Provisional Maturity Science Review For NOAA-21 Volcanic Ash Algorithm

Presented by Justin Sieglaff

Date: 08/24/2023

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.

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)

PROVISIONAL MATURITY REVIEW MATERIAL

Outline

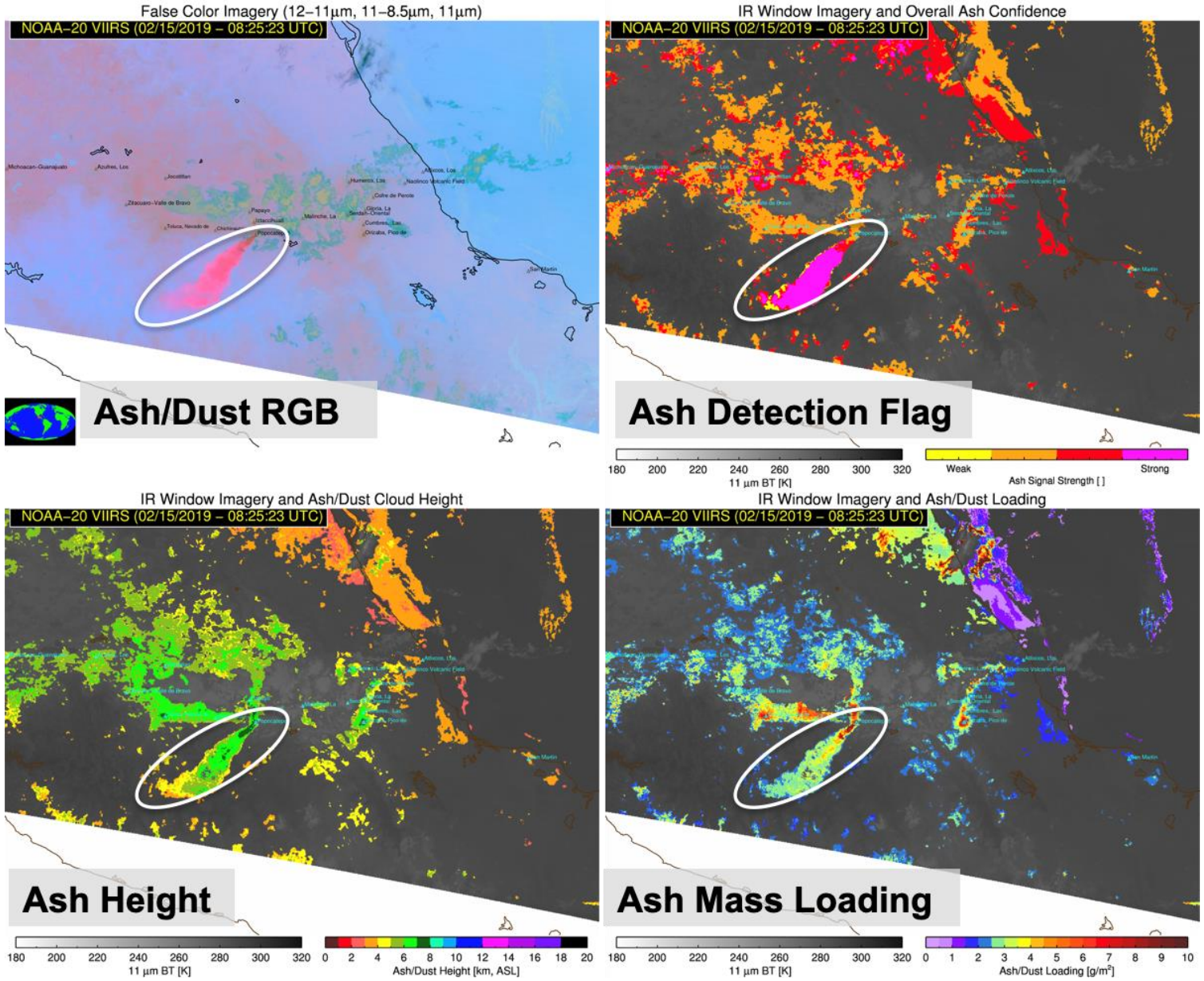
- Algorithm Cal/Val Team Members
- Product Overview/Requirements
- Evaluation of algorithm performance to specification requirements
  - Algorithm version, processing environment
  - Evaluation of the effect of required algorithm inputs
  - Quality flag analysis/validation
  - Error Budget
- User Feedback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

