Beta/Provisional Maturity Science Review For NOAA-21 Cloud Top Phase

CIMSS Cloud Top Phase: Steve Wanzong, David Loveless, Yue Li, Mike Foster, William Straka
NOAA Cloud Science Team Lead: Mark Kulie

Presented by Steve Wanzong
Date: 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.

BETA/PROVISIONAL MATURITY REVIEW MATERIAL

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 Check List)
- Conclusion
- Path Forward

Cloud Top Phase Cal/Val Team Members

Name	Organization	Major Task
Mike Foster	UW-Madison/CIMSS	CIMSS Phase PI
Mark Kulie	NOAA-NESDIS-STAR-SMCD	Team Lead
Yue Li	UW-Madison/CIMSS	Algorithm Development/Maintenance
David Loveless	UW-Madison/CIMSS	Algorithm Development/Maintenance
William Straka	UW-Madison/CIMSS	ASSISTT Integration
Steve Wanzong	UW-Madison/CIMSS	Algorithm Validation
David Donahue	OSPO	Cloud Algorithm PAL
Shuang Qiu	OSPO	Product Area Lead

Product Overview

- Enterprise Cloud Phase uses the following channels
  - M14 (8.55 um)
  - M15 (10.7 um)
  - M16 (12.0 um)
- The cloud team assumes that all sensor input is valid given full maturity for the VIIRS SDRs
- There are known SRF differences between the SRFs in the 11µm and 12µm channels, both used for ACHA, between NOAA-21 and NOAA-20/SNPP.

		Band No.	Driving EDR(s)	Spectral Range (um)	Horiz Sample Interval (km) (track x Scan)	
					Nadir	End of Scan
Reflective Bands	VisNIR	M1	Ocean Color Aerosol	0.402 - 0.422	0.742 x 0.259	1.60 x 1.58
		M2	Ocean Color Aerosol	0.436 - 0.454	0.742 x 0.259	1.60 x 1.58
		M3	Ocean Color Aerosol	0.478 - 0.498	0.742 x 0.259	1.60 x 1.58
		M4	Ocean Color Aerosol	0.545 - 0.565	0.742 x 0.259	1.60 x 1.58
		I1	Imagery EDR	0.600 - 0.680	0.371 x 0.387	0.80 x 0.789
		M5	Ocean Color Aerosol	0.662 - 0.682	0.742 x 0.259	1.60 x 1.58
		M6	Atmosph. Correct.	0.739 - 0.754	0.742 x 0.776	1.60 x 1.58
		I2	NDVI	0.846 - 0.885	0.371 x 0.387	0.80 x 0.789
		M7	Ocean Color Aerosol	0.846 - 0.885	0.742 x 0.259	1.60 x 1.58
	SWMIR	M8	Cloud Particle Size	1.230 - 1.250	0.742 x 0.776	1.60 x 1.58
		M9	Cirrius/Cloud Cover	1.371 - 1.386	0.742 x 0.776	1.60 x 1.58
		I3	Binary Snow Map	1.580 - 1.640	0.371 x 0.387	0.80 x 0.789
		M10	Snow Fraction	1.580 - 1.640	0.742 x 0.776	1.60 x 1.58
		M11	Clouds	2.225 - 2.275	0.742 x 0.776	1.60 x 1.58
		I4	Imagery Clouds	3.550 - 3.930	0.371 x 0.387	0.80 x 0.789
		M12	SST	3.660 - 3.840	0.742 x 0.776	1.60 x 1.58
		M13	SST Fires	3.973 - 4.128	0.742 x 0.259	1.60 x 1.58
Emissive Bands	LWIR	M14	Cloud Top Properties	8.400 - 8.700	0.742 x 0.776	1.60 x 1.58
		M15	SST	10.263 - 11.263	0.742 x 0.776	1.60 x 1.58
		I5	Cloud Imagery	10.600 - 12.400	0.371 x 0.387	0.80 x 0.789
		M16	SST	11.638 - 12.488	0.742 x 0.776	1.60 x 1.58

Product Overview

- The fundamental output of the ECP is the cloud phase.

- The cloud phase output corresponds to the following cloud phase categories
  - 0 – Clear
  - 1 – Liquid water phase
  - 2 – Supercooled water phase
  - 3 – Mixed phase
  - 4 – Ice phase (opaque, semi-transparent, multi-layered)
  - 5 – Unknown

Importance: used by downstream cloud algorithms, including cloud height, which is critical for assigning the height of VIIRS polar wind vectors.

NOAA Enterprise Cloud Algorithms

Cloud Probability/ Mask

Cloud Cover Layers

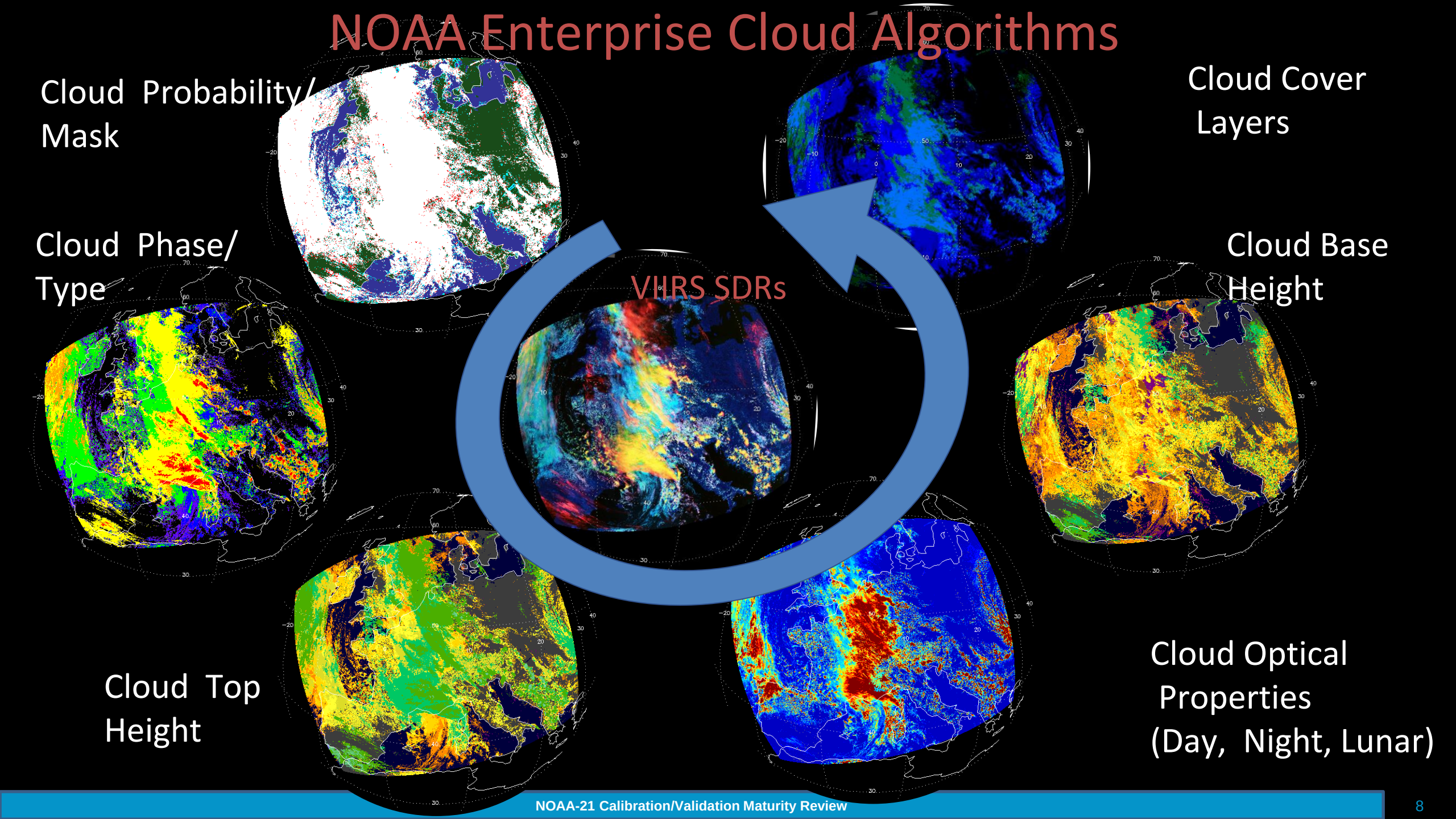
Cloud Phase/ Type

VIIRS SDRs

Cloud Base Height

Cloud Top Height

Cloud Optical Properties (Day, Night, Lunar)



Product Overview/Requirements

- Cloud Phase.
- JPSS Ground Segment Data Product Specification; October 2019.

