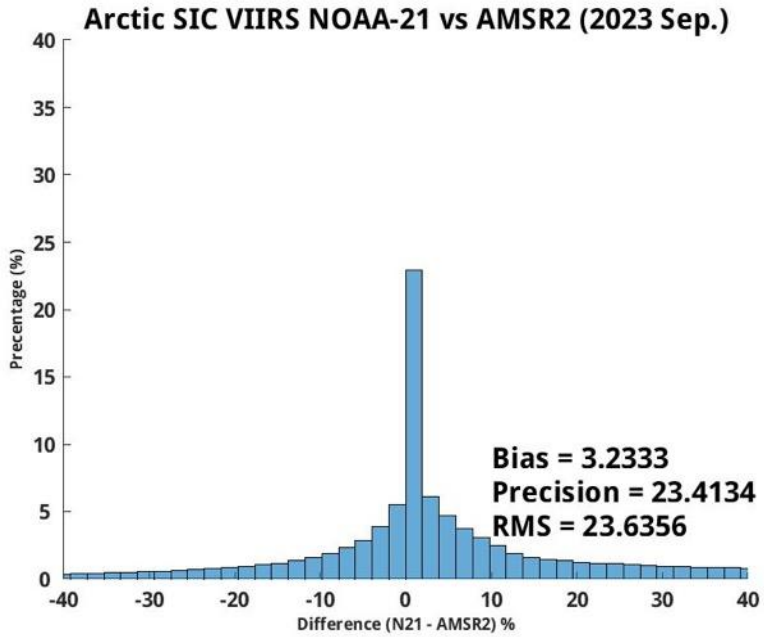
Sea Ice Concentration: NOAA-21 **vs. AMSR2**, **Arctic**





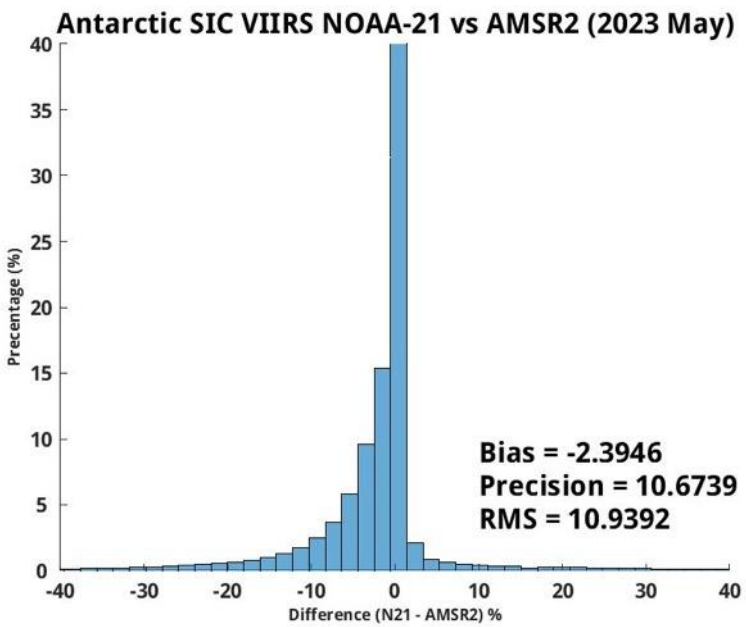


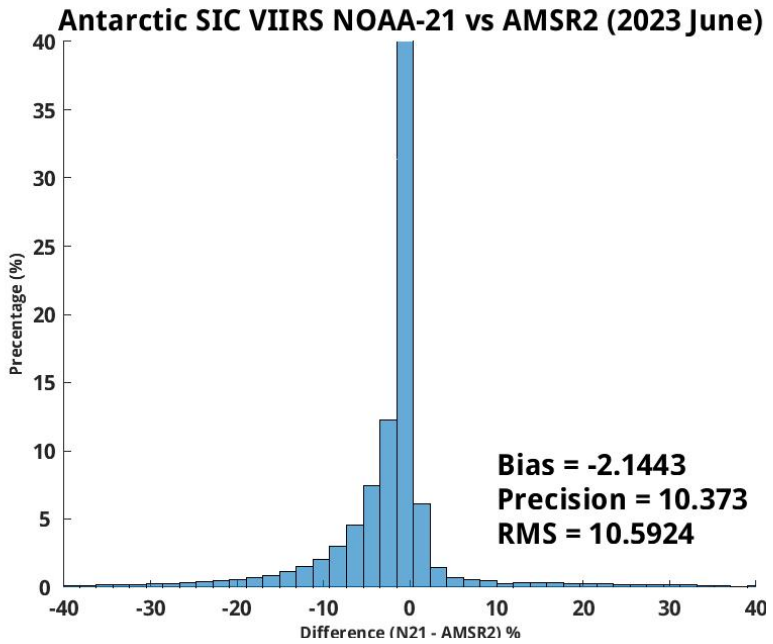


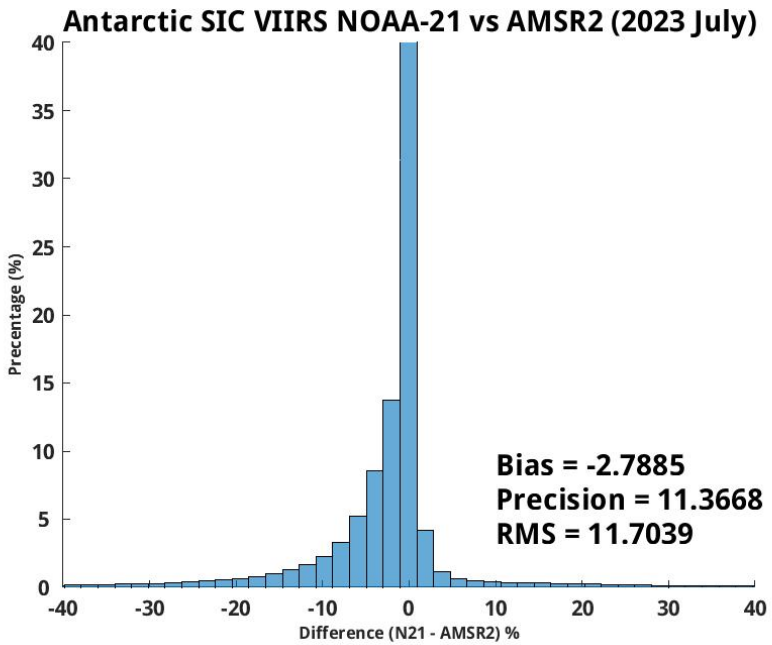


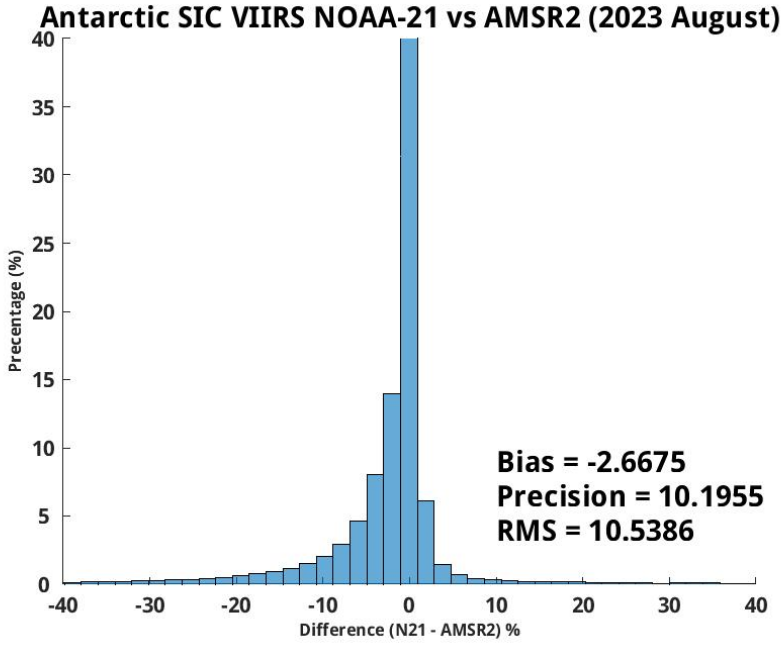
Histogram by month, from May to September 2023

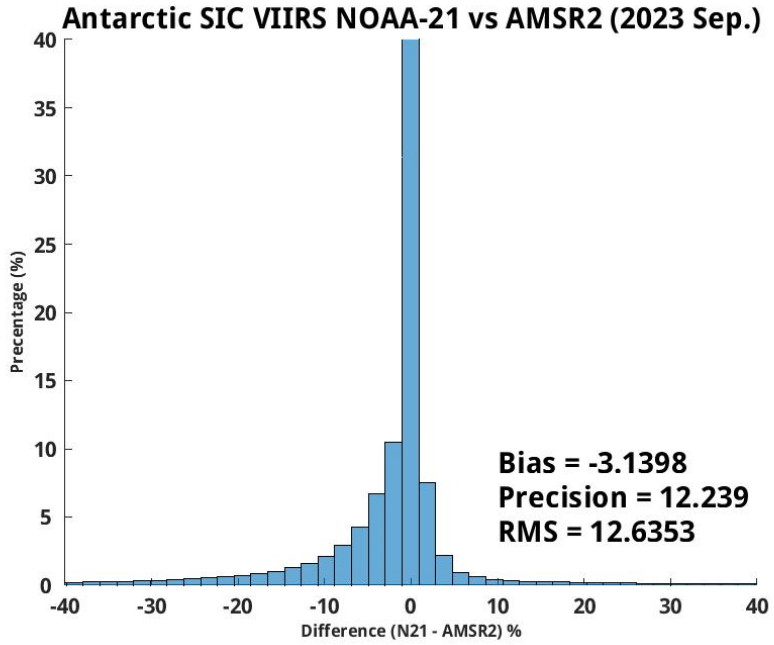
Sea Ice Concentration: NOAA-21 **vs. AMSR2**, **Antarctic**