Volcanic Ash Cal/Val Team

Algorithm Cal/Val Team Members

Name	Organization	Major Task
Mike Pavolonis	NOAA/NESDIS	STAR Aviation Science Team Lead and PI
Justin Sieglaff	UW/SSEC/CIMSS	UW/CIMSS Aviation Team Lead
Brianne Andersen	UW/SSEC/CIMSS	Product validation and algorithm improvements
Corey Calvert	UW/SSEC/CIMSS	Product validation and algorithm improvements

Volcanic Ash Overview/Requirements



Requirement Check List – Volcanic Ash

DPS	Requirement	Performance
DPS-586	The Volcanic Ash Detection and Height product shall provide detection, concentration, and top height of volcanic ash, for the total column, globally, under cloud-free conditions, in daytime, for aerosol optical depth greater than 0.15, at the refresh rates of the instrument.	Requirement Met Slides 17-19, 34
DPS-587	The Volcanic Ash Detection and Height product shall provide volcanic ash concentration with a measurement accuracy of 2 tons per square kilometer.	Requirement Met Slides 24, 28, 32, 35
DPS-589	The Volcanic Ash Detection and Height product shall provide volcanic ash concentration with a measurement precision of 2.5 tons per square kilometer.	Requirement Met Slides 25, 29, 33, 35
DPS-588	The Volcanic Ash Detection and Height product shall provide volcanic ash top height with a measurement accuracy of 3 kilometers.	Requirement Met Slides 25, 29, 33, 35

Volcanic Ash Overview/Requirements

Product performance requirements

Attribute	Threshold	Observed/validated
Geographic coverage	Clear, for AOD > 0.15, daytime only	Clear, AOD > 0.15
Vertical Coverage	Total column	Total column
Vertical Cell Size	Total column	Total column
Horizontal Cell Size	0.8 km	0.8 km
Mapping Uncertainty	3 km	3 km
Measurement Range	AOD > 0.15	0.2-50 tons/km^2
Measurement Accuracy	60% correct detection	Loading: 2 tons/km^2 Height: 3 km
Measurement Precision	NA	Loading: 2.5 tons/km^2

Processing Environment and Algorithms (1 slide)

- Description of processing environment and algorithms used to achieve the maturity stage:
  - **Algorithm version: VolcanicAshv3r2_npp[j01,n21]**
  - Version of LUTs used: April 2020
  - Version of PCTs used: n/a
  - Effective date: October 18, 2022 (for SNPP and NOAA-20)
    - NOAA-21 data available from the NCCF I&T (PDA) stream since February 9, 2023
  - Evaluation periods are tied to NOAA-21 SDR Maturity dates:
    - NOAA-21 VIIRS SDR Beta: February 23, 2023
    - **NOAA-21 VIIRS SDR Provisional: March 30, 2023**
    - **NOAA-21 VIIRS Volcanic Ash EDR available: April 2023**

Manual Analysis of NOAA-21 VIIRS Volcanic Ash Cases

Version of NOAA-21 volcanic ash EDR evaluated: v3r2

Evaluation Methods:

1. Evaluation of ash detection using human expert analysis

2. Validation of height and loading using advection patterns

3. Comparisons to NOAA-20 ash products

4. Comparisons of NOAA-21 EDR to VOLCAT

Manual Analysis of NOAA-21 VIIRS Volcanic Ash Cases

- 42 volcanic ash cases were identified and analyzed, totaling over 25,000 NOAA-21 VIIRS M-band pixels

- Ash clouds from a variety volcanoes were included:
  - Sheveluch (8 cases)
  - Popocatepetl (25 cases)
  - Cotopaxi (1 case)
  - Fuego (2 cases)
  - Sangay (2 cases)
  - Ruiz (1 case)
  - Sabancaya (3 cases)

- The diurnal cycle is sampled
- Tropical and mid-latitude ash clouds are sampled
- Ash pixels are mixture of over land and over water
- Period of cases is April - July 2023, additional months will continue to be added for Full Maturity review
- NOAA-20 VIIRS was also analyzed for 28 of the 42 NOAA-21 cases and are used for comparisons