Attribute	DPS	Requirement/Threshold	Performance
Coverage	DPS-712	The Cloud Phase product shall provide the cloud phase, globally, day and night, whenever detectable clouds are present, at the refresh rates of the instrument.	
Probability	DPS-713	The Cloud Phase product shall provide the cloud phase with an 80% probability of correct typing.	

Processing Environment and Algorithms

- Description of processing environment and algorithms used to achieve the maturity stage:
  - v3r2
  - Software is unchanged from Spring 2022 Super Dap.

Executive Summary

- Visual Inspection, Phase Zonal Plots, CALIOP comparisons, ABI comparisons.
- Missing/Incomplete data sets at UW-Madison.
- **Recommendation: Beta/Provisional Maturity (effective March 30, 2023).**

- Note: CALIOP data ends in June 2023.
- Note: Phase developer (Mike Pavolonis) has ended his commitment to this project.

Algorithm Performance Evaluation

We have chosen independent sources of cloud top Phase that provide qualitative and quantitative analysis of the performance using more than 15 days from June 2023.

We also compare to non-NDE generated Phase data to diagnose NDE-specific issues.

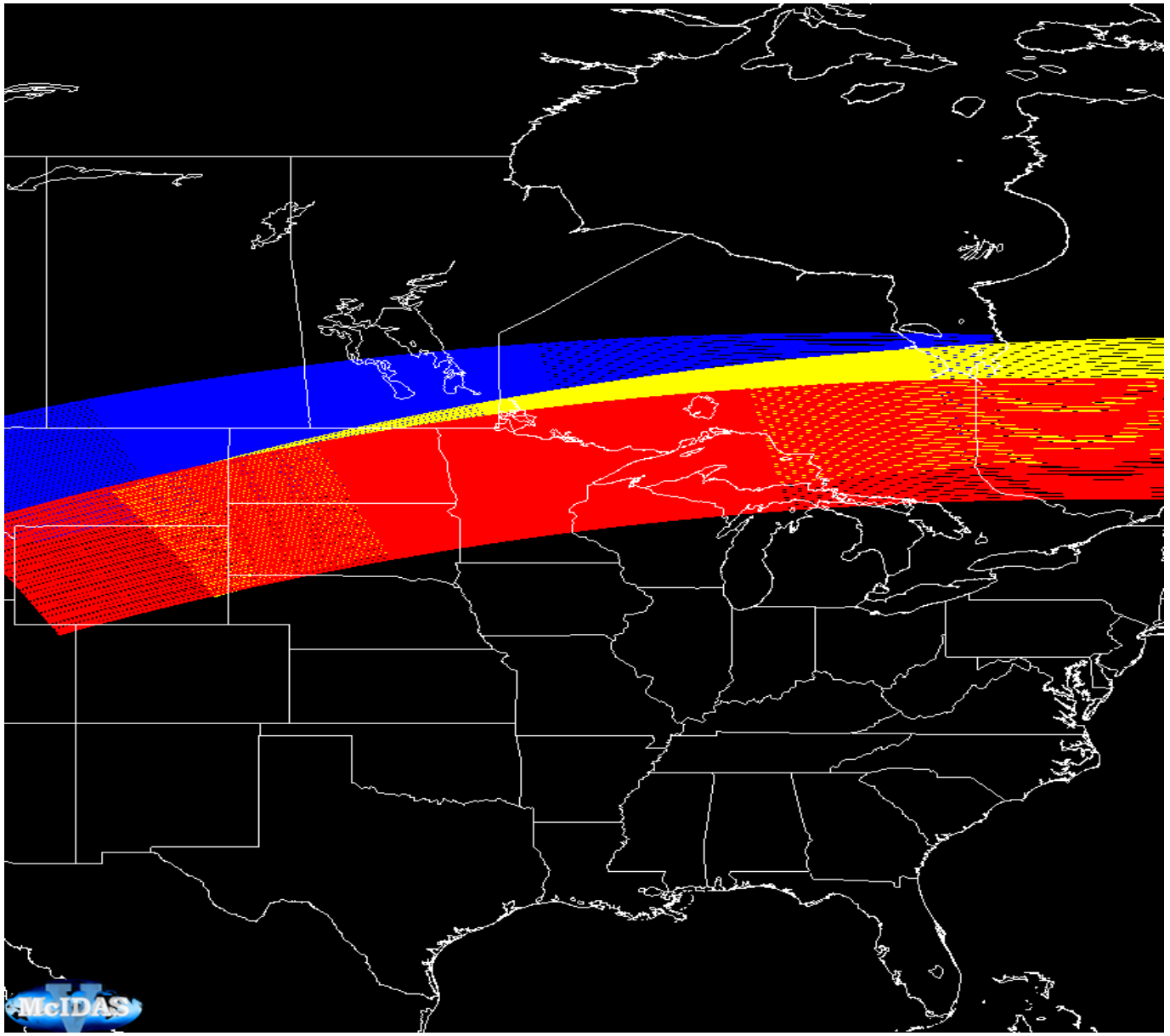
Our Specific Validation Strategies are:

1. Visual inspection of NDE Phase against CLAVR-x Phase.
2. Intercomparison of NDE Phase using NOAA-21, NOAA-20 and SNPP.
3. Intercomparison of NDE NOAA-21 Phase with ABI Phase.
4. Validation against NASA CALIPSO/CALIOP.