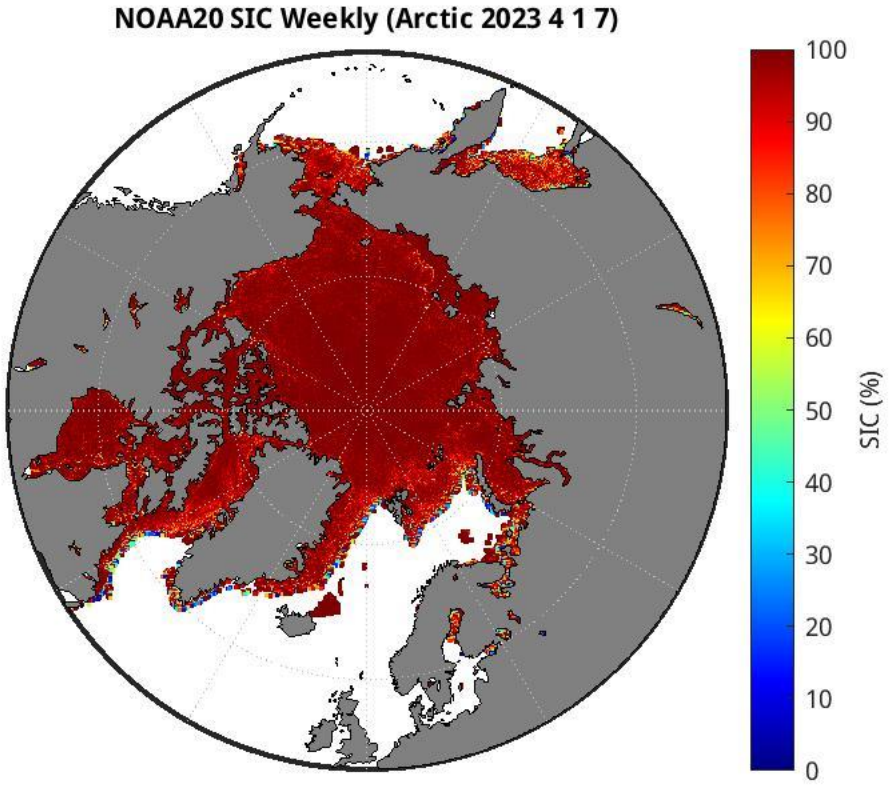


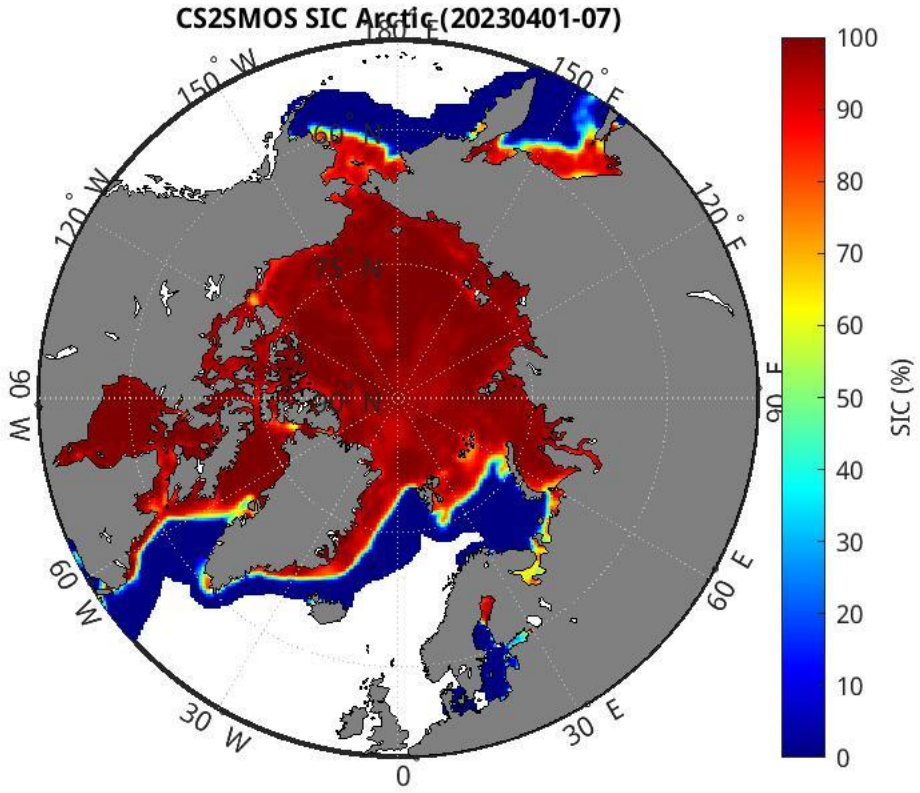




Histogram by month, from May to September 2023

Sea Ice Concentration: NOAA-20 vs. CryoSat-2/SMOS* Arctic



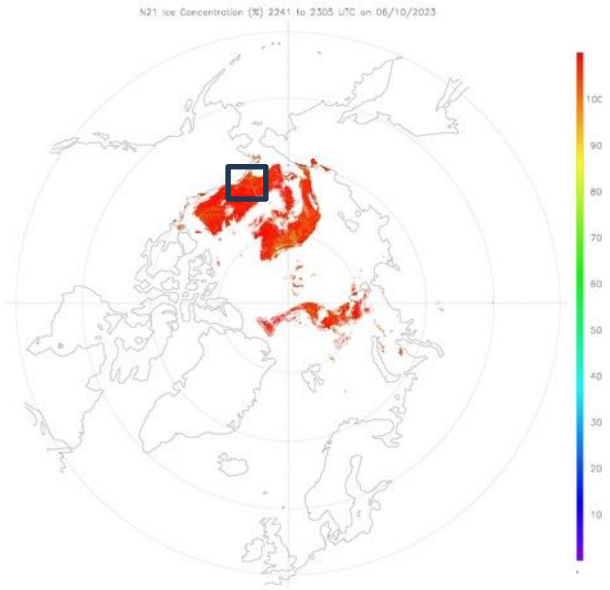


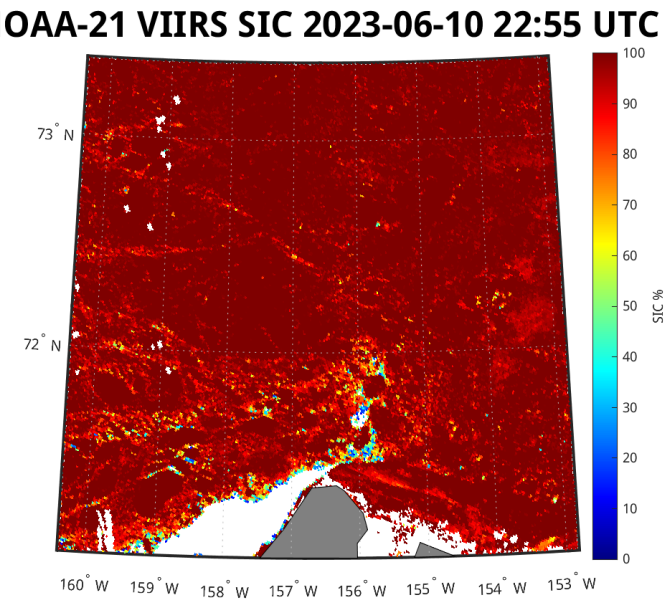
Weekly averaged SIC April 1-7, 2023

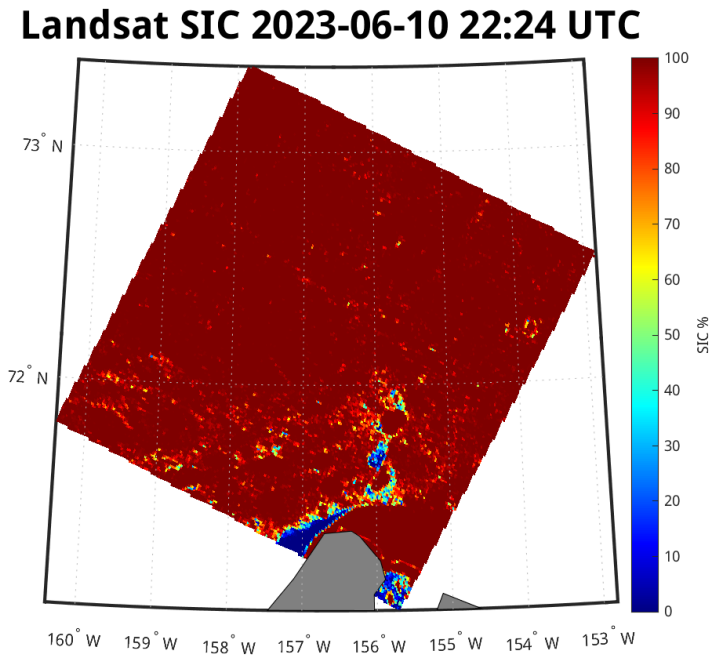
Validation source for Upcomming Arctic Winter.

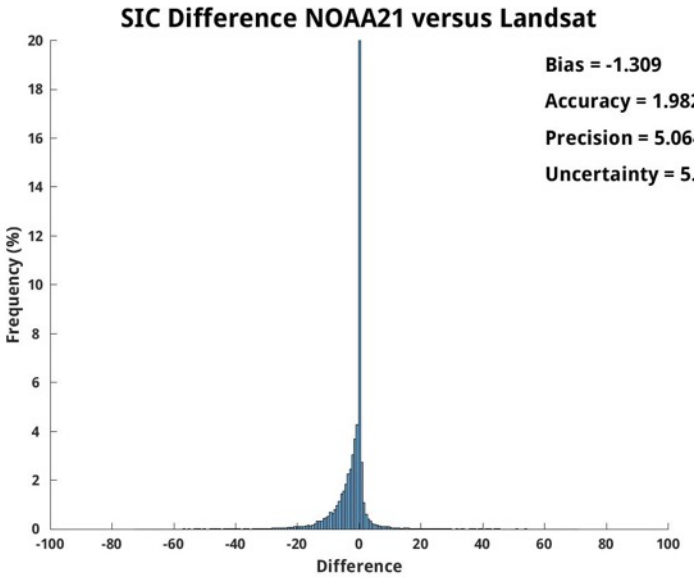
*SMOS is ESA's Soil Moisture and Ocean Salinity satellite with an L-band microwave imager. CryoSat-2 carries a radar altimeter.

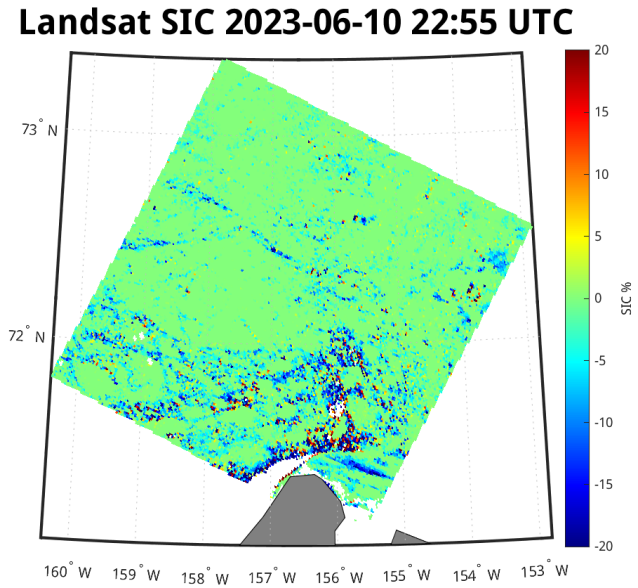
Sea Ice Concentration: NOAA-21 vs. Landsat, Arctic 2023-06-10 22-23 UTC

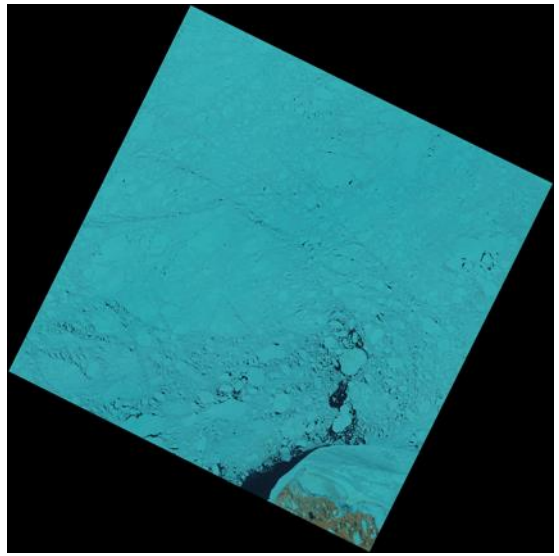




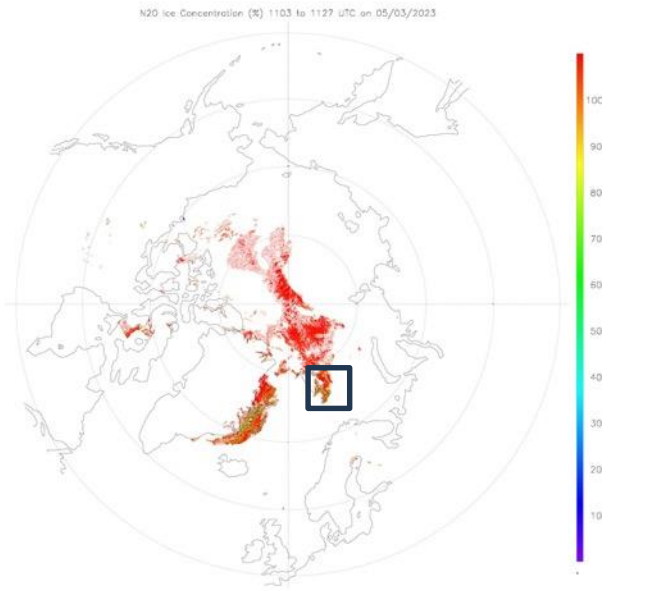


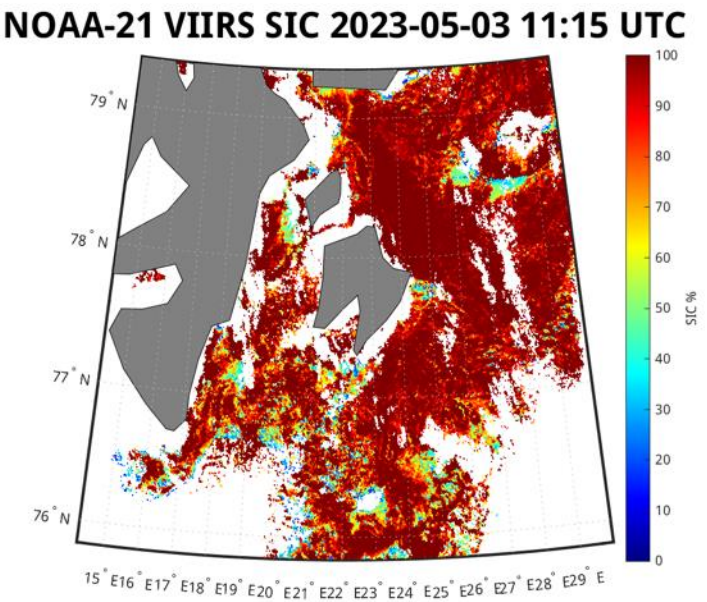


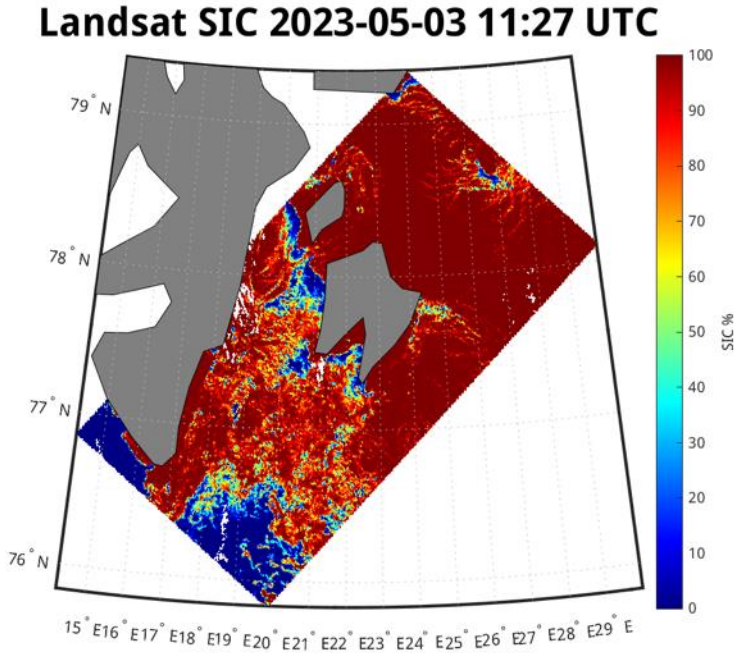


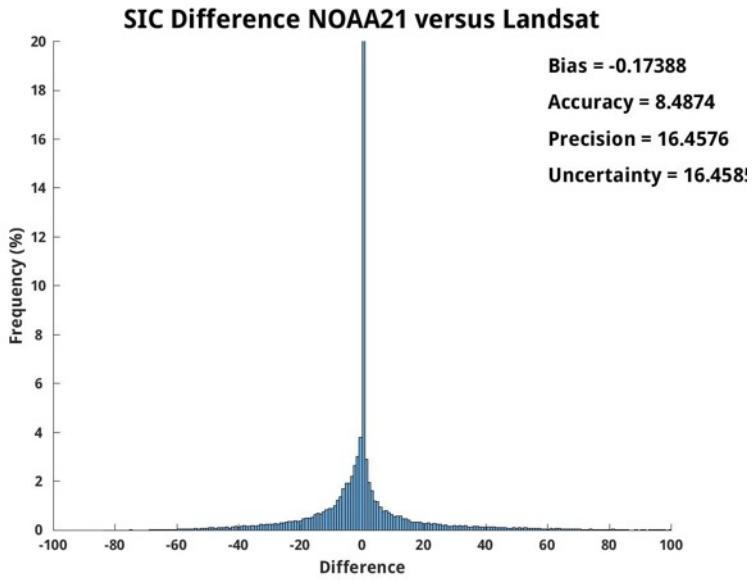


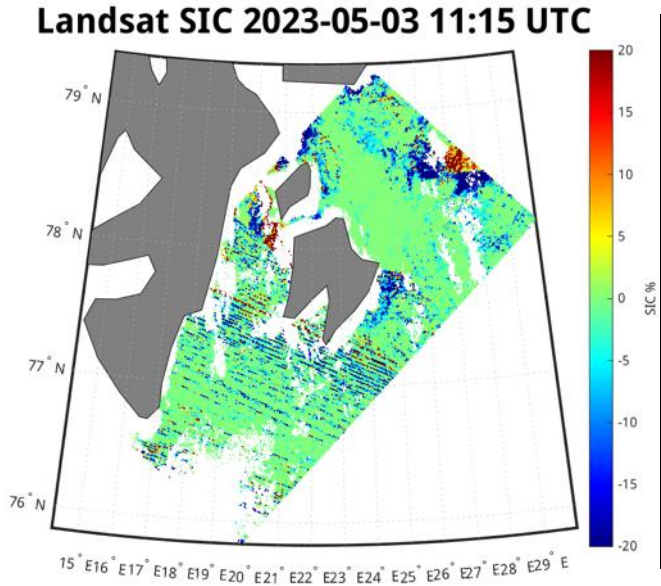
Sea Ice Concentration: NOAA-21 vs. Landsat, Arctic 2023-05-03 11-12 UTC