Validation of ash detection using human expert analysis

How to use Enterprise Volcanic Ash Algorithm Output

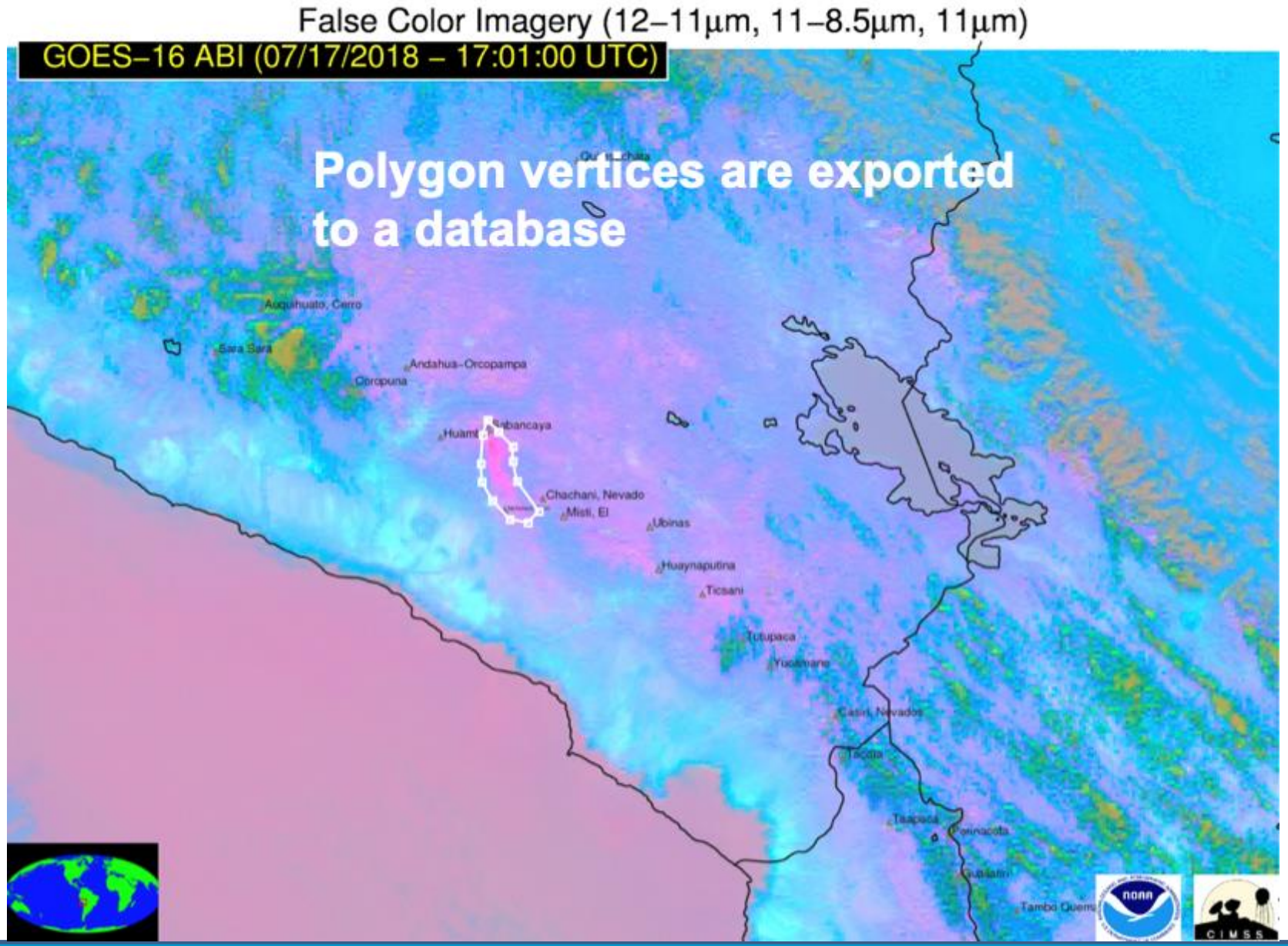
The fundamental outputs of the VA is the ash cloud top height and ash mass loading. Additional QF can be used to obtain algorithm ash detection confidence flags.

- **The ash cloud top height provides the height [km; above mean sea level] for the highest ash cloud layer for pixels determined to potentially contain volcanic ash.**

- **The ash mass loading provides the column integrated total ash mass contained within the pixel [g m^{-2} equal to tons km^{-2}] for pixels determined to potentially contain volcanic ash.**

- **The ash detection QF flags denote the confidence that volcanic ash is present in the pixel:**
  - **0: high confidence; 1: moderate confidence; 2: low confidence; 3: very low confidence; 4: ash not present**