Algorithm Performance Evaluation

Visual Comparisons

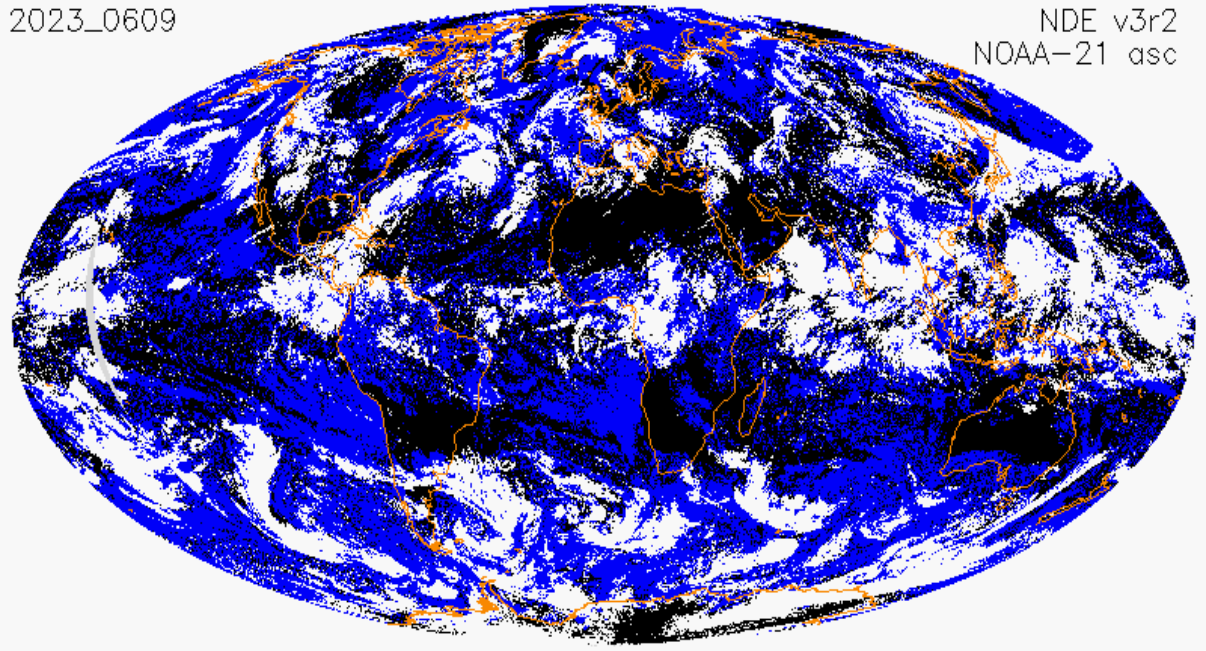
Algorithm Performance Evaluation



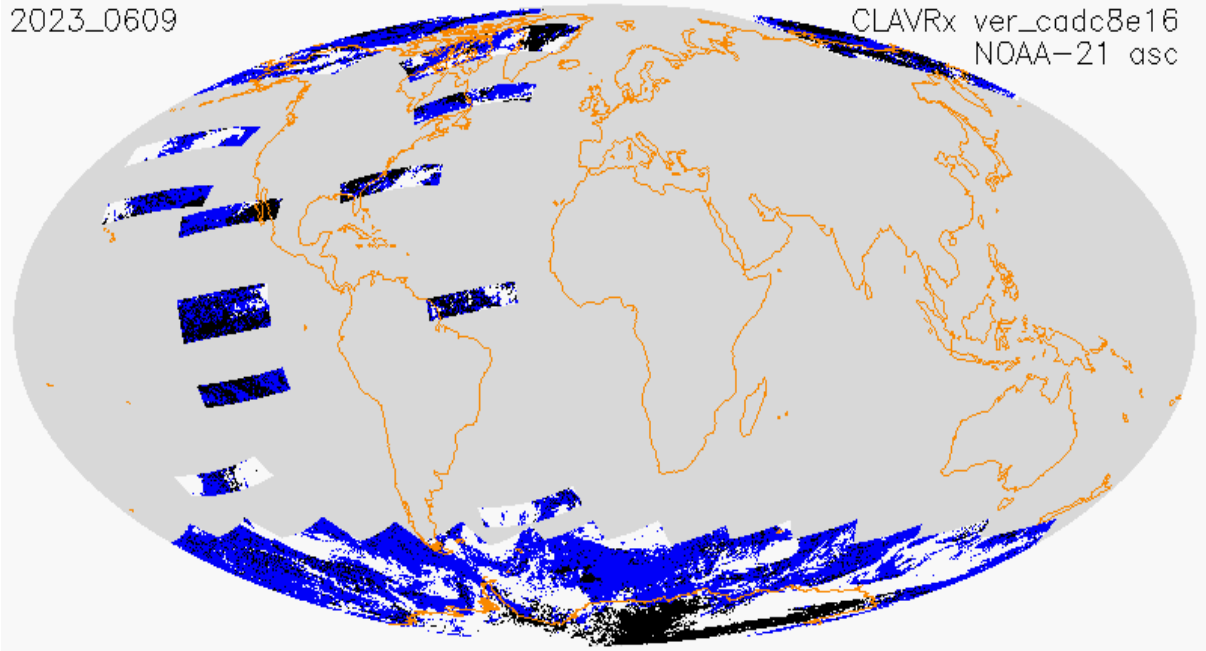
- NOAA-21 : 2023 1017 1857 UTC
- NOAA-20 : 2023 1017 1835 UTC
- SNPP : 2023 1017 1926 UTC

NOAA-21 Cloud Top Phase Level2b (Ascending)

NDE

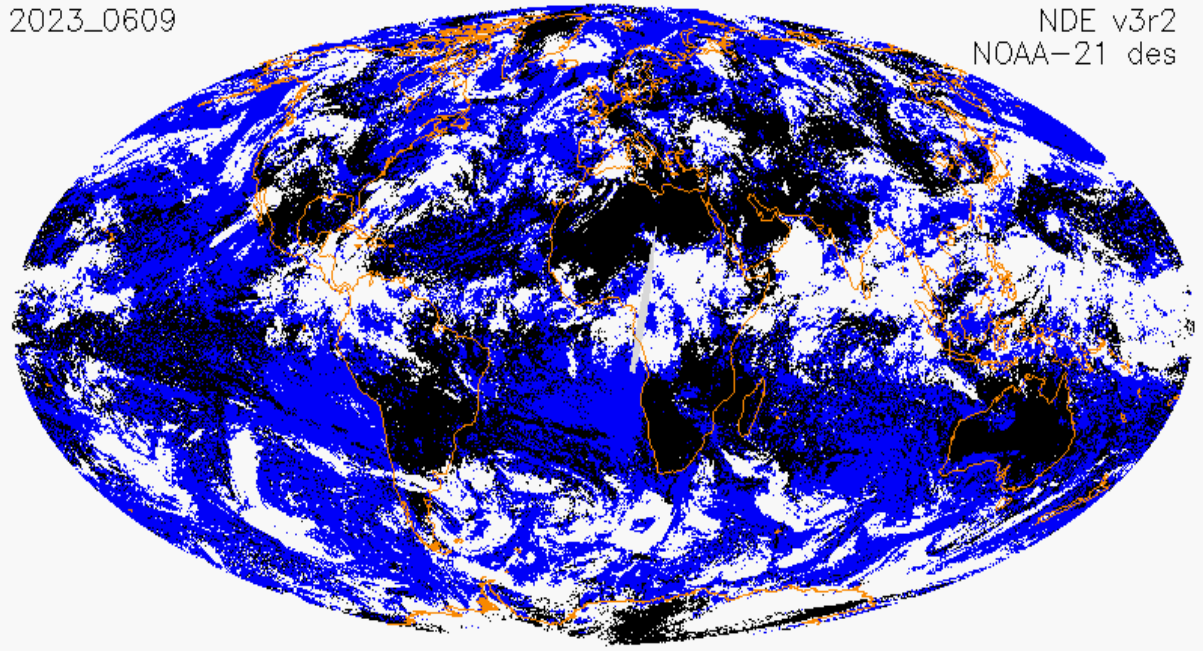


ECM Phase (via CLAVR-x)

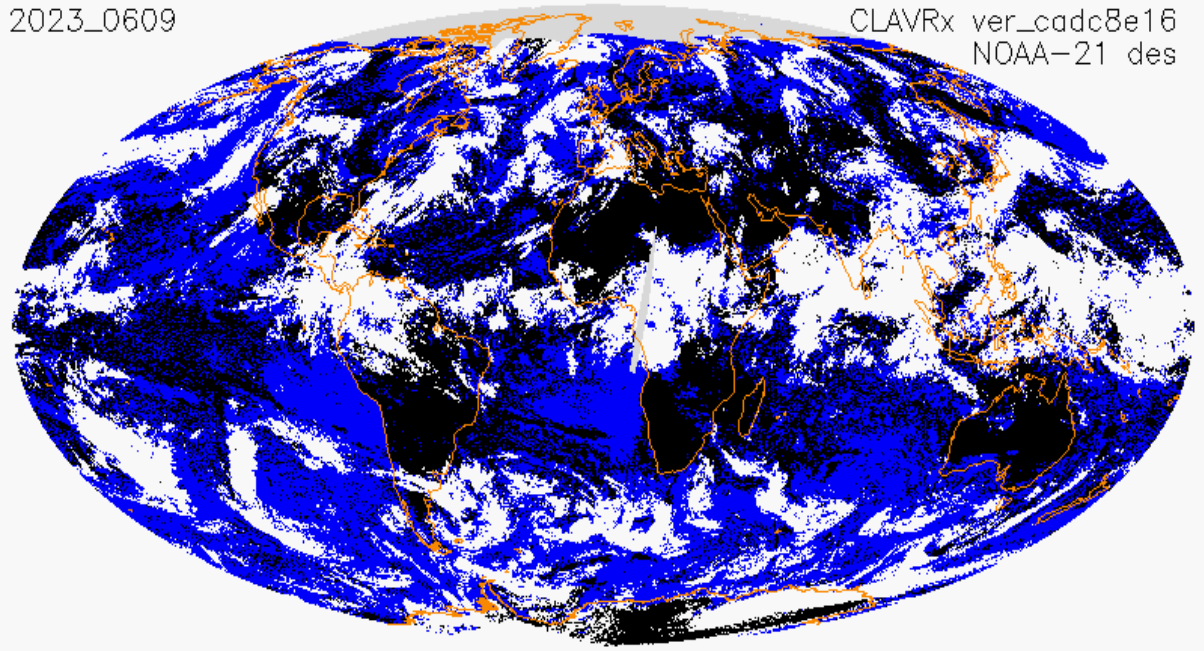


NOAA-21 Cloud Top Phase Level2b (Descending)