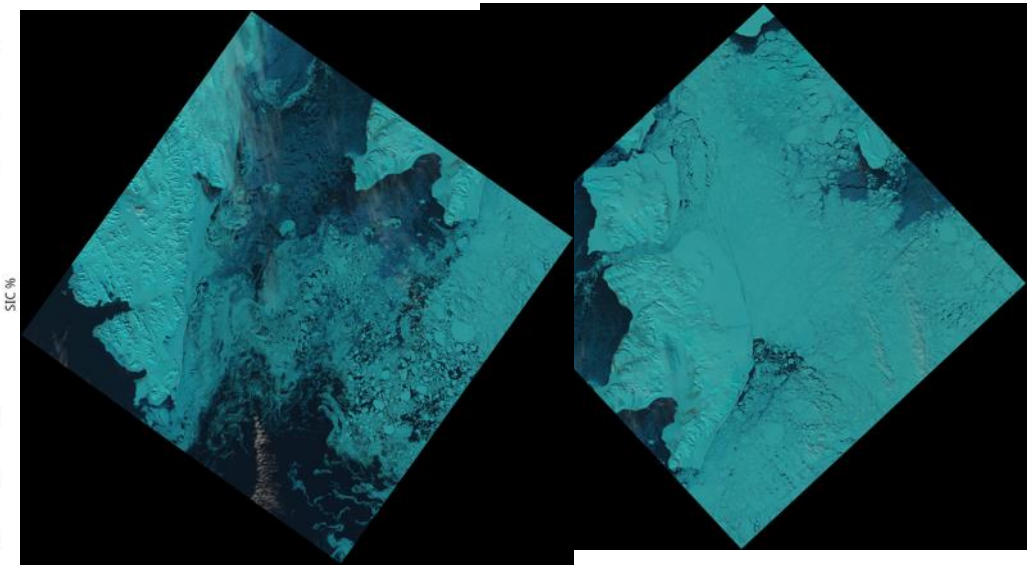




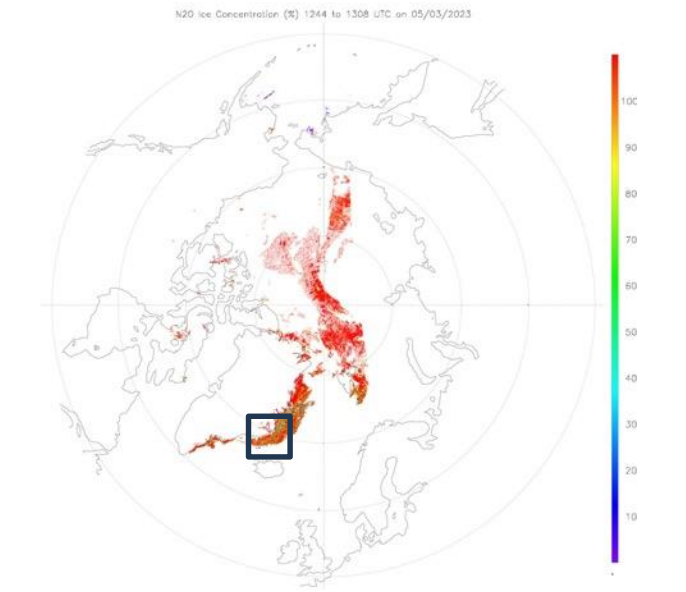


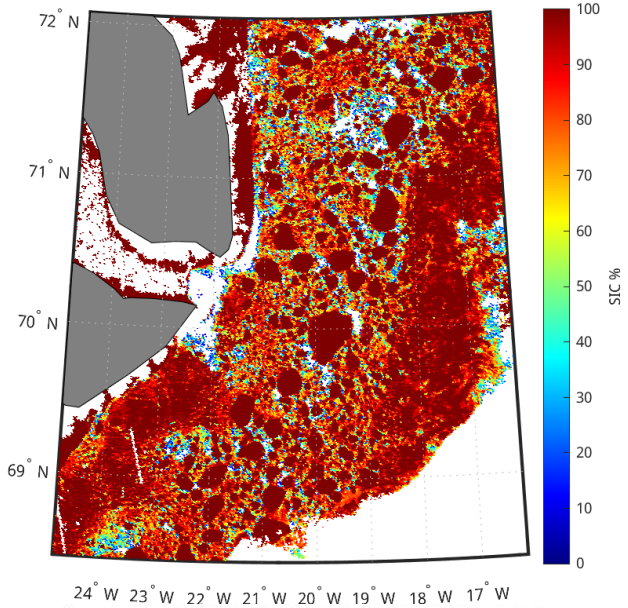


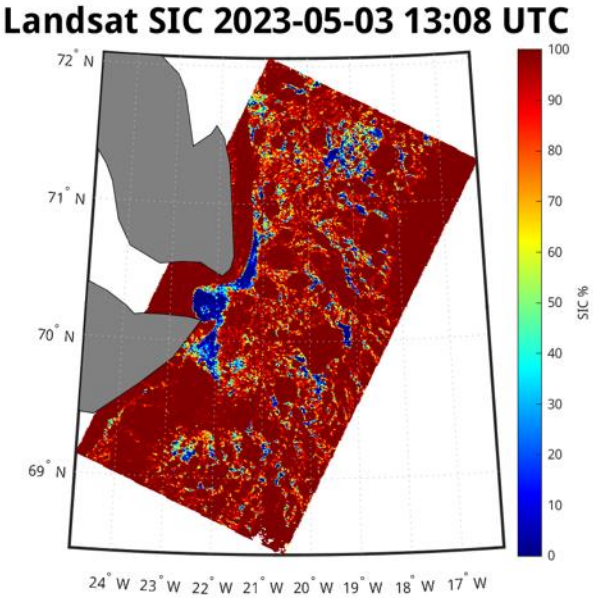


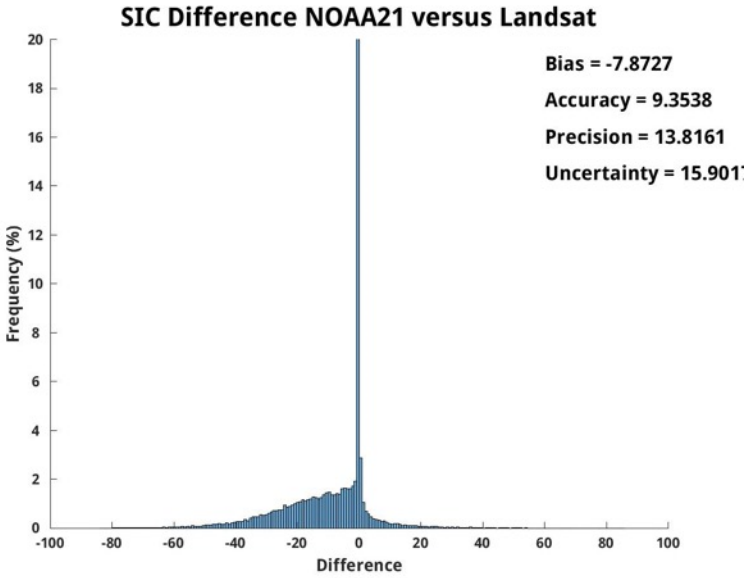


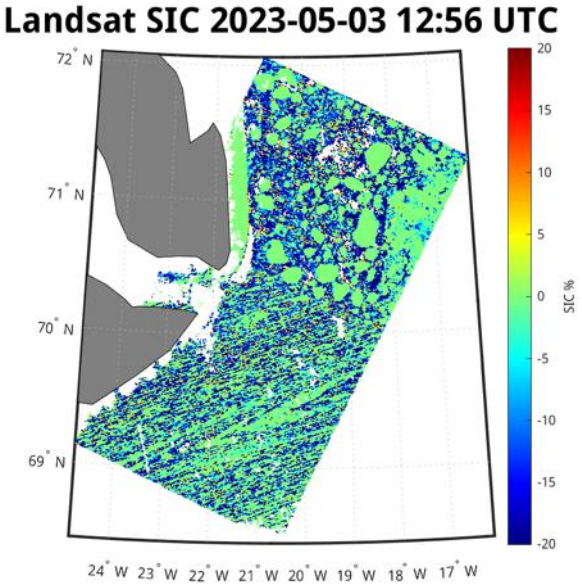
Sea Ice Concentration: NOAA-21 vs. Landsat, Arctic 2023-05-03 13 UTC

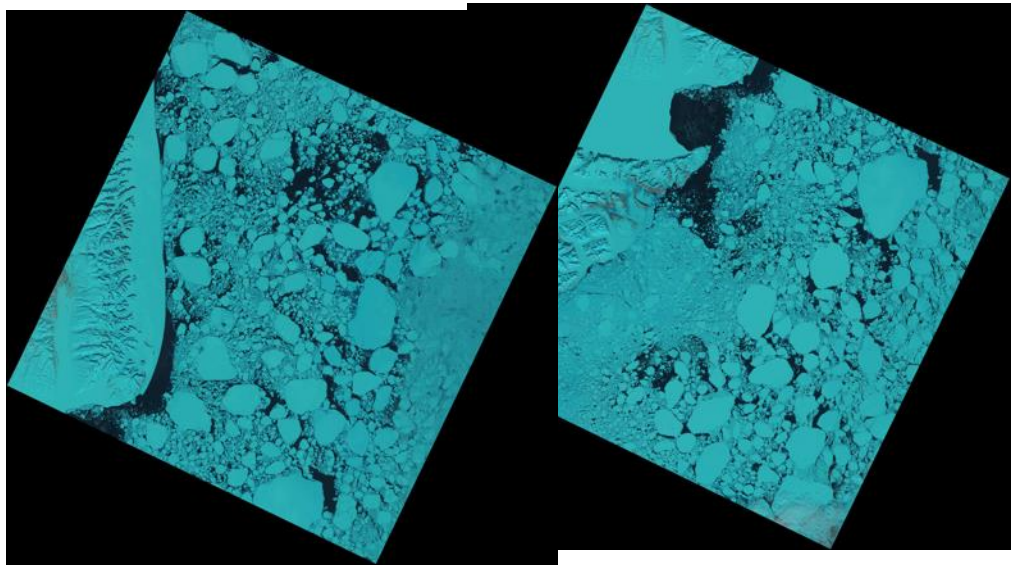




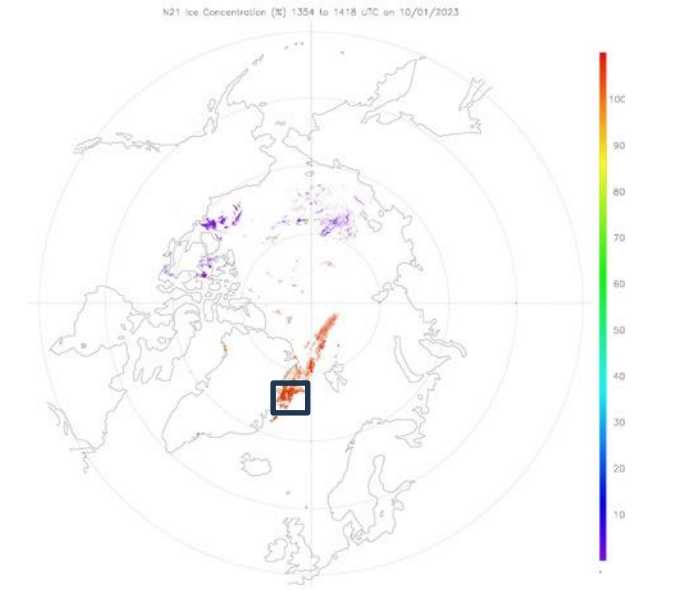


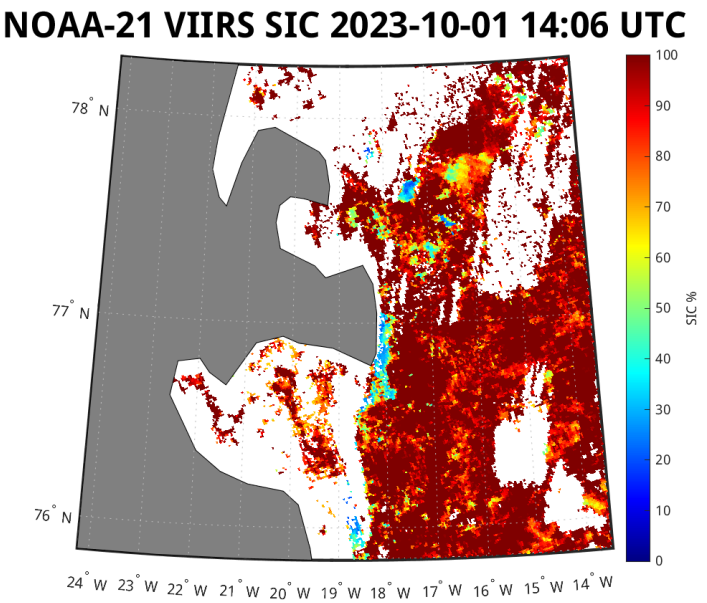


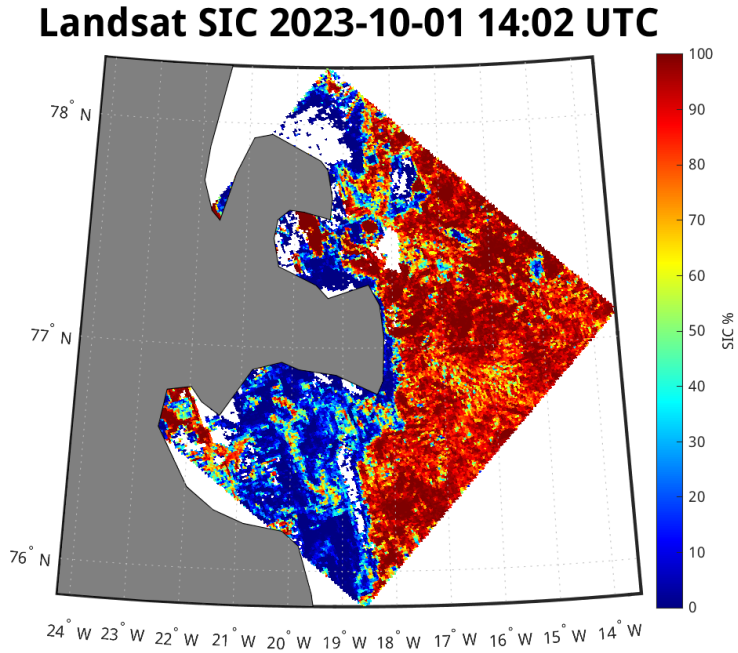


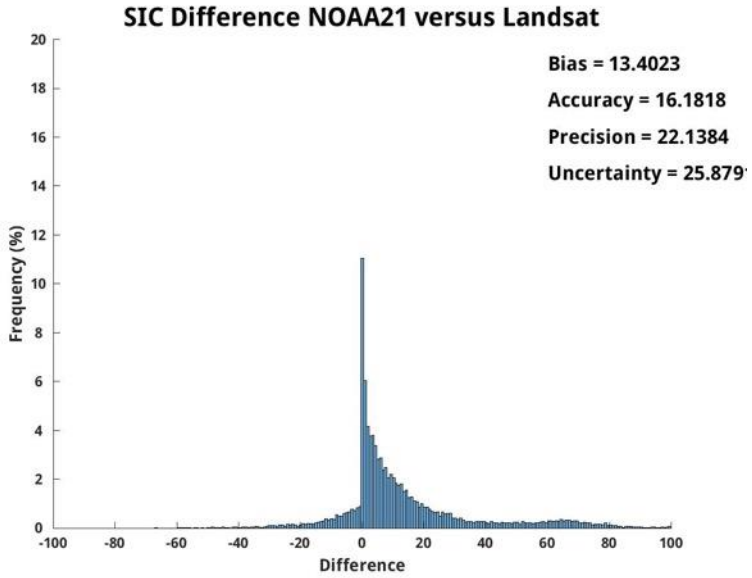


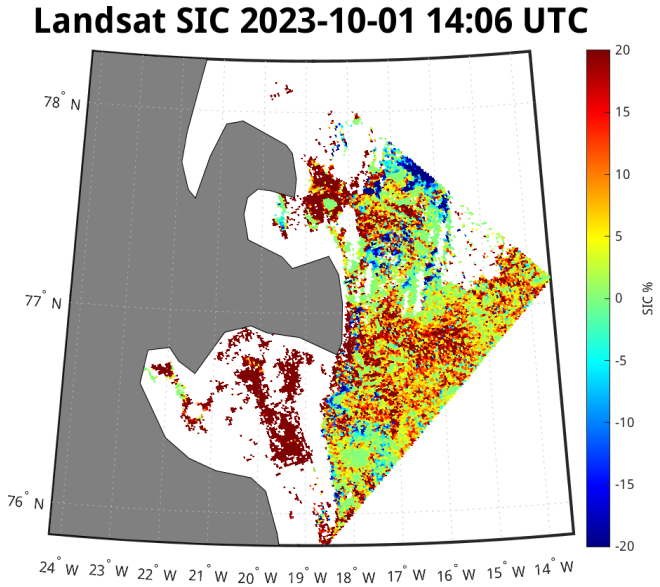
Sea Ice Concentration: NOAA-21 vs. Landsat, Arctic 2023-10-01 14 UTC