Web-based Tool to Identify and Export Ash Polygons



Ash Detection: Finding a needle in the haystack

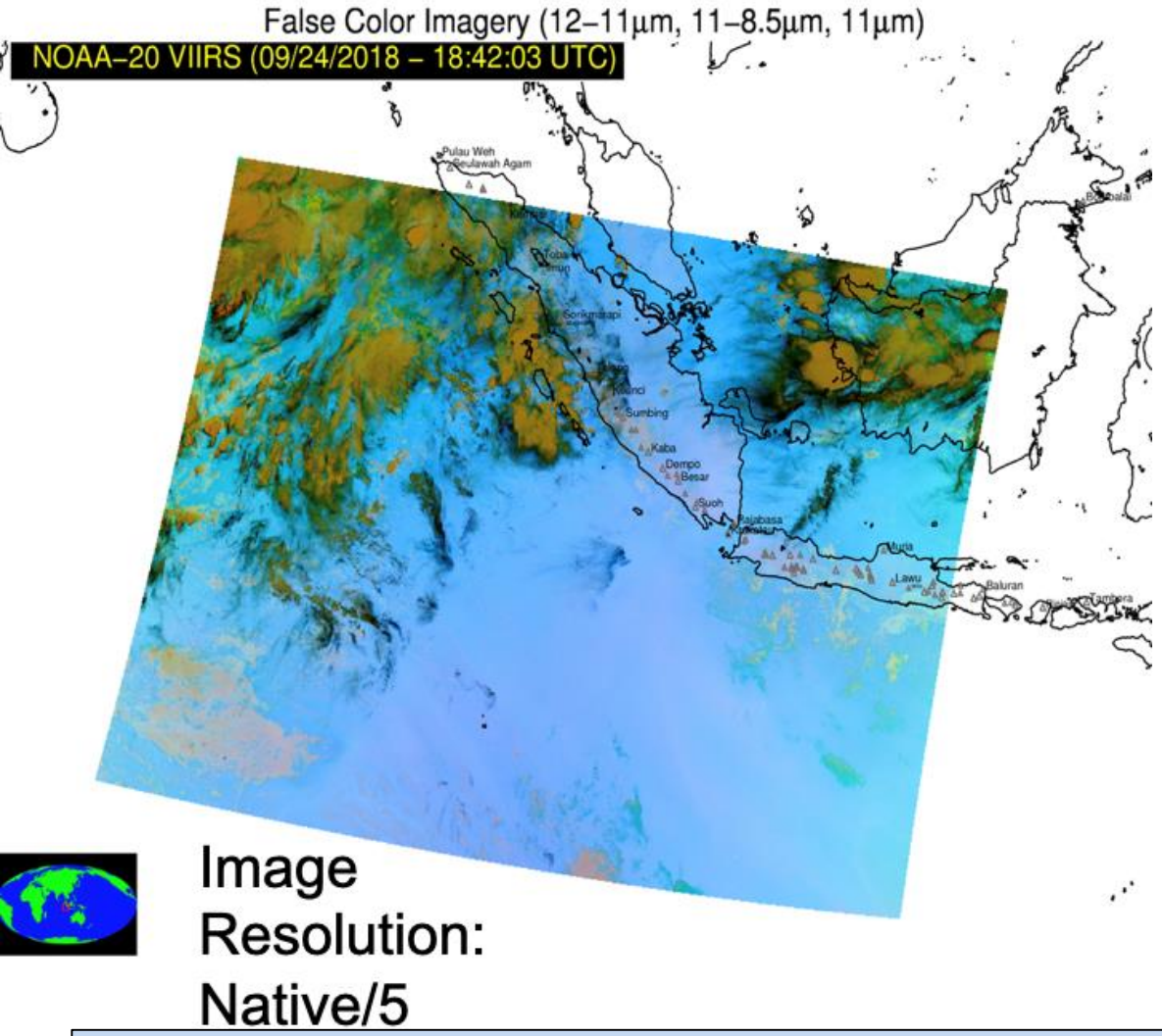


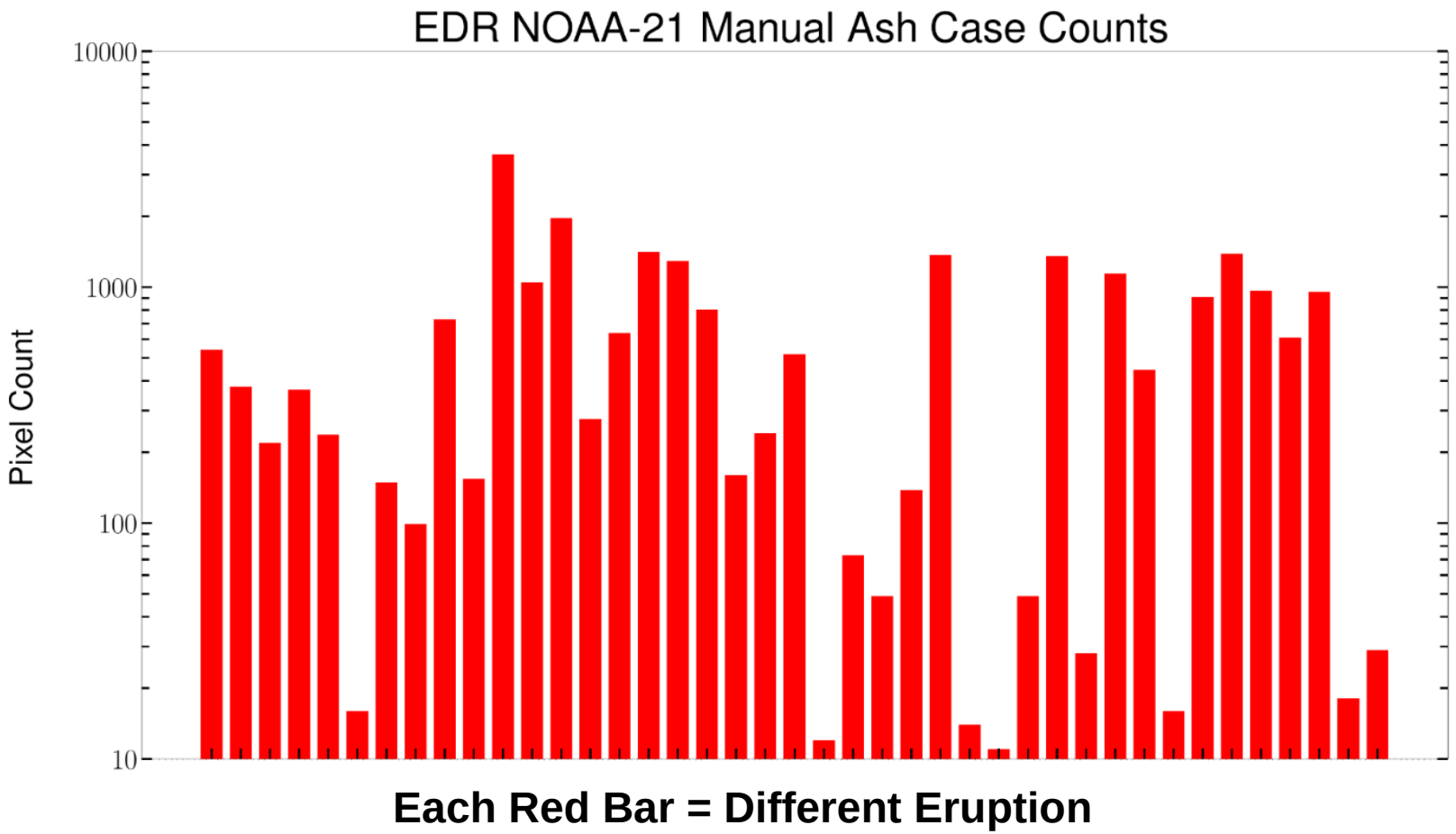
Image Resolution: Native/5

Image Resolution: Native * 1.5

Quantitative ash detection is a huge challenge since usually only a small minority of pixels actually contain ash, and many non-ash pixels will exhibit spectral signatures that are consistent with ash