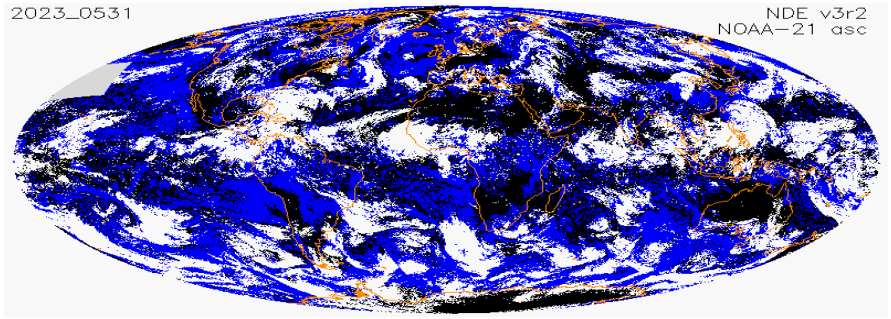
NDE



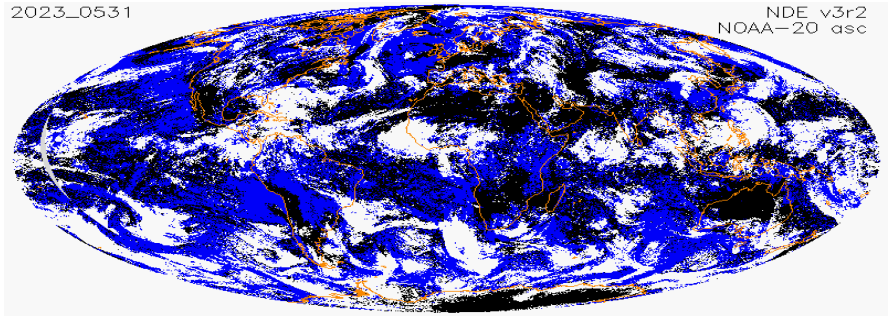
ECM Phase (via CLAVR-x)



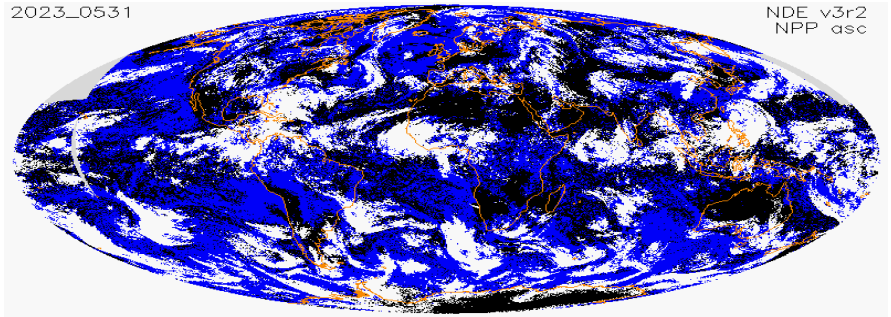
VIIRS Cloud Top Phase Level2b (Ascending)



NOAA-21

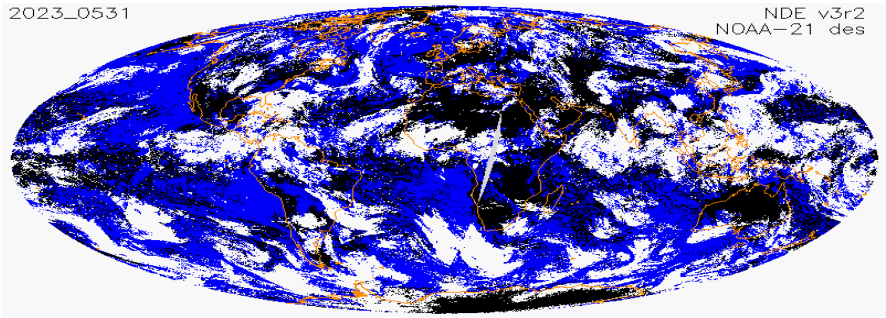


NOAA-20

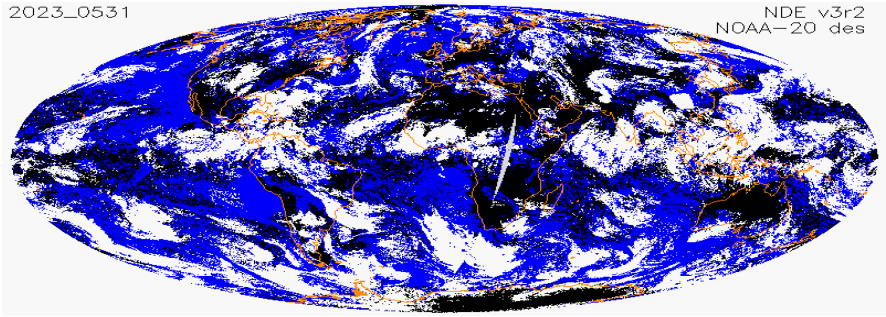


SNPP

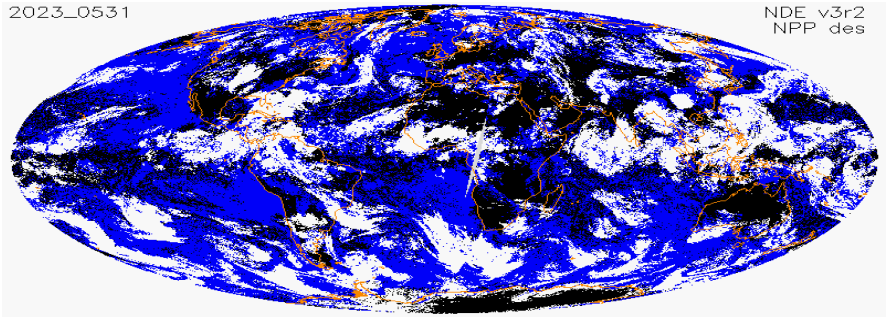
VIIRS Cloud Top Phase Level2b (Descending)