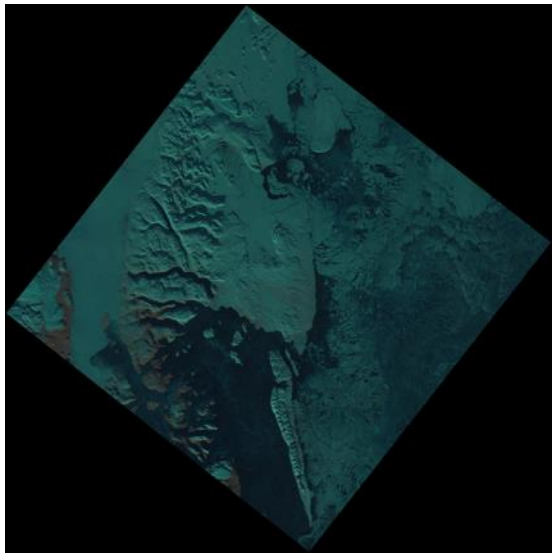






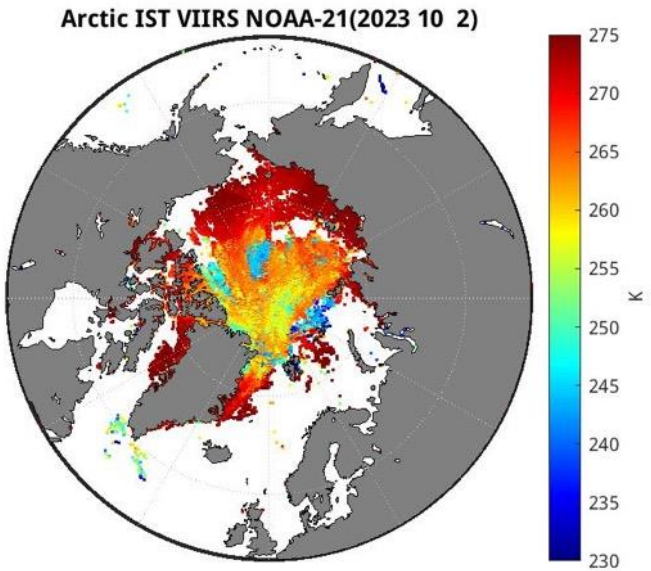




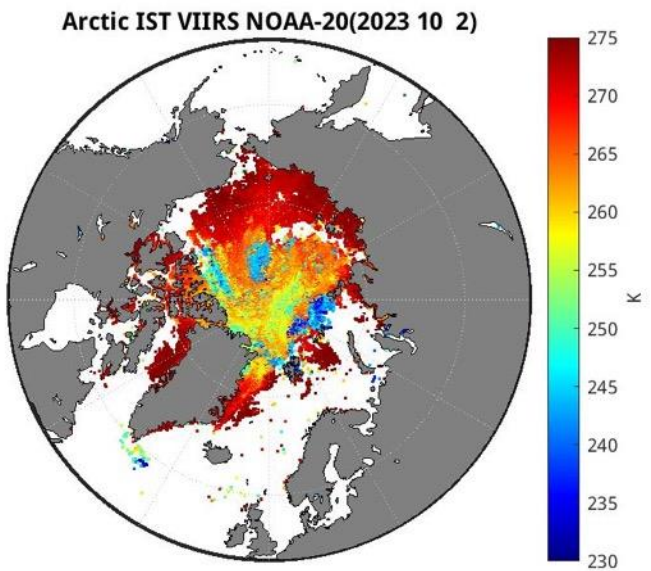


Ice Surface Temperature: NOAA-21 vs. NOAA-20, Arctic

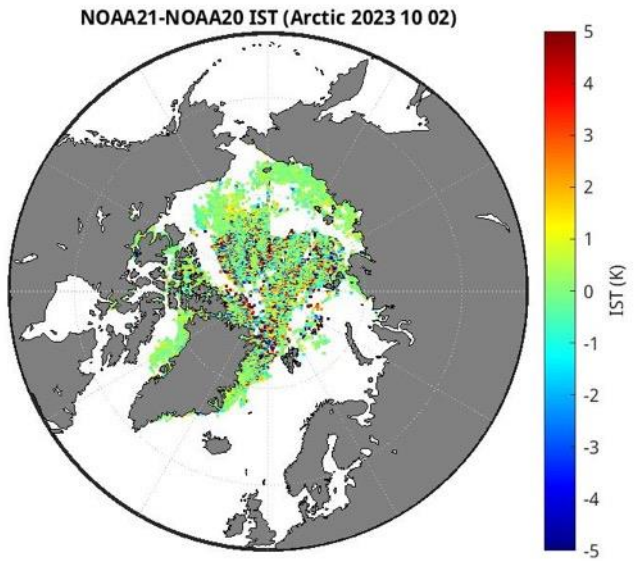
NOAA-21

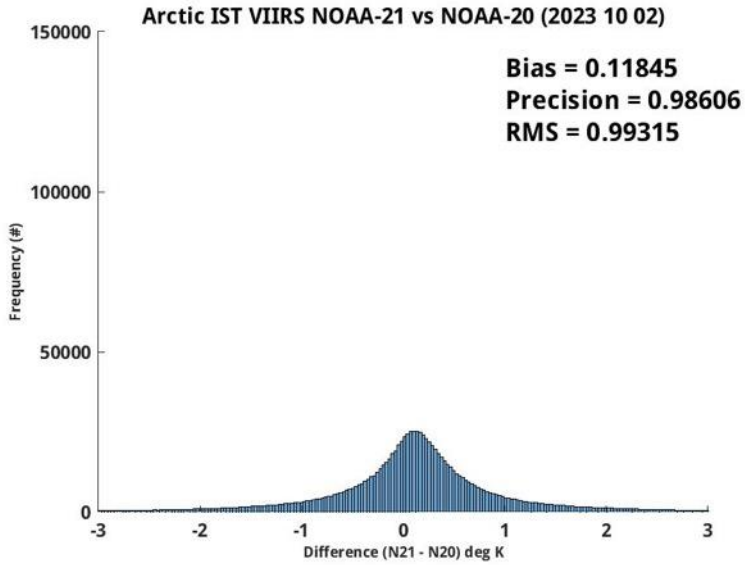


NOAA-20



NOAA-21 minus NOAA-20

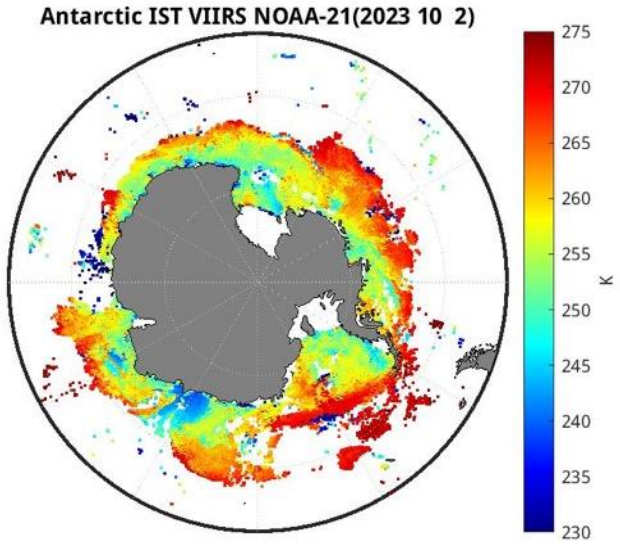




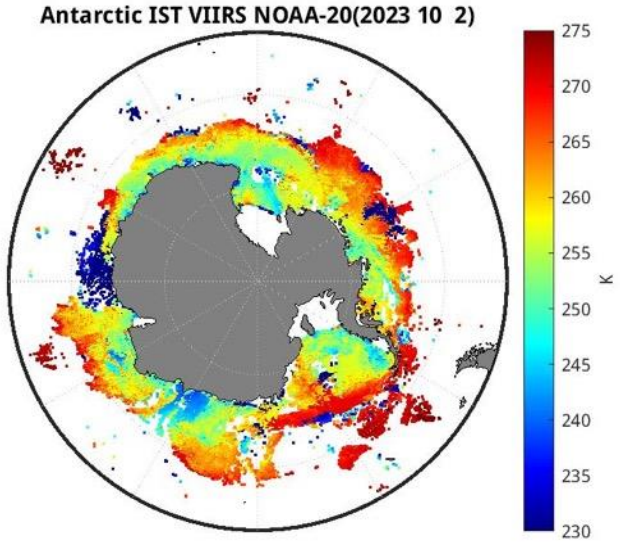
Comparison of October 2, 2023, statistical mean ice surface temperature was done with individual overpasses within one hour.