Ash Detection: Finding a needle in the haystack

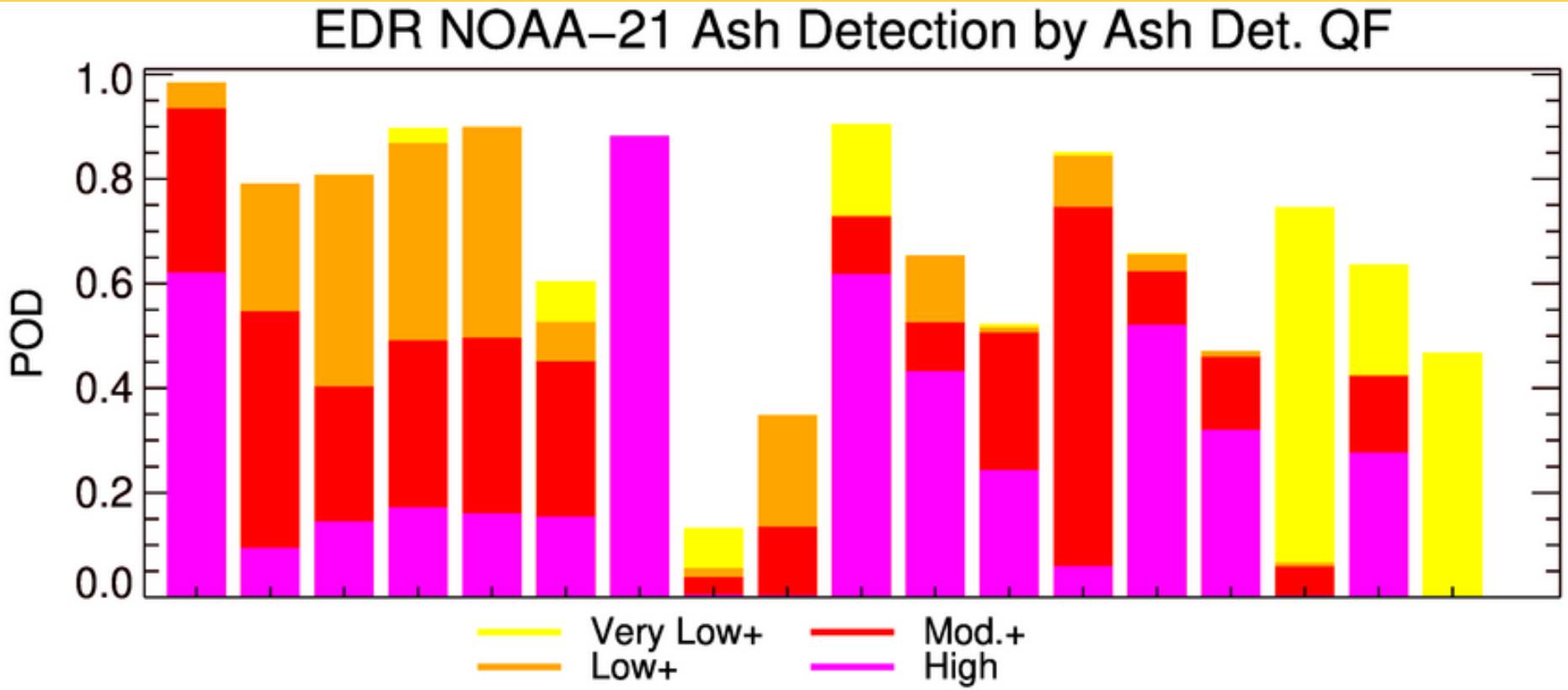
Pixel counts for a sampling of ash clouds observed by NOAA-21



- The most commonly occurring ash clouds only encompass 1000 pixels or less at a given time (see bar chart to the left)
- A VIIRS M-Band 6-min granule contains ~9.8 million Earth view pixels at the 750 m resolution

- Thus, the number of *non-ash* pixels is typically at least 3 to 4 **orders of magnitude** greater than the number of ash pixels, at any given time

Ash Detection Assessment



Each Bar = Different Eruption

- Comprehensive ash detection is not possible without including pixels flagged as “very low confidence” by the ash detection component of the algorithm.
- Even when “very low confidence” detections are included, the ash detection often significantly underperforms relative to the human expert analysis.
- False detection significantly increases as the confidence in the ash detection decreases.