NOAA-21



NOAA-20

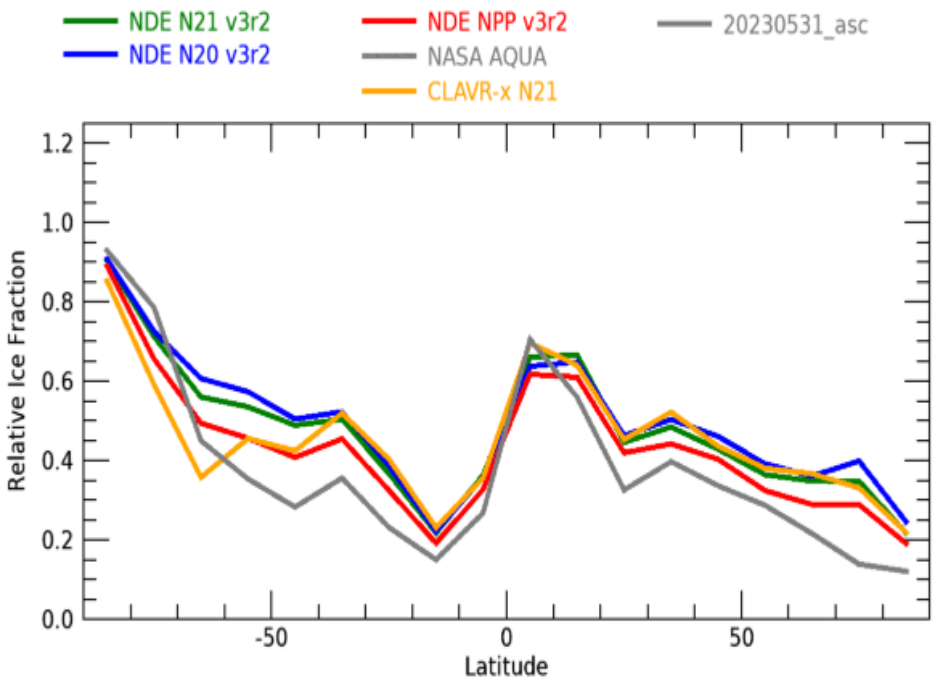


SNPP

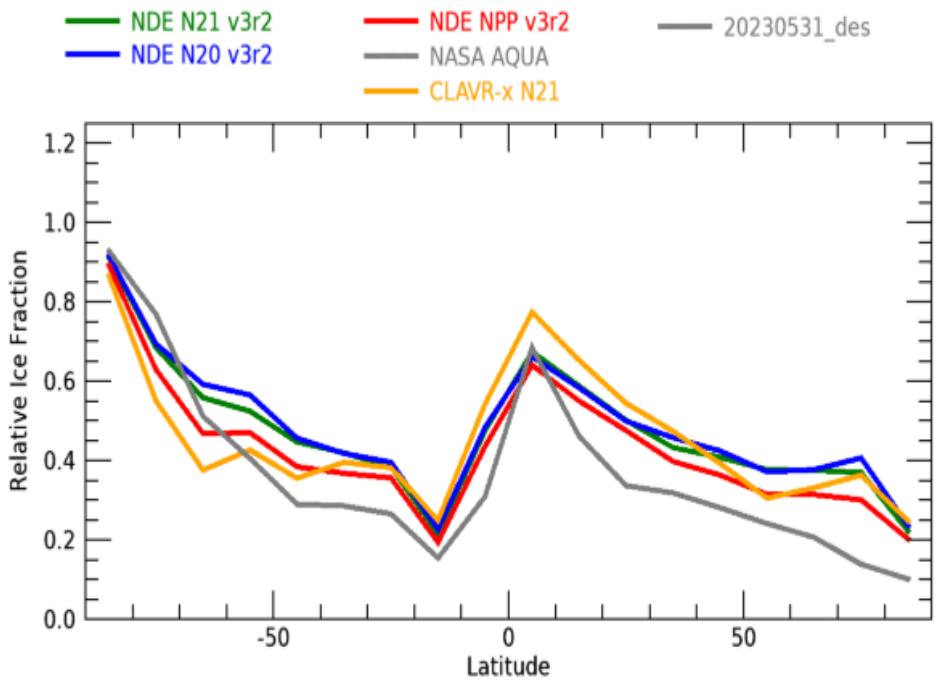
Zonal Plots

VIIRS Cloud Top Phase Zonal Plots

Ascending



Descending



Confusion Matrix - NOAA-21 vs ABI

NOAA-21 versus GOES-16

- The NOAA-21 cloud phase product was co-located with the GOES-16 phase on June 19, 2023.
- Co-location criteria: VIIRS and ABI cloud masks both indicate a cloud is present and the ABI viewing angle was less than 60^{o}

GOES-16 vs. NOAA-21 Cloud Phase Confusion Matrix				
GOES-16 Ice	7,105,358 (3.7%)	1,857,149 (1.0%)	7,513,220 (3.9%)	73,847,705 (38.6%)
GOES-16 Mixed	721,791 (0.4%)	1,376,537 (0.7%)	2,496,757 (1.3%)	921,726 (0.3%)
GOES-16 SC	2,040,991 (1.1%)	6,072,710 (3.2%)	1,199,373 (0.7%)	615,289 (0.3%)
GOES-16 Liquid	74,232,524 (38.8%)	2,666,000 (1.4%)	1,244,356 (0.7%)	7,225,004 (3.8%)
191,136,496	NOAA-21 Liquid	NOAA-21 SC	NOAA-21 Mixed	NOAA-21 Ice

Percentage of NOAA-21 results that match GOES-16: 80.4%

NOAA-21 versus GOES-18

- The NOAA-21 cloud phase product was co-located with the GOES-18 phase on June 19, 2023.
- Co-location criteria: VIIRS and ABI cloud masks both indicate a cloud is present and the ABI viewing angle was less than 60^{o}

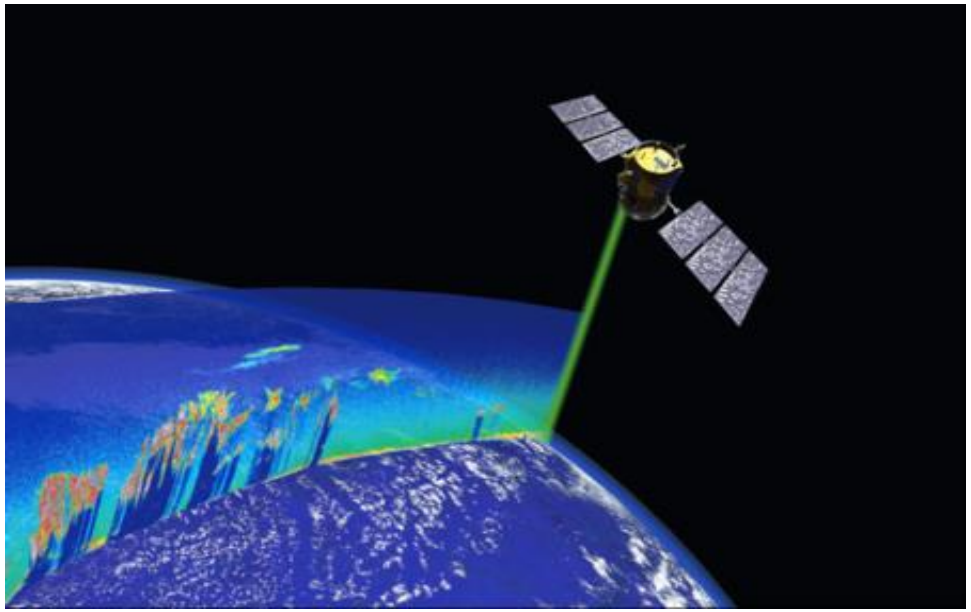
GOES-18 vs. NOAA-21 Cloud Phase Confusion Matrix				
GOES-18 Ice	9,927,785 (4.5%)	2,439,697 (1.1%)	11,448,637 (5.2%)	74,859,119 (33.8%)
GOES-18 Mixed	1,191,518 (0.5%)	2,481,116 (1.1%)	3,452,598 (1.6%)	719,405 (0.3%)
GOES-18 SC	2,020,635 (0.9%)	6,63,359 (2.8%)	982,122 (0.4%)	198,427 (0.1%)
GOES-18 Liquid	93,520,214 (42.2%)	3,208,374 (1.4%)	1,672,153 (0.8%)	7,220,740 (3.3%)
221,505,904	NOAA-21 Liquid	NOAA-21 SC	NOAA-21 Mixed	NOAA-21 Ice