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

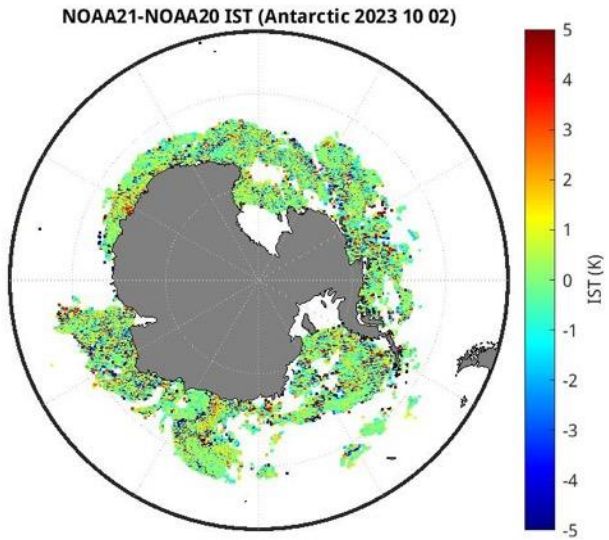
NOAA-21

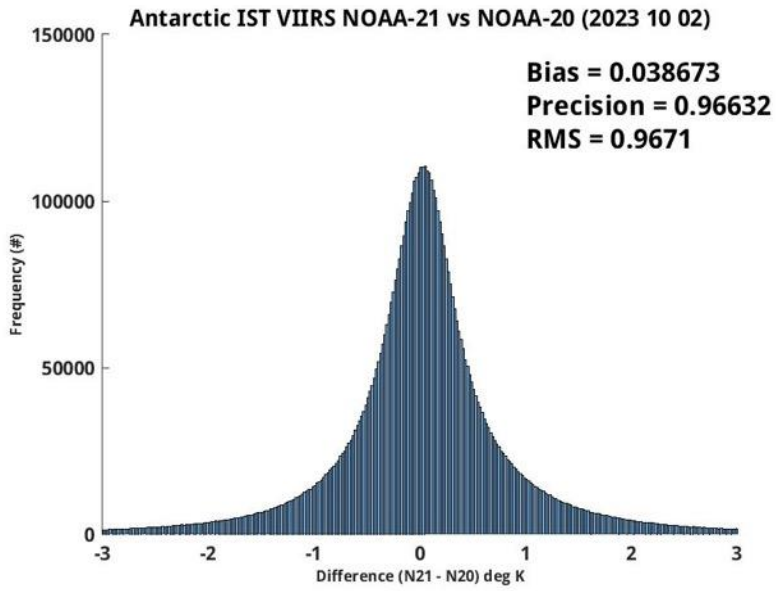


NOAA-20



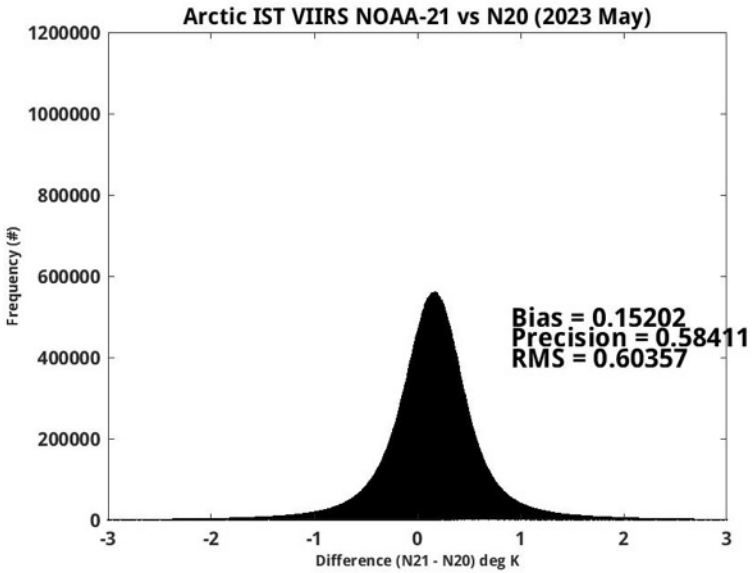
NOAA-21 minus NOAA-20

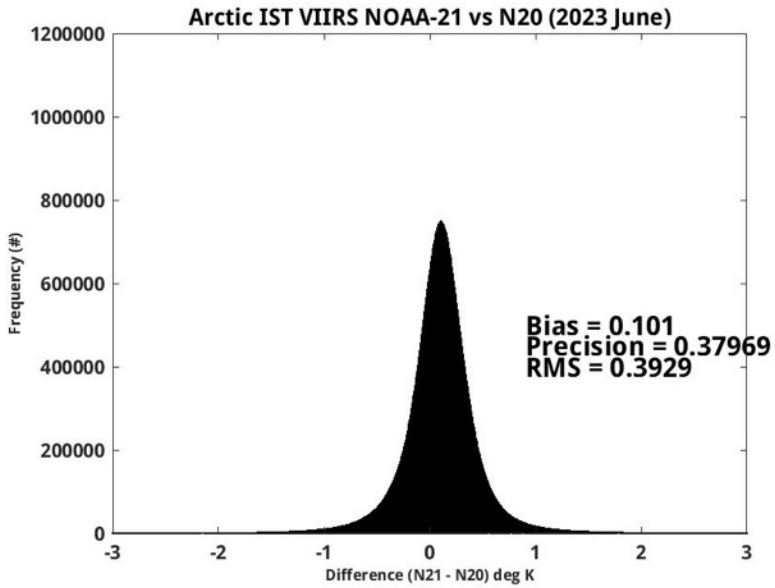


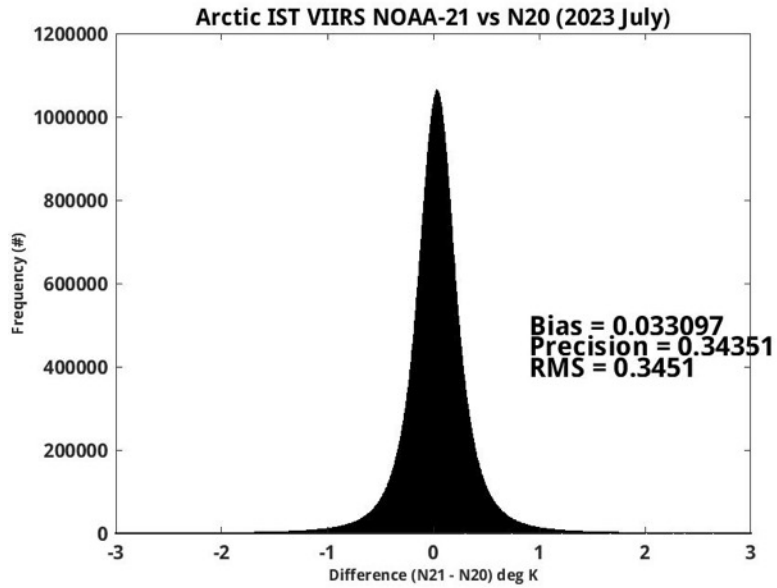


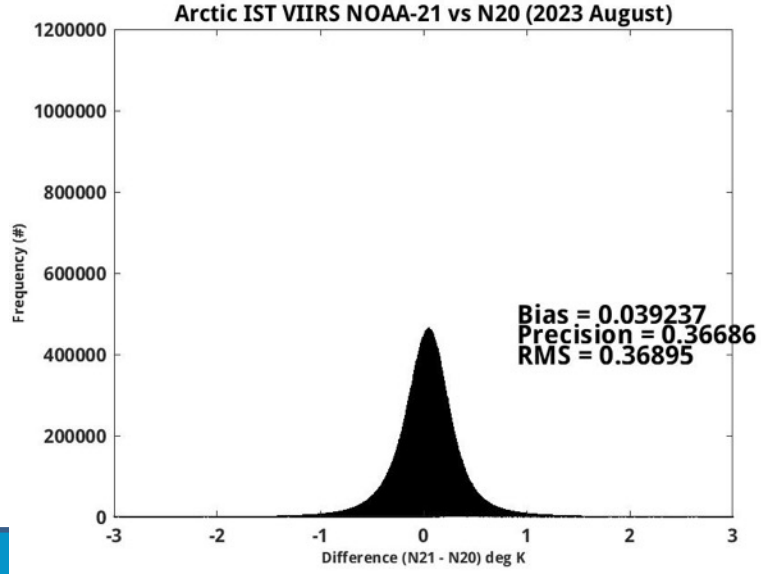
Comparison of October 2, 2023, statistical mean ice surface temperature was done with individual overpasses within one hour.

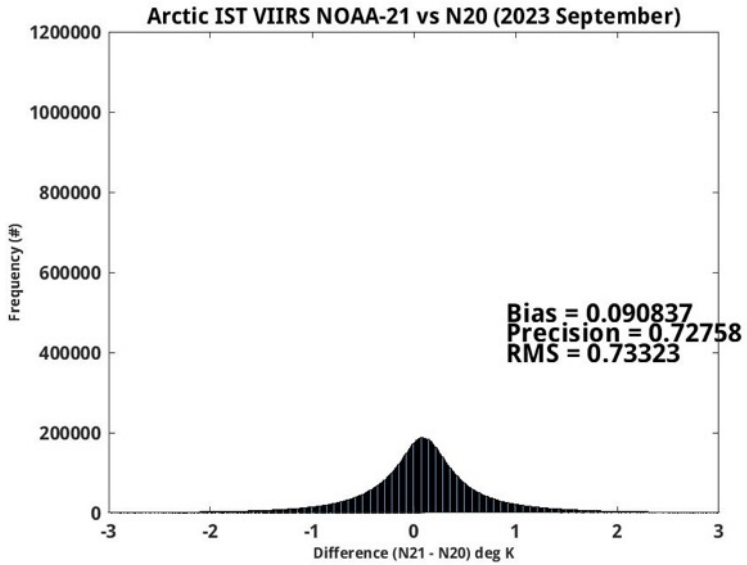
Ice Surface Temperature: NOAA-21 **vs.** NOAA-20, **Arctic**





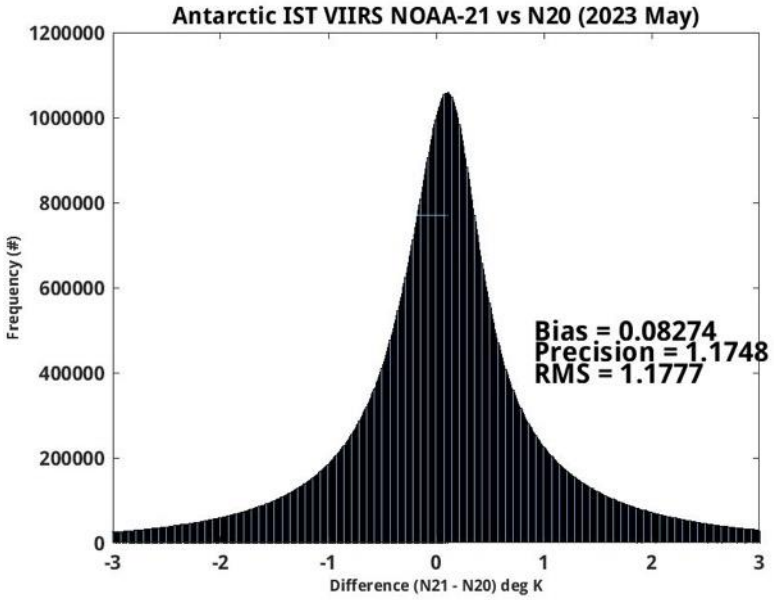


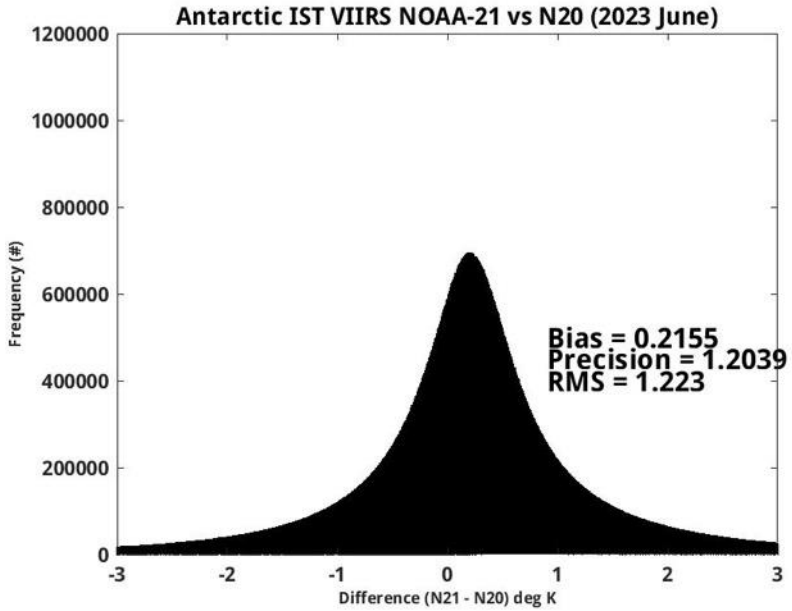


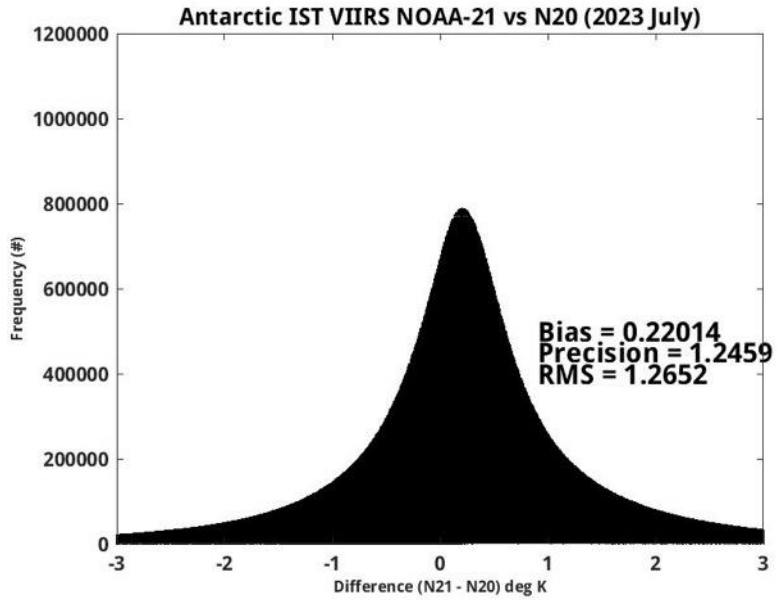


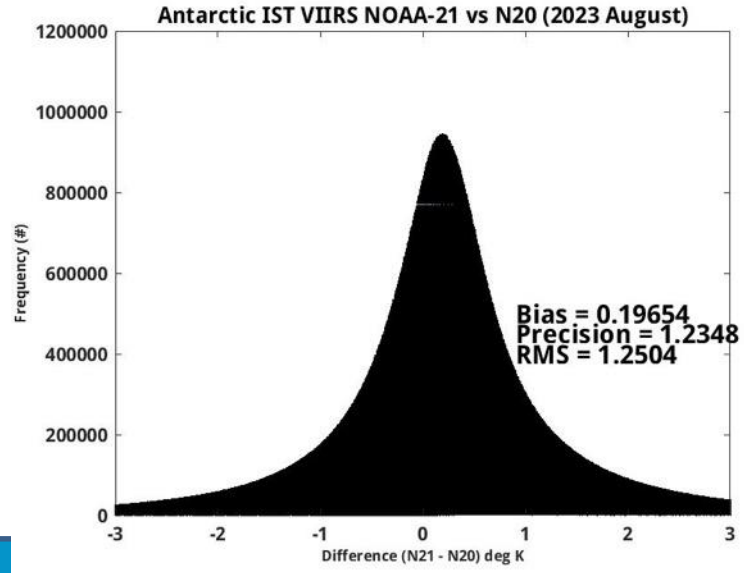
Histogram by month with individual overpasses within one hour, from May to September 2023

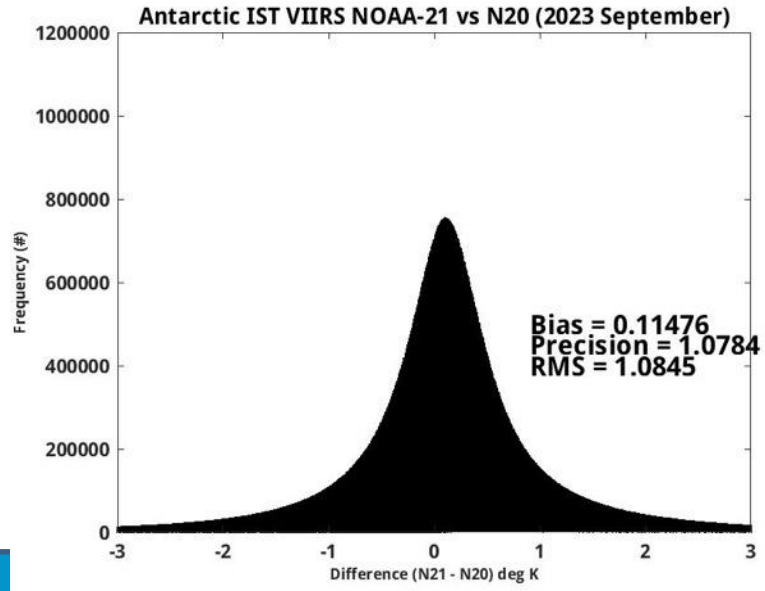
Ice Surface Temperature: NOAA-21 **vs.** NOAA-20, **Antarctic**





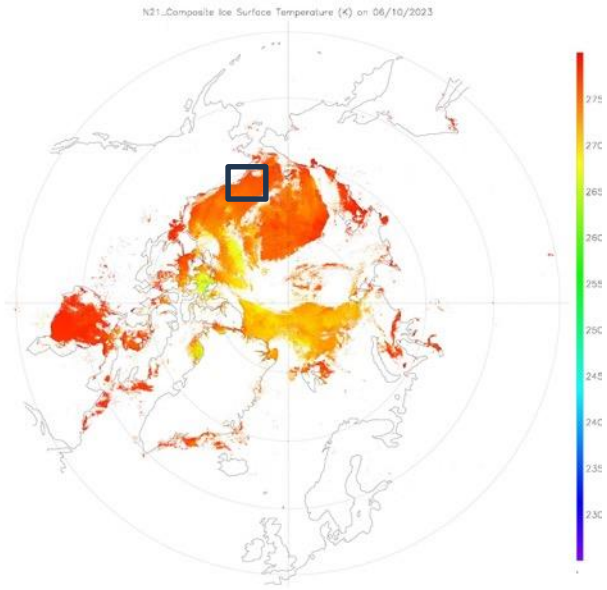


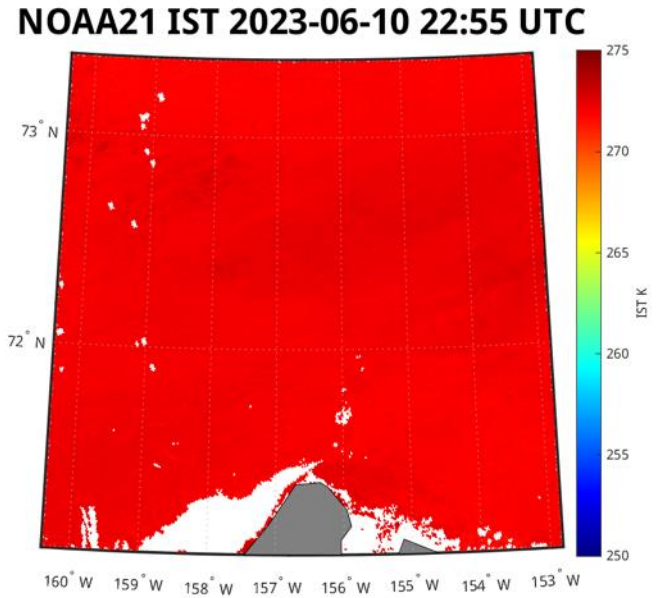


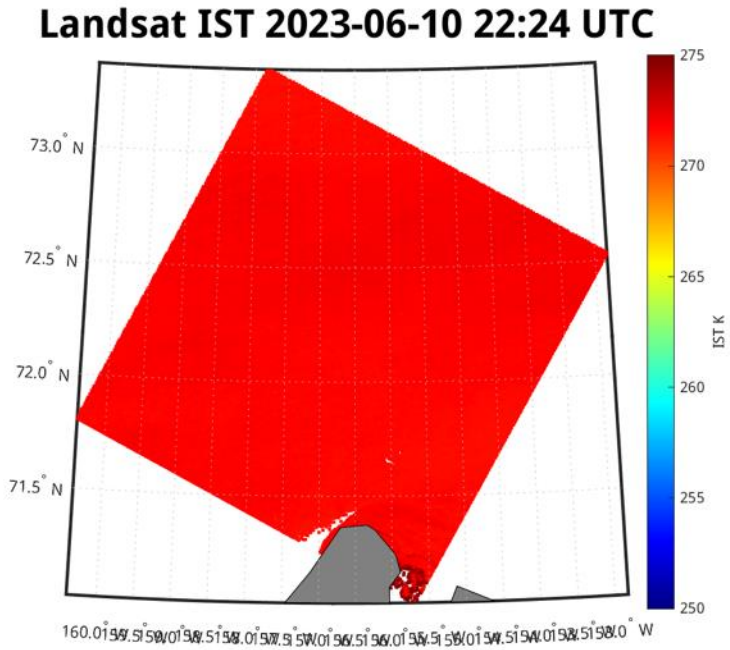


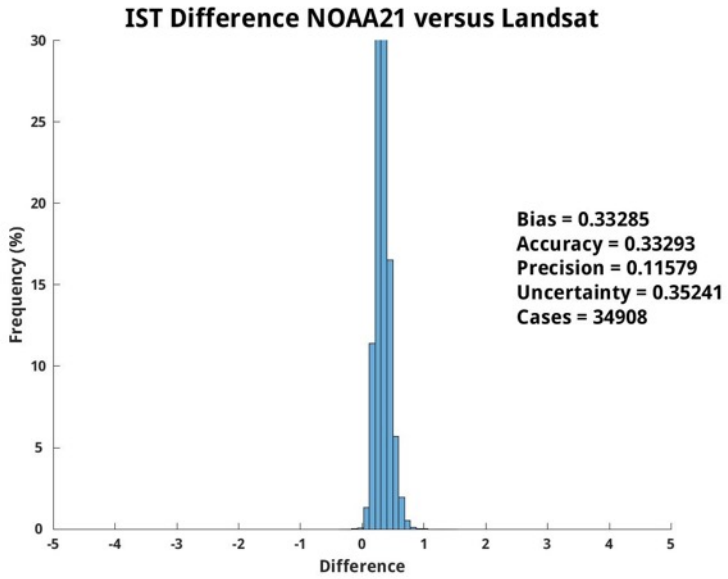
Histogram by month with individual overpasses within one hour, from May to September 2023