Validation of Ash Height and Loading Using Advection patterns

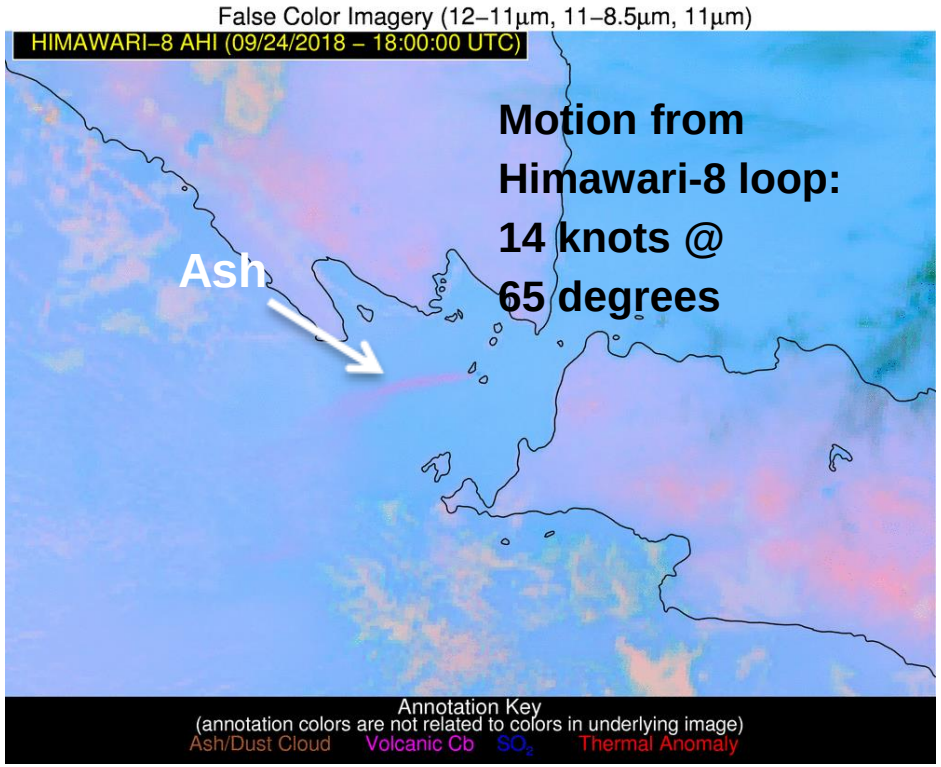
Advection Patterns

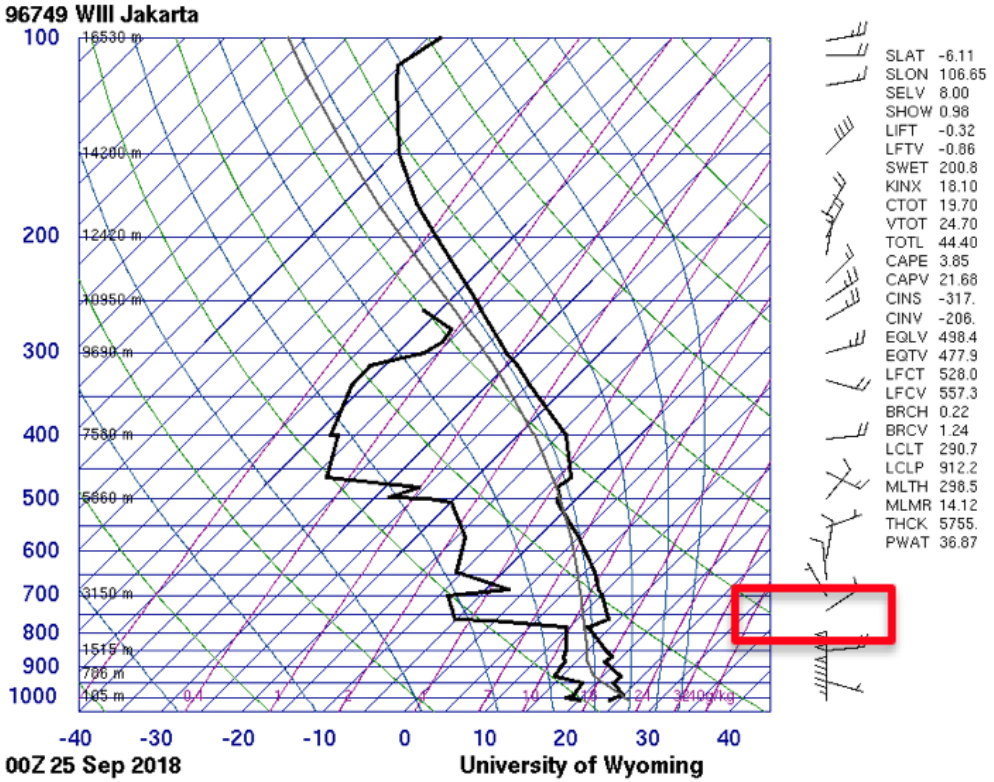
- As outlined in validation plan, given that CALIOP observations of volcanic ash, that are co-located with NOAA-21, are rare, alternative validation methods are utilized. (Additionally the CALIOP mission just ended in early August)

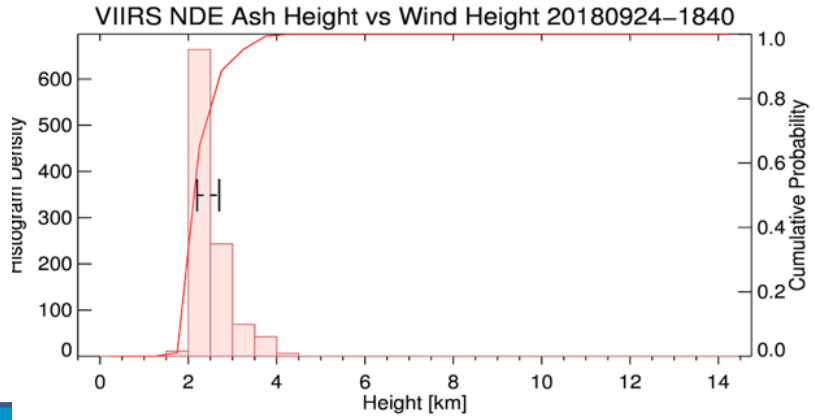
- Manual analysis of false color imagery is used to pixels that truly contain ash