Percentage of NOAA-21 results that match GOES-18: 81.9%

NOAA-21 vs CALIOP

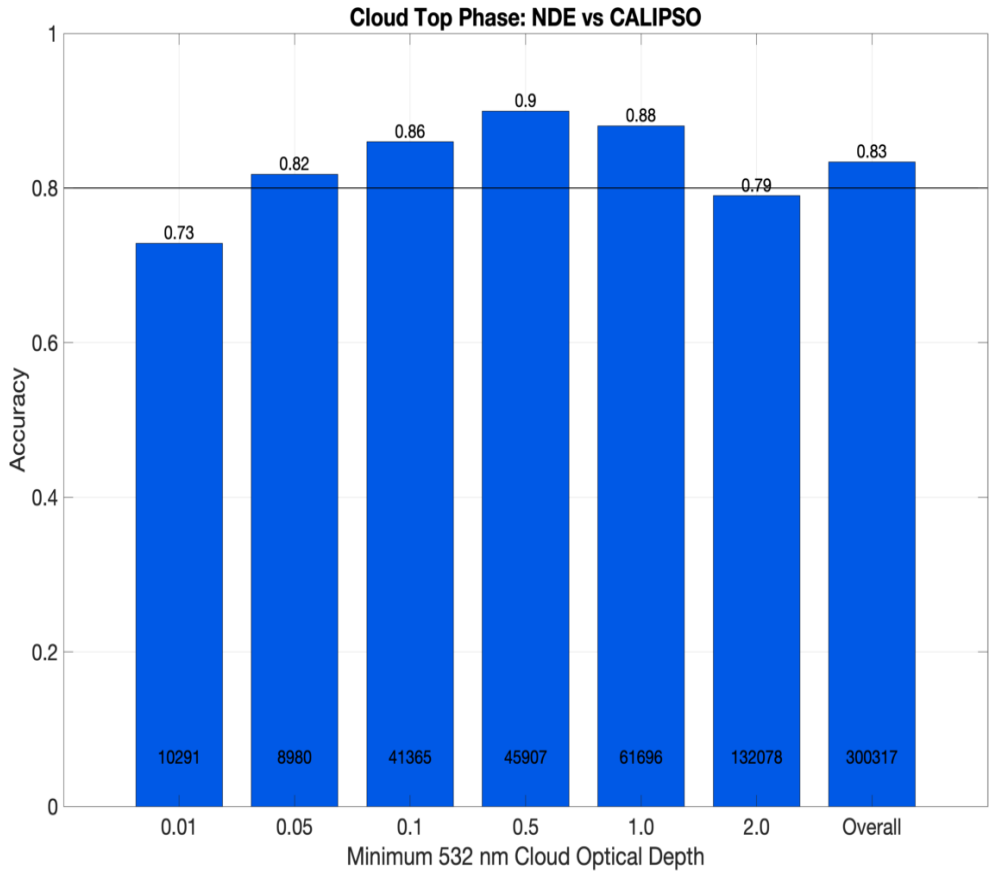
Algorithm Performance Evaluation

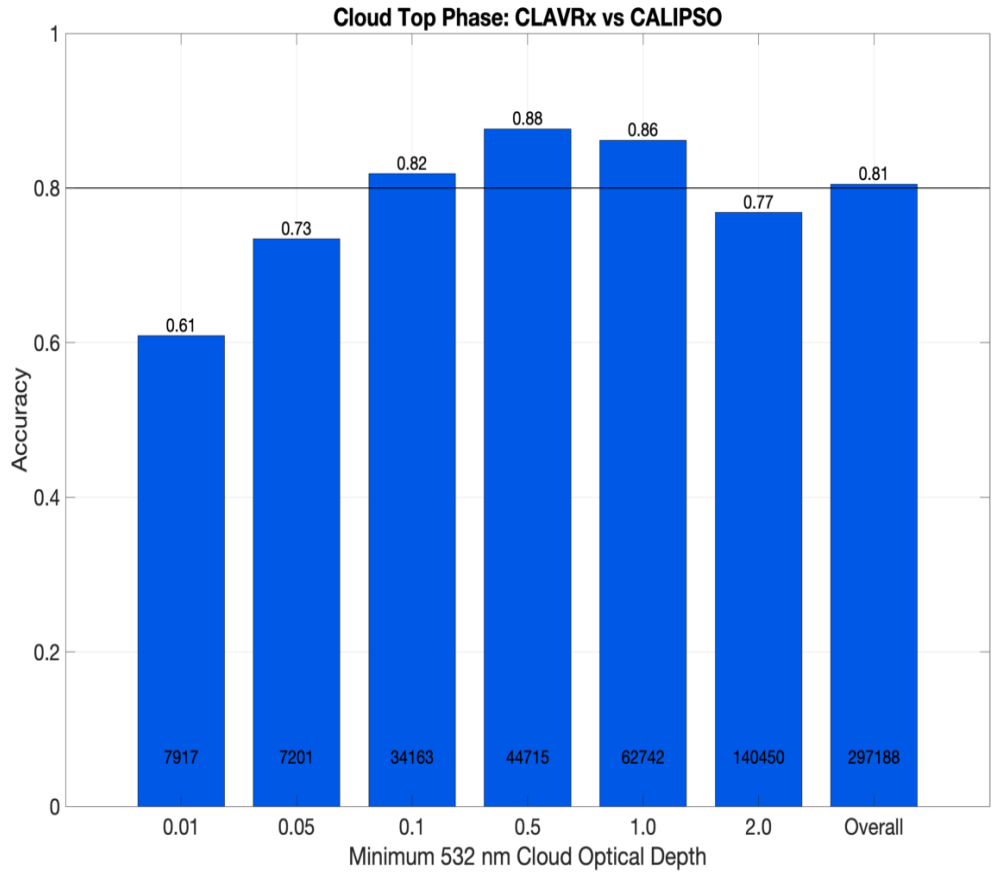
- CALIOP is a lidar onboard of CALIPSO.
- **CALIOP Cloud algorithm results are considered as “Truth”.**
- Nine days of CALIOP and NOAA-21 Matchup data are used from May and June, 2023.
- Filters applied to NOAA-21:
  - Scan time difference ± 15 minutes,
  - Sensor Zenith Angle < 80.0.



Algorithm Performance Evaluation

When clouds with an optical depth of 0.10 (common definition of detectable clouds for passive measurements) or greater are considered, the NOAA-21 cloud top phase product meets the accuracy specification. Classification of optically thick clouds mid-level clouds remains a challenge.