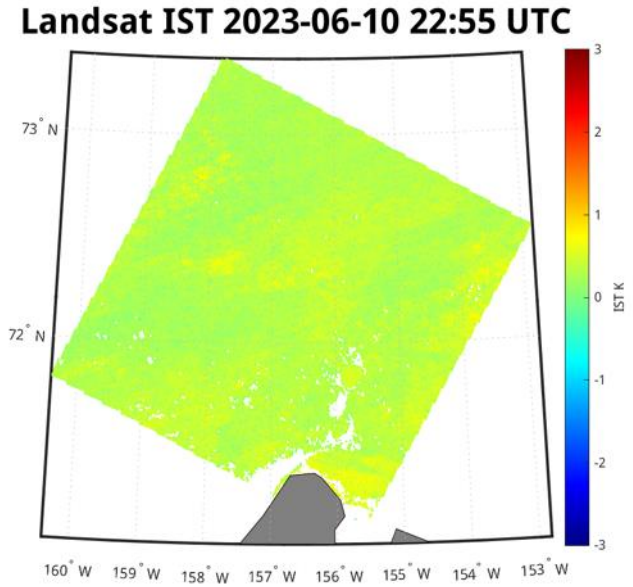
Sea Ice Temperature: NOAA-21 vs. Landsat, Arctic 2023-06-10 22-23 UTC

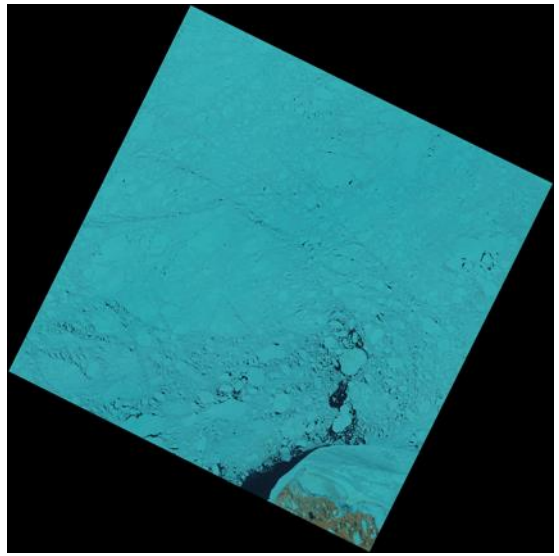




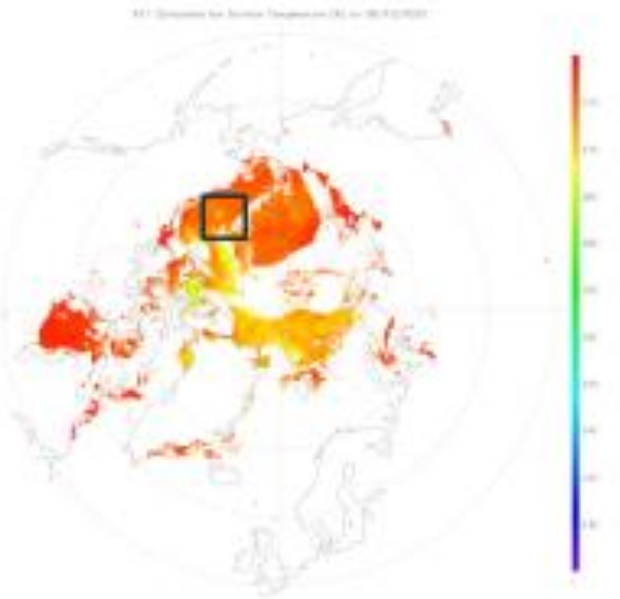




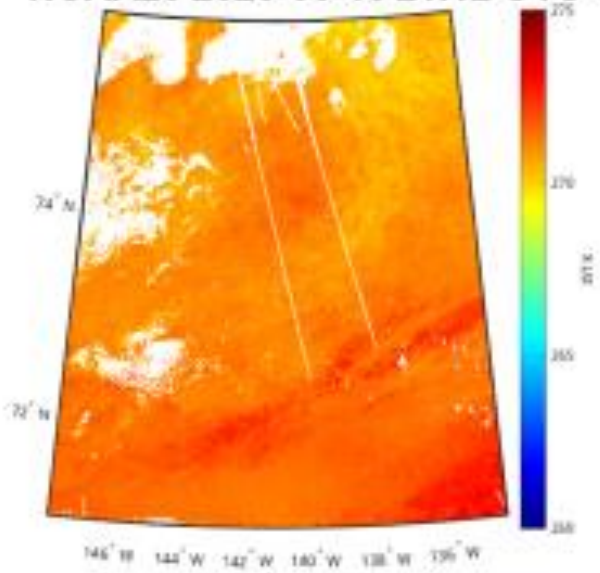




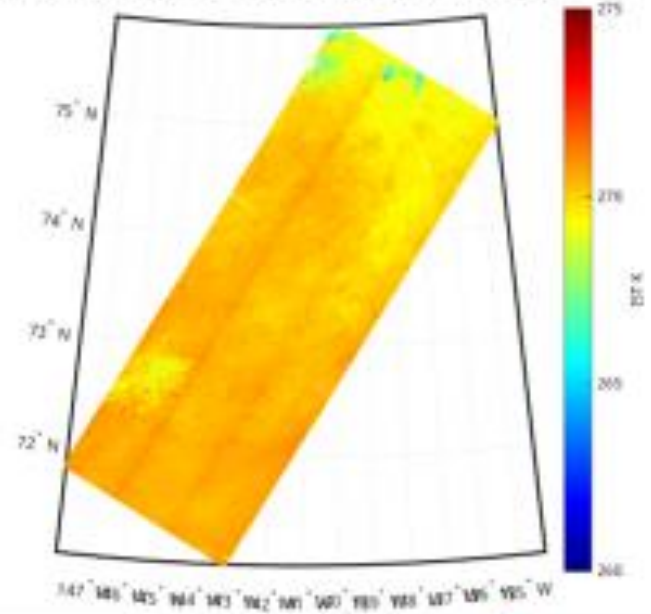
Sea Ice Temperature: NOAA-21 vs. Landsat, Arctic 2023-06-10 21 UTC



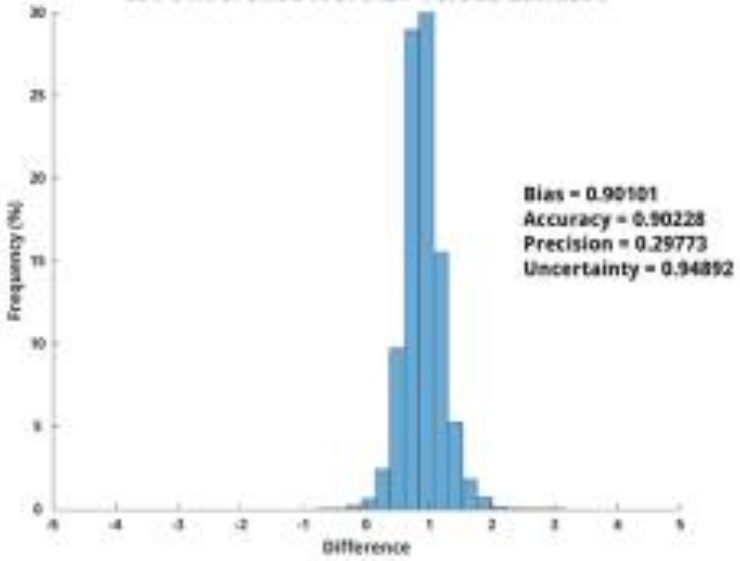
NOAA20 2023-06-10 21:12 UTC



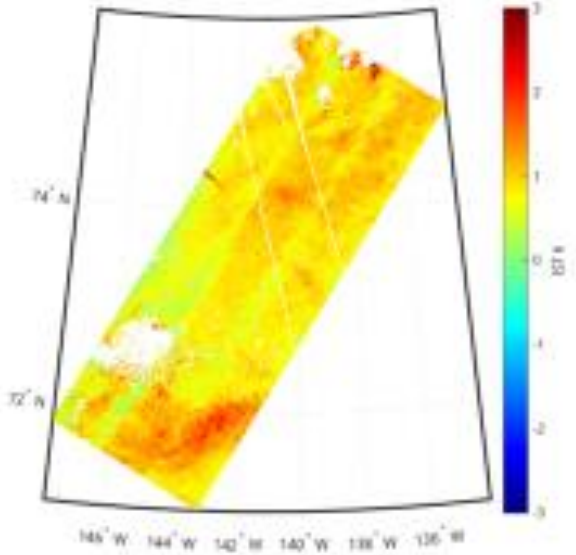
Landsat IST 2023-06-10 21:34 UTC



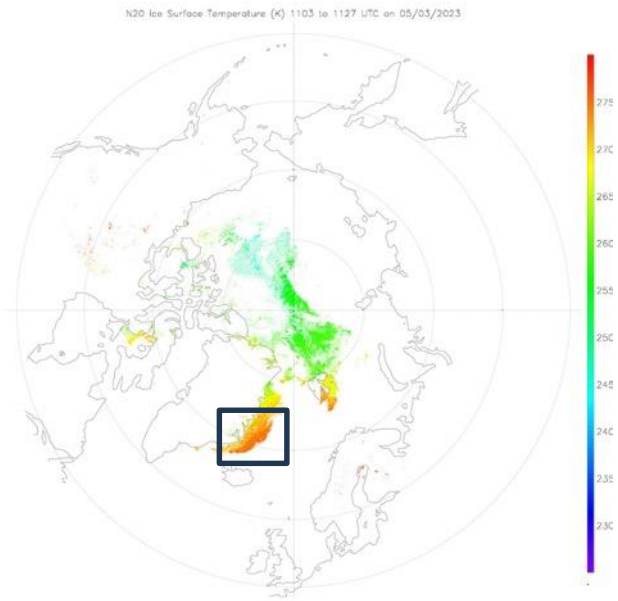
IST Difference NOAA21 versus Landsat

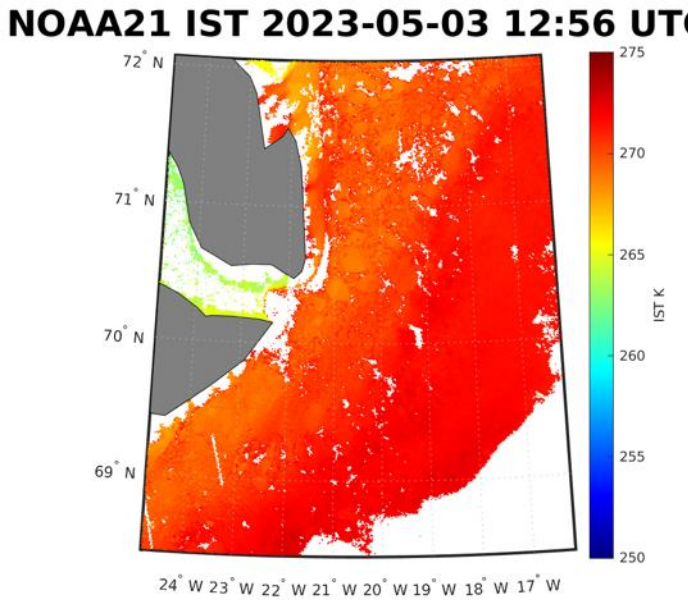


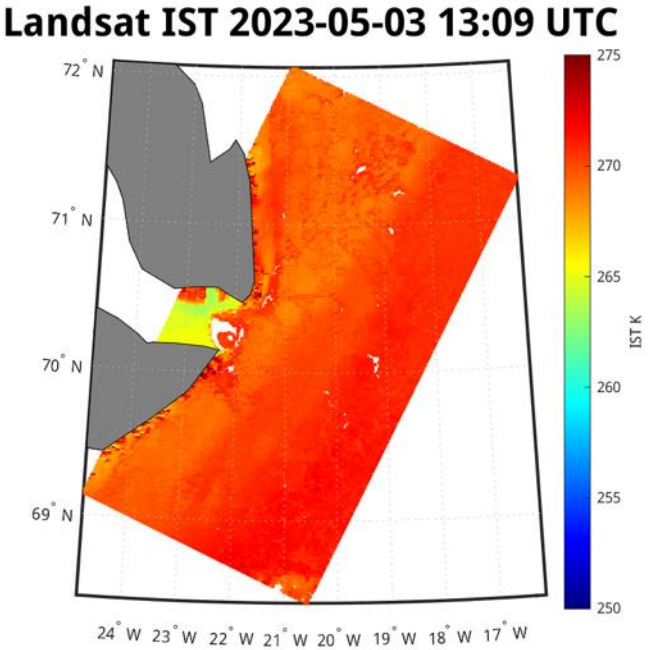
VIIRS-Landsat IST 2023-06-10 21:12 UTC

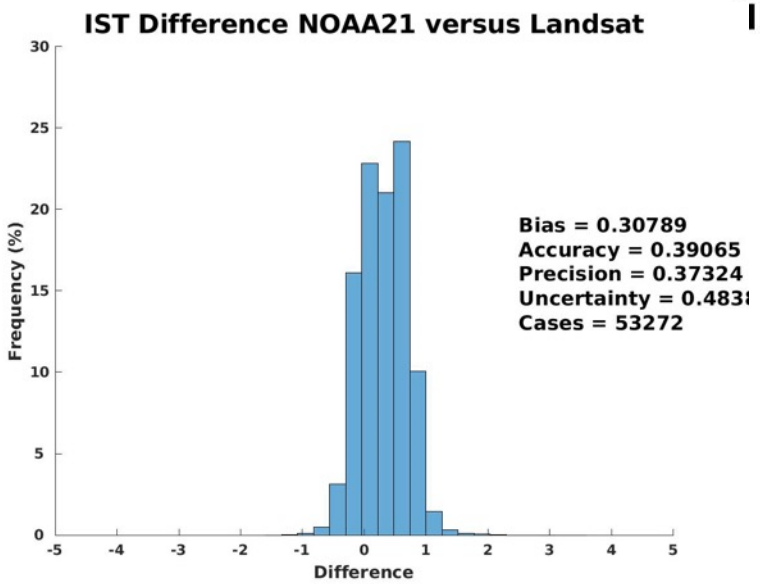


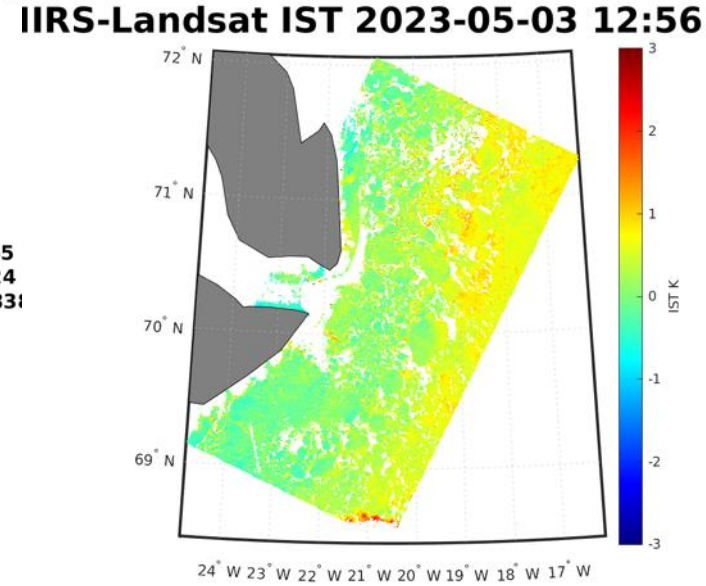
Ice Surface Temperature: NOAA-21 vs. Landsat, Arctic 2023-05-03 11-12 UTC