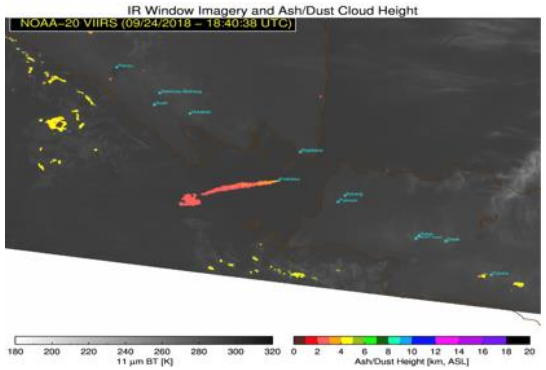
- **Ash Height:** Use false color image movies to extract ash cloud motion (speed and direction). Use nearby radiosonde to assign the satellite derived motion a height range (only cases where vertical shear is sufficient to constrain height to a ~1 km layer were used)
- **Ash Mass Loading:** Satellite-derived mass loading is a strong function of the assigned cloud height. Thus, the cloud motion derived height range can be used to compute a highly representative range of “truth” mass loading.

Advection Patterns



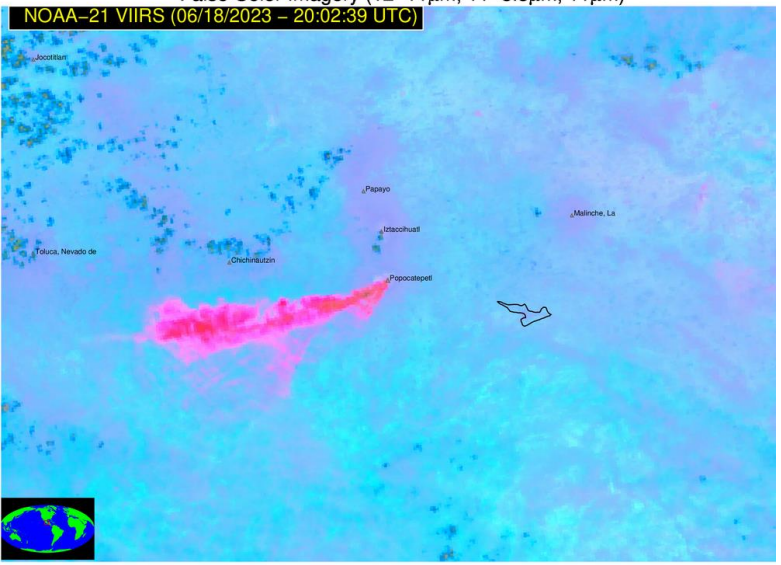




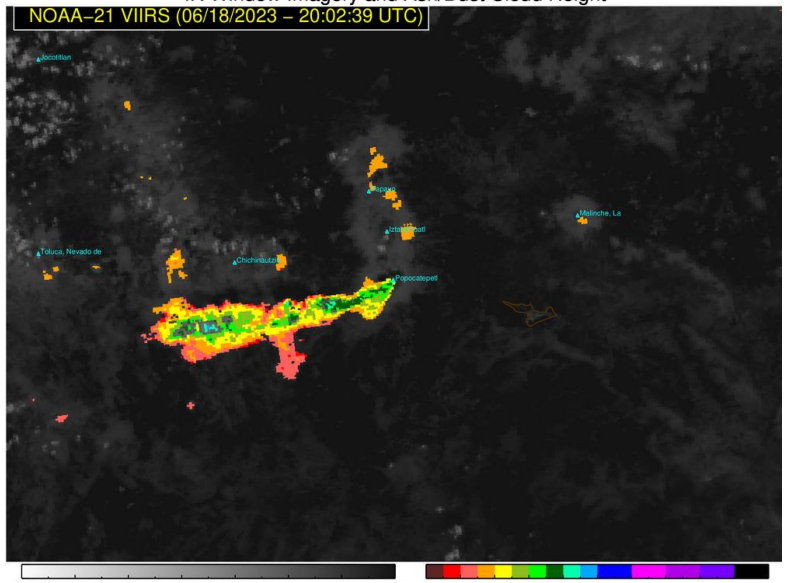


NOAA-21 EDR Products