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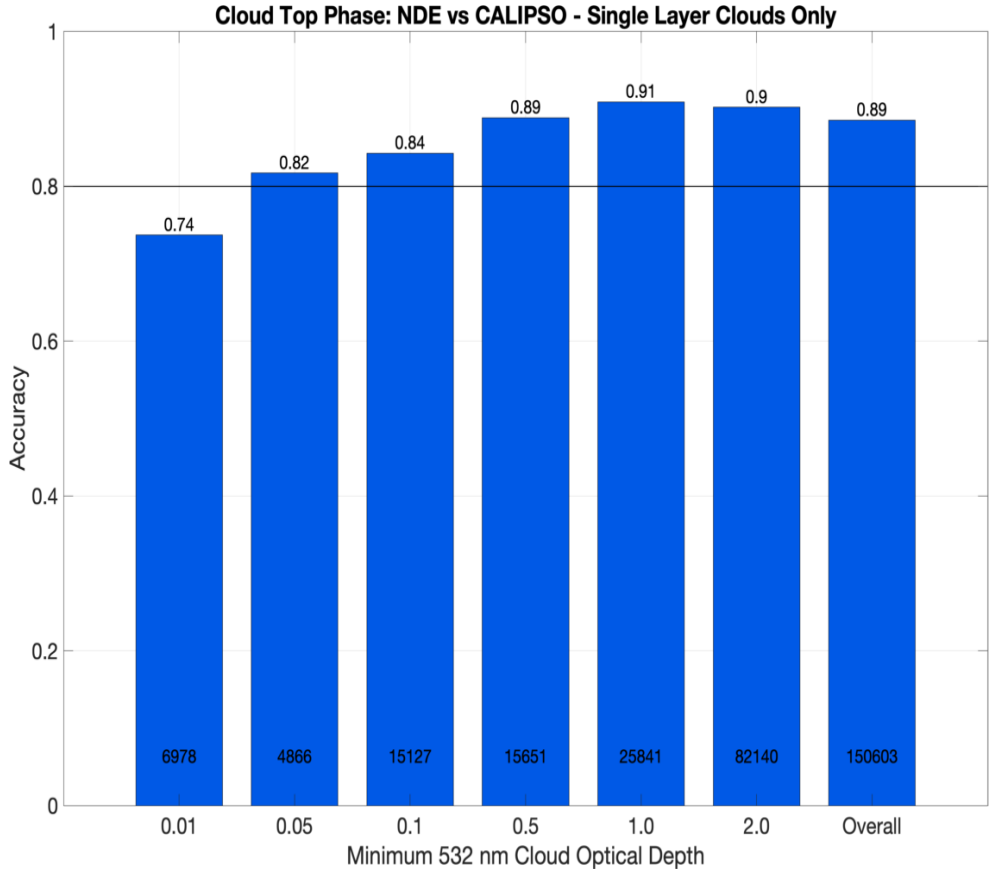
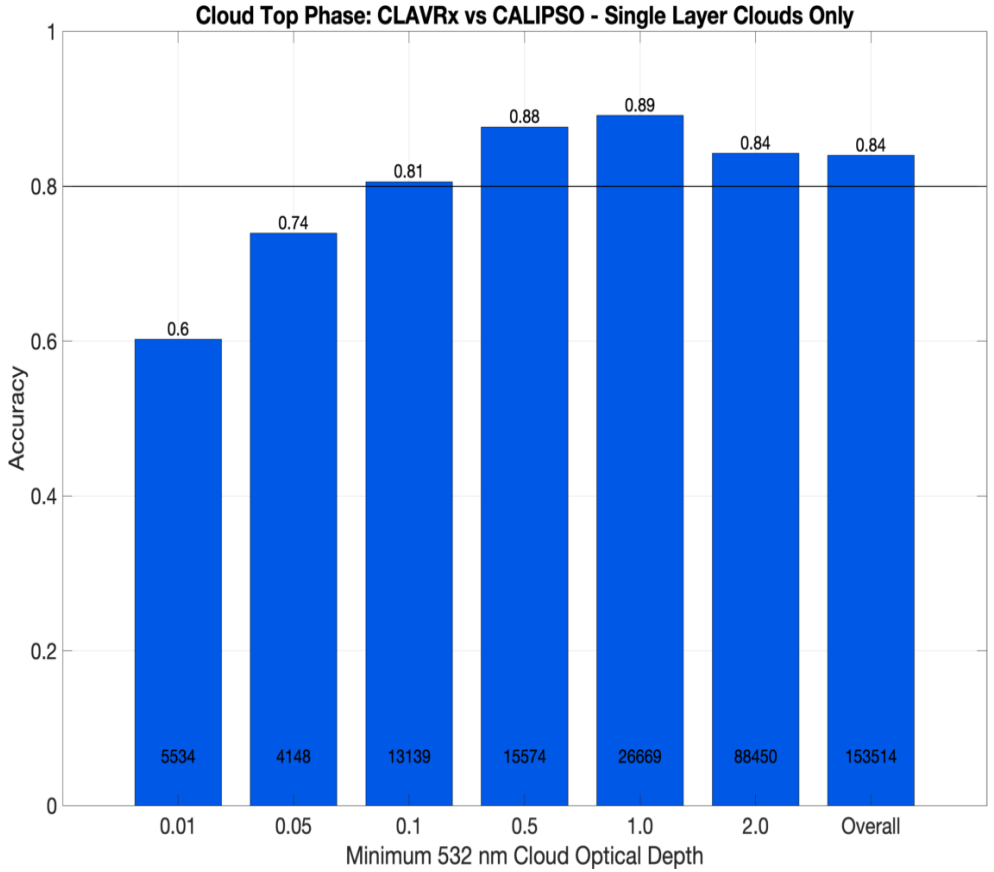




Error Budget

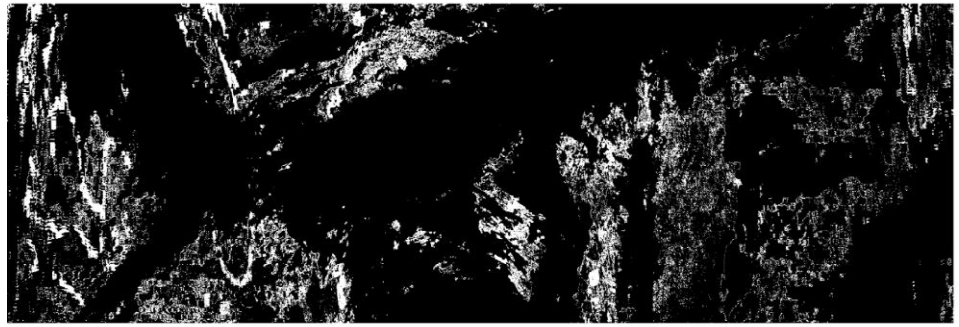
Compare analysis/validation results against requirements, present as a table. Error budget limitations should be explained. Describe prospects for overcoming error budget limitations with future improvements of the algorithm, test data, and error analysis methodology.

Attribute Analyzed	DPS	Requirement/ Threshold	Pre-Launch Performance	On-orbit Performance			Meet Requirement?	Additional Comments
				NOAA-21	NOAA-20	S-NPP		
Coverage	712	Global, Day, Night	N/A	Yes	Yes	Yes	Yes	
Probability	713	Cloud phase with an 80% probability of correct typing.	80%	> 80% when 532 nm cloud optical depth > 0.05	N/A	N/A	Yes	Mixed phase issues?

Quality flag analysis/validation

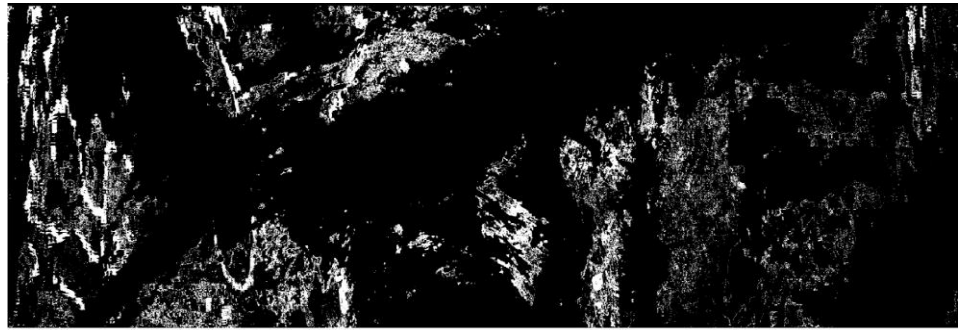
- Defined Quality Flags
  - "**CloudPhaseFlag**"
  - Cloud Phase and Type Quality Flag
  - 0-1, but variable is packed.
  - Bit description
    - 1 - overall quality
    - 2 - level1b quality
    - 3 - beta ratio quality
    - 4 - ice cloud determination quality
    - 5 - surface emissivity quality
    - 6 - satellite zenith angle quality
  - Could this be renamed to "**CloudPhaseFlagPacked**"?