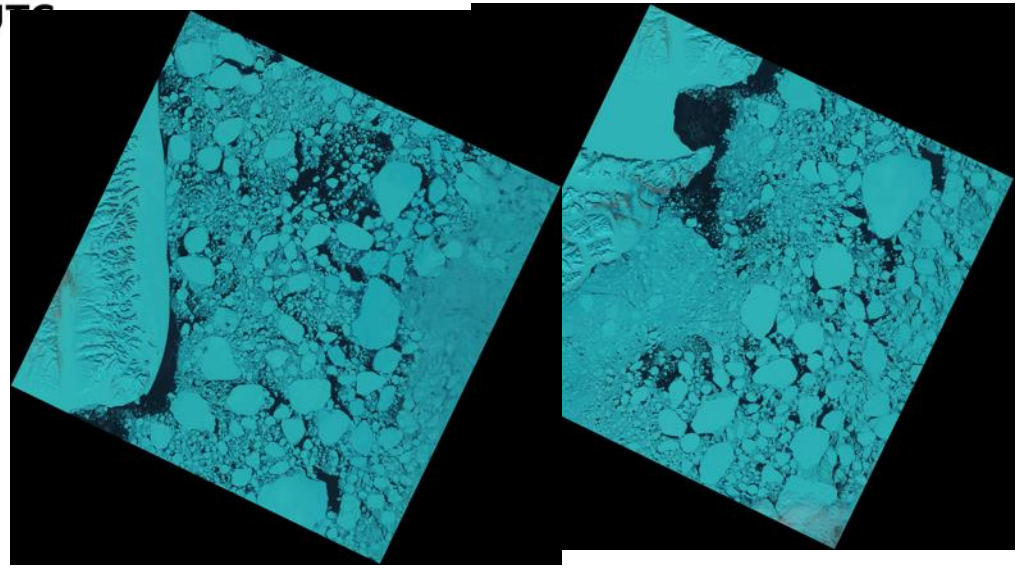




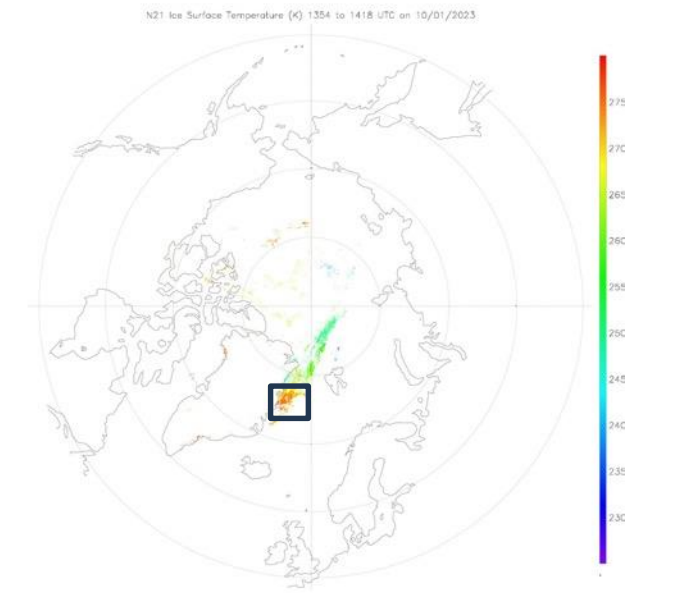


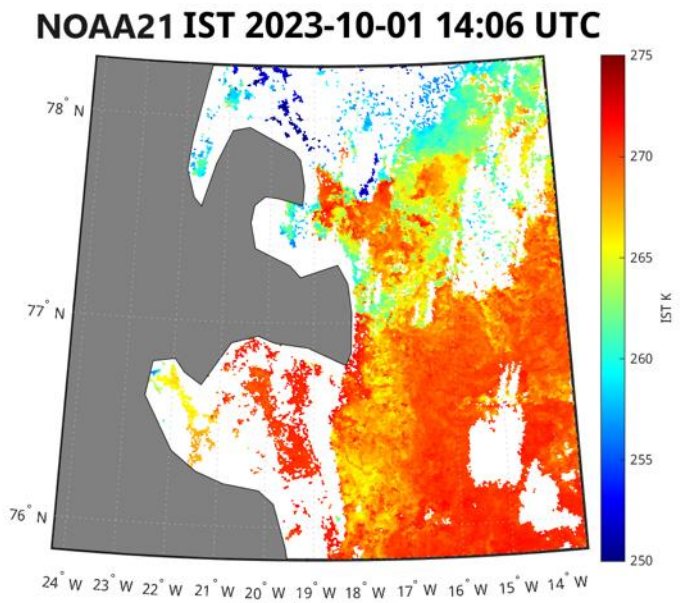


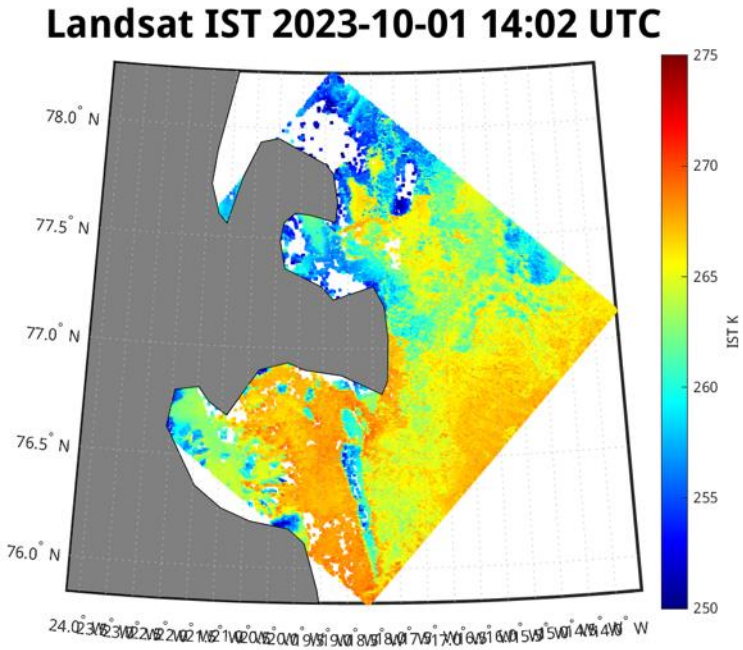


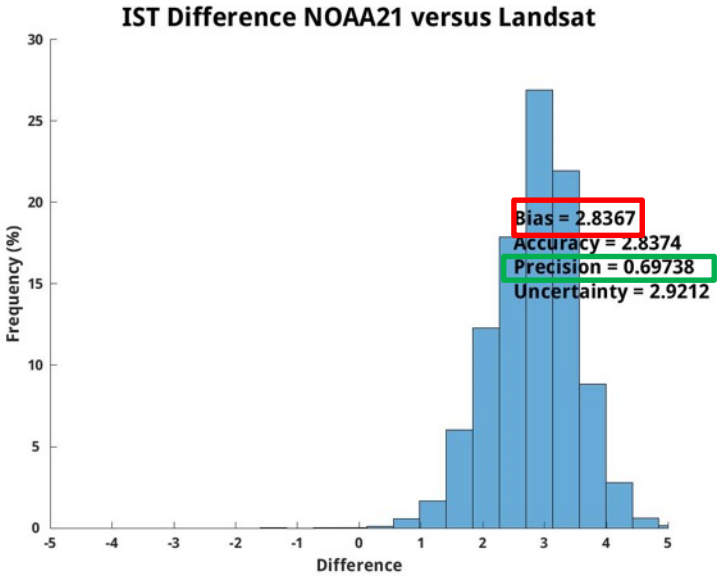


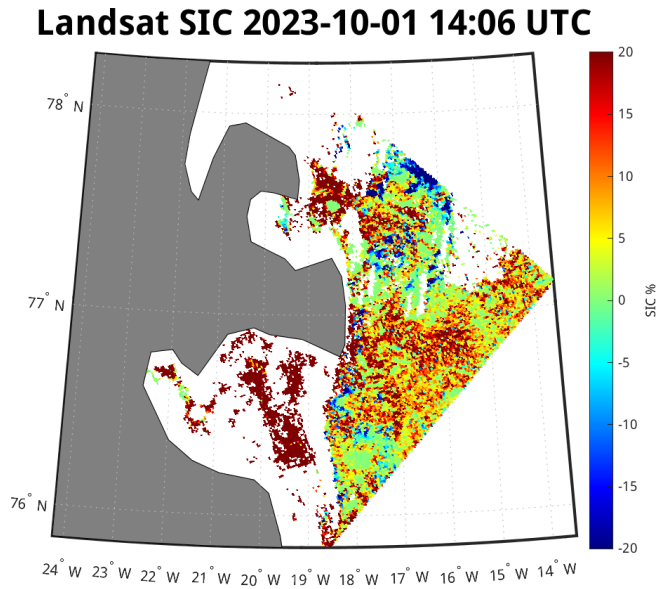
Ice Surface Temperature: NOAA-21 vs. Landsat, Arctic 2023-06-10 22-23 UTC