CloudPhaseFlag (June 10, 2023 at 1916 utc)

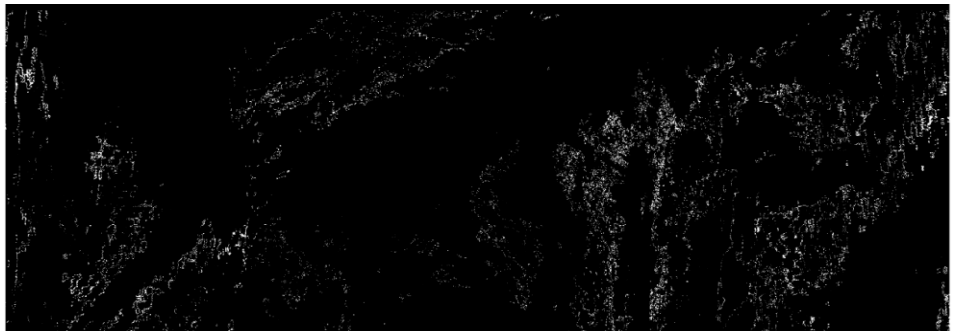


Bit 1

Bit 2



Bit 3



Bit 4

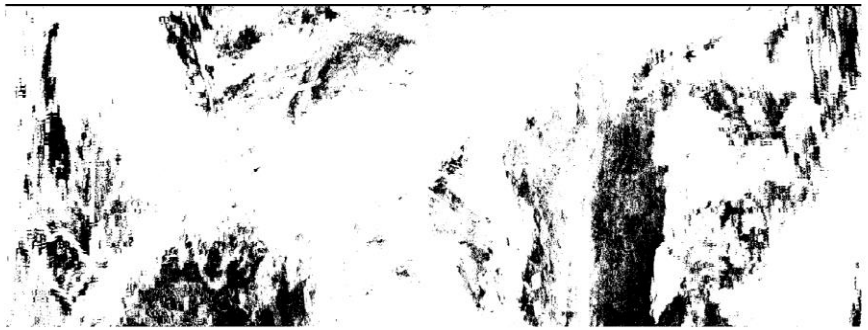
Bit 5

Bit 6

Quality flag analysis/validation

- Defined Quality Flags
  - "**CloudTypePacked**"
  - Cloud Phase and Type Diagnostic Flag
  - 0-1, but variable is packed.
  - Currently 31 tests spread over a packed byte(s) array.
  - Look to the Phase ATBD, section 3.4.3.3 for a complete description of each test.

CloudTypePacked

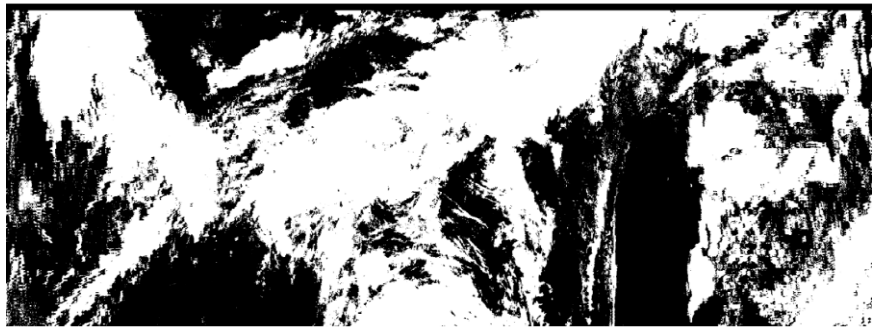


Byte1, Bit 1

Pixel is earth geolocated, has valid spectral data, and is cloudy

Byte2, Bit 8

Result of Sub-classify Ice Cloud (SCIC) Test



Byte 3, Bit 2

Result of Supercooled Liquid Water (SLW) Test

Downstream Product Feedback

Algorithm	Product	Downstream Product Feedback - Reports from downstream product teams on the dependencies and impacts
ACHA, Winds (indirectly)	Height, Pressure, Temperature	Phase mistakes will make cloud products worse and will impact AMV height assignment.
CBH	Cloud Base Height	Product passes Beta/Provisional Maturity using Cloud Top Phase as input
CCL	Cloud Cover Layers	Product passes Beta/Provisional Maturity using Cloud Top Phase as input

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
Developer is no longer involved.	Mike Pavolonis and Corey Calvert are no longer affiliated with the enterprise cloud phase.	Low	Potential to use ECM phase as a replacement. Analysis on this replacement has started.
Short Dataset	For a provisional review, there should be seasonal data available.	Low	For future upgrades, reprocess older data.
CALIOP end of life	CALIOP reached its end of life in June 2023.	Mid	Will need to re-run data historical datasets that overlap CALIOP. NOAA-21 will be limited as seasonal analysis will not have all seasons.

Documentations

Science Maturity Check List	Yes ?
ReadMe for Data Product Users	Will update after this review.
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 for theoretical basis (Pavolonis 2010)
Regular Validation Reports (at least annually) (Demonstrates long-term performance of the algorithm)	As requested. We could add this to our long term monitoring page.

Check List - Provisional Maturity

Beta/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, especially inclusive in the various reviews of this product.
Product is recommended for potential operational use (user decision) and in scientific publications after consulting product status documents.	Yes

Conclusion

- Cal/Val results summary:
  - **Team recommends algorithm Beta/Provisional maturity as of March 30, 2023.**
    - Comparisons to space-based lidar indicate that the NOAA-21 VIIRS cloud phase EDR meet the accuracy requirements documented in the DPS.
    - Current algorithm development is not being actively maintained.
    - While the Cloud team recommends PROVISIONAL based on the evaluation of the current algorithm, the cloud team is actively working on evaluating the use of the cloud phase information provided by the Enterprise cloud mask. Once that is mature, the cloud team suggests retirement of the Enterprise Phase algorithm in lue of the product from the ECM.

Path Forward

- Lessons learned for NOAA-21 Cal/Val
  - Will need to identify a CALIOP substitute for future satellites.
  - Mixed phase continues to be an issue.
- Planned improvements
  - No improvements to the ECP are planned.
  - The cloud team plans to focus on improving the phase from the ECM to replace the enterprise cloud phase. This will be done in concert with the other satellites using the enterprise phase algorithm.
- Future Cal/Val activities / milestones
  - This is a complicated problem while we wait for EarthCARE in September 2024.
  - Investigate ground based lidar systems such as: NASA Micro-Pulse Lidar Network

Backups

Maturity Review - Entry Criteria

- Product Requirements
- Pre-launch Performance Matrix/Waivers
- Provisional Maturity Performance Validation
  - On-orbit instrument performance assessment
    - Identify all of the instrument and product characteristics you have verified/validated as individual bullets
    - Identify pre-launch concerns/waivers, mitigation and evaluation attempts with on-orbit data
- Users/Downstream-Products feedback
- Risks, Actions, Mitigations
  - Potential issues, concerns
- Path forward (to the next maturity stage)
- Summary

Maturity Review - Exit Criteria

- Provisional Maturity Performance is well characterized and meets/exceeds the requirements:
  - On-orbit instrument performance assessment
    - Provide summary for each identified instrument and product characteristic you have validated/verified as part of the entry criteria
    - Provide summary of pre-launch concerns/waivers mitigations/evaluation and address whether any of them are still a concern that raises any risk.
- Updated Maturity Review Slide Package addressing review committee's comments for:
  - Cal/Val Plan and Schedules
  - Product Requirements
  - Provisional Maturity Performance
  - Risks, Actions, Mitigations
  - Path forward (to the next maturity stage)

Algorithm Inputs

- Required Algorithm Inputs
  - Primary Sensor Data
  - Ancillary Data
  - Upstream algorithms
  - LUTs / PCTs

Algorithm Inputs

- Required Algorithm Inputs
  - Primary Sensor Data
  - Ancillary Data
  - Upstream algorithms
  - LUTs / PCTs
    - No LUTs
    - Surface type and other static ancillary data

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 Check List)
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Evaluation of algorithm performance to specification requirements

- Findings/Issues from {previous-maturity}/last Review
  - There is no previous review.

- Improvements since {previous-maturity}/last Review
  - Algorithm has remained unchanged for several years.

- Algorithm performance evaluation
  - Validation data sets include comparisons with CLAVR-x, NOAA-20, SNPP, ABI and CALIOP.
  - Validation methods include visual inspection, comparisons with ABI and CALIOP.
  - Validation results indicate a stable product.
  - CIMSS should include cloud phase in the long term monitoring found here: Cloud Product Trends
- Inter-sensor comparison
  - Compared with S-NPP and NOAA-20 and also CLAVR-x NOAA-21.
  - Compared with ABI operational Phase.
  - Compared with CALIOP Phase.