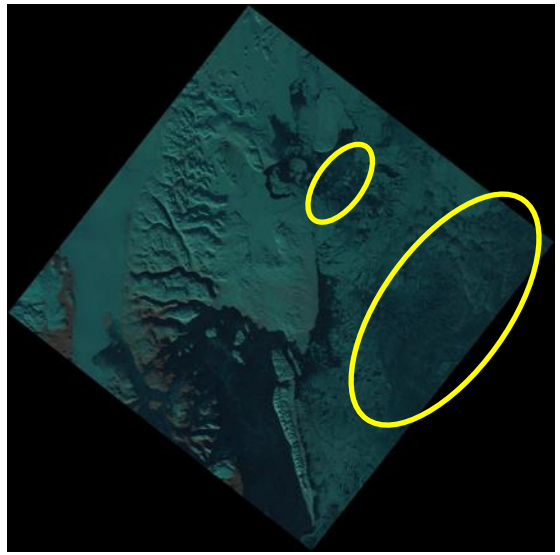




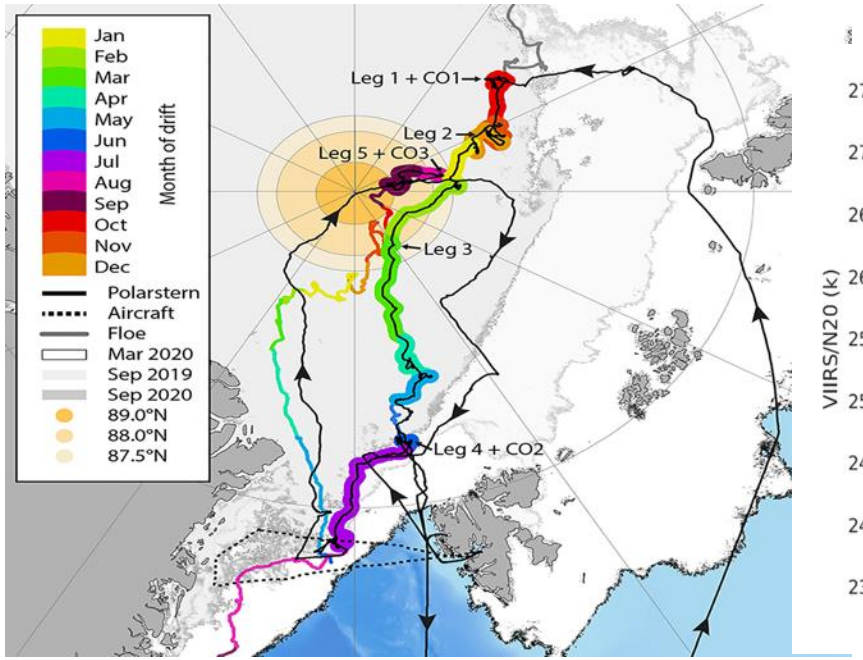


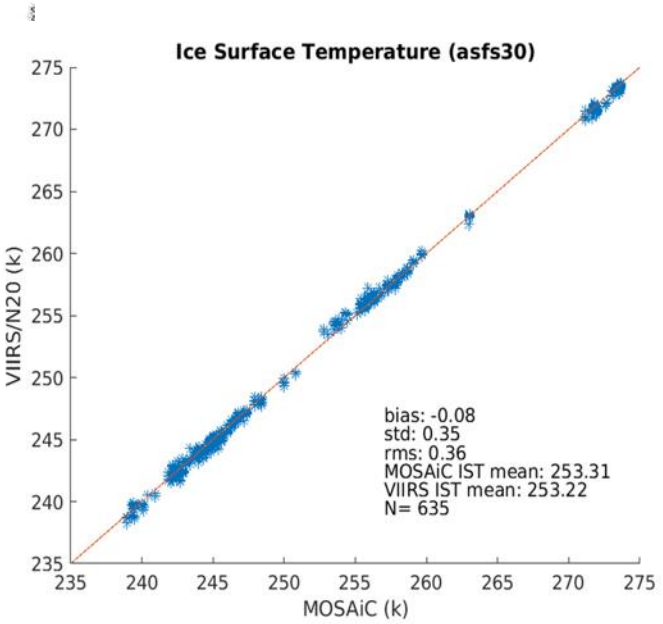


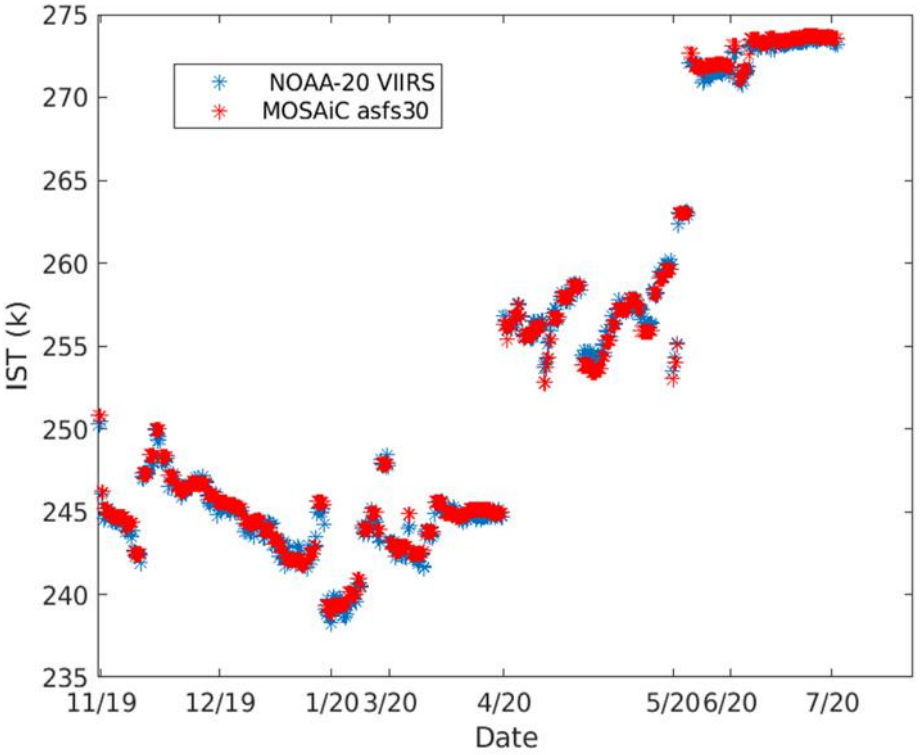




NOAA-20 Ice Surface Temperatures compared to MOSAiC 2019-20 Field Campaign







Validation study of VIIRS NOAA-20 IST compared to MOSAiC IST over November 2019 through July 2020, show very good agreement between IST and surface measurements from campaign. The broad temperature range covers all seasons.

Note: NOAA-21 data are not available for the MOSAiC time period. Subsequent slides demonstrate that NOAA-20 and -21 ice properties are nearly identical (same algorithms), so the MOSAiC results for NOAA-20 would be effectively the same for NOAA-21.

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: LUT for ice surface temperature algorithm
- Evaluation of the effect of required algorithm inputs (mainly cloud mask)
  - Study / test cases: Landsat 20 July, north of Svalbard, Norway (78-80 deg N; 8-25 deg W, northeast of Greenland Sea), Near Point Barrow Alaska and Beaufort Sea on 10 June, south of Svalbard on 5 May (SIC only), off Greenland east-central coast on 3 May and 1 October.
  - 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 for Ice Concentration and Ice Surface 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	vsN20/vs* -0.09%;-**0.64%** +0.14K;**+0.9 K**	-1.6%	N/A	**YES; YES**	**Larger SIC differences found over MIZ.**
Precision		25% SIC 1.5 K IST	3.9% 0.08K	vsN20/vs* 10.4%;**14.3 %** 0.8K;**0.47K**	12.3%	N/A	**YES; YES**	**Precision found to be 1.1 K over the Antarctic.**
Uncertainty		25% SIC 1 K IST	3.9% 0.2K	vsN20/vs* 10.4%;**14.6 %** 0.85K;**1K**	12.4%	N/A	**YES; YES**	**Larger IST differences were found over the Antarctic.**
			SIC IST	***SIC vs AMSR2 IST vs Landsat**	*SIC vs AMSR2		**SIC;IST**	

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	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 Middlebusher	NAVOCEAN	Ice forecasting (modeling)	Concentration improved the accuracy of the ice edge forecast by more than 30%.

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	False clear pixels in Antarctic v3r2 cloud mask, causing larger errors in IST. Problem limited to low sun angles over Arctic.	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

Check List - Provisional Maturity - Ice Concentration and Temperature

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 – Ice Concentration and Ice Surface Temperature

- NOAA-21 VIIRS Ice Concentration and Ice Surface Temperature Products have been evaluated using a large set of products from May to October 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.** Effective date: May 1, 2023, starting orbit 2436.

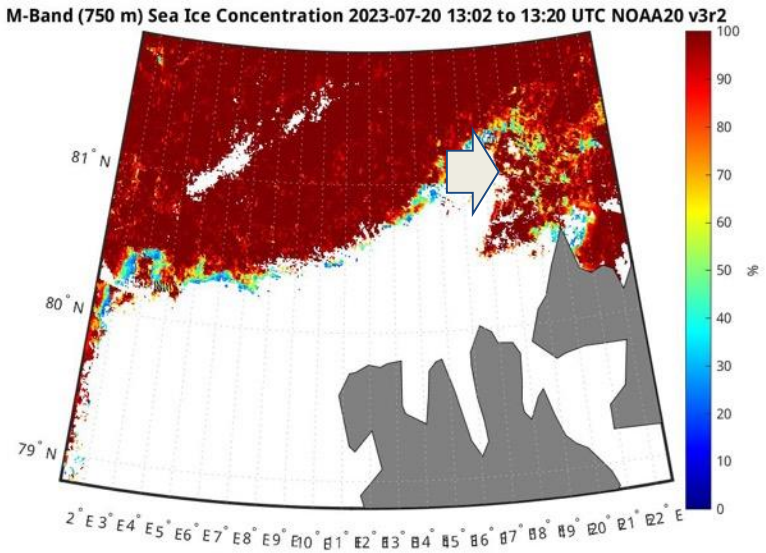
Path Forward

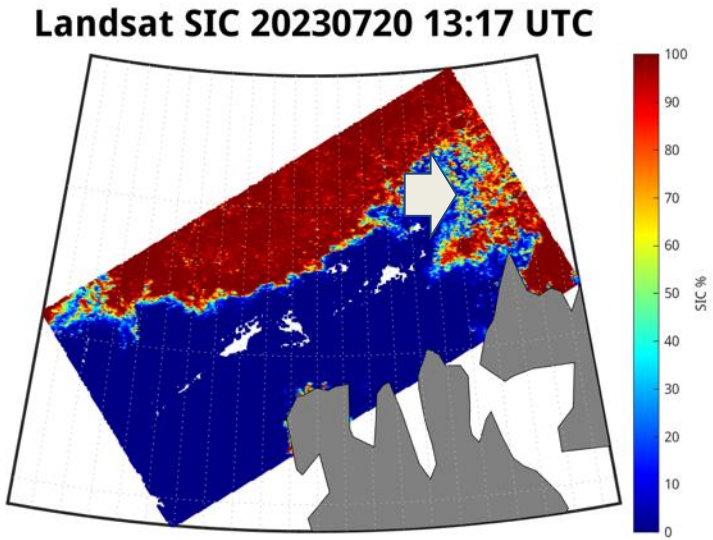
- More calibration/validation may reveal the causes of the found issues, relatively larger uncertainties observed in Marginal Ice Zone Sea Ice Concentration, Ice Surface Temperature precision slightly above specification requirement over the Antarctic.. Possible adjustments/improvements will be carried 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.
- 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.
  - More Landsat cases. Include cases over the Antarctic sea ice during summer period.
  - Comparison to other IST and SIC validation sources such as MIRS (IST), Cryosat-2 and SAR (SIC) for dark period validation over Polar Regions.

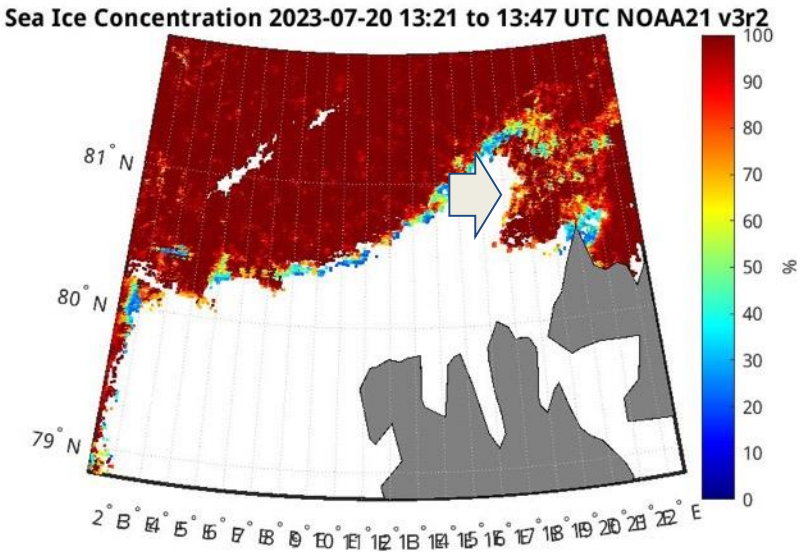
Backup Slides

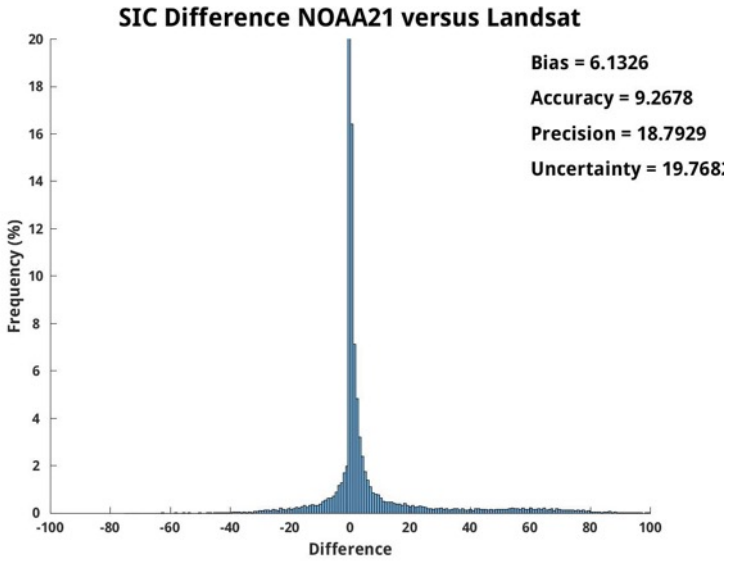
NOAA-20 and 21 NDE v3r2 Sea Ice Concentration vs. Landsat

Near Svalbard on 23 July, 2023 13-14 UTC





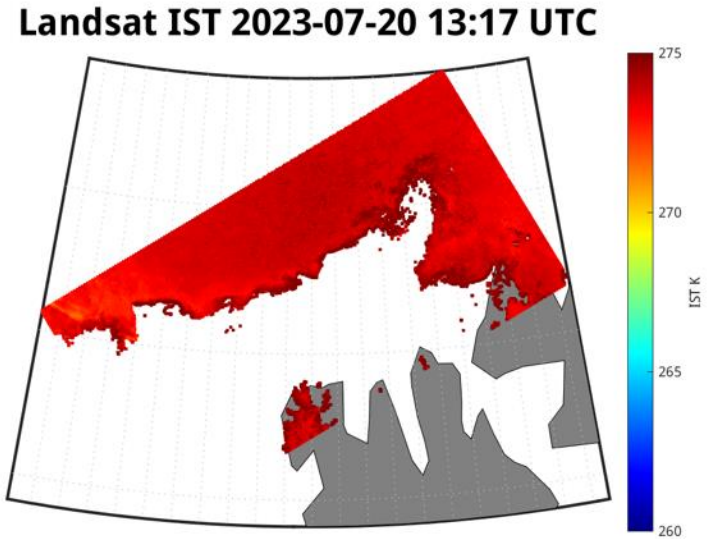


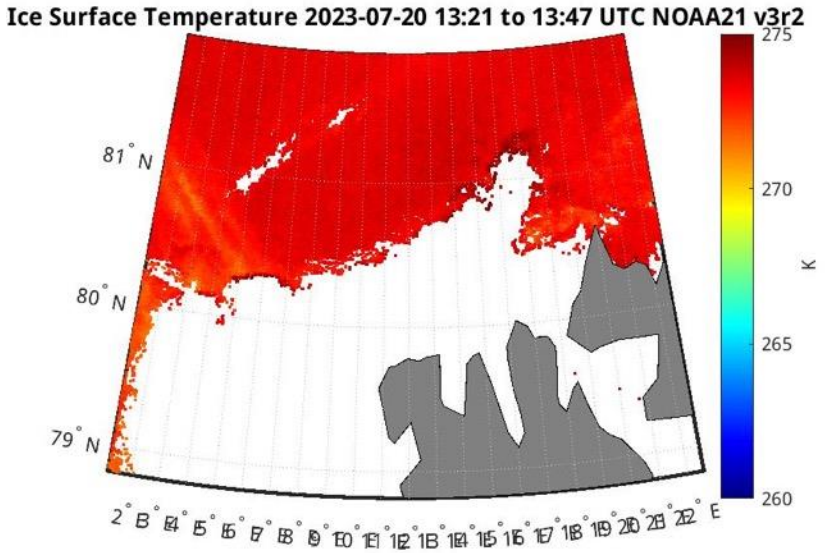


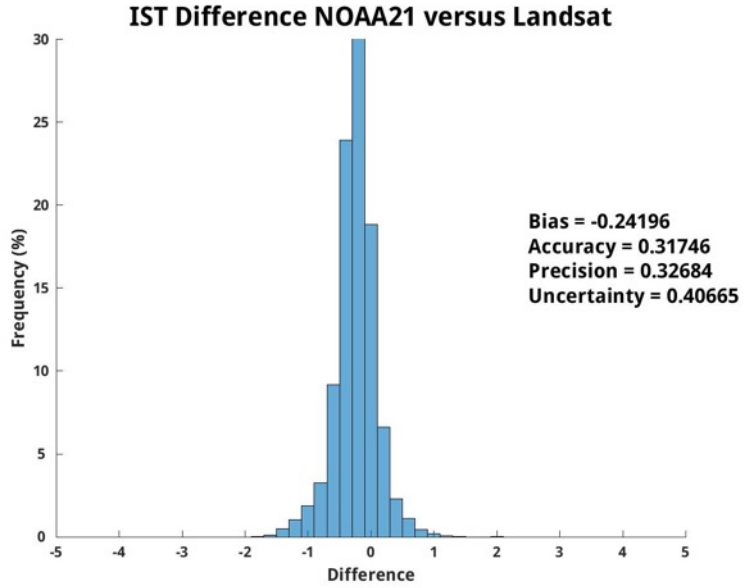
- NDE N20/21 SIC does a good job capturing Sea Ice edge **and** pack ice to the north.
- Positive bias in NDE N20/21 SIC in Marginal Ice Zone (MIZ) to the northeast (see arrow).
- Missing SIC=0 in NDE. Instead we see only SIC=missing value.
- A solution to these remaining issues are being investigated.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

Case study of NOAA-21 NDE v3r2 IST to Landsat IST

Near Svalbard on 23 July, 2023 13-14 UTC







- 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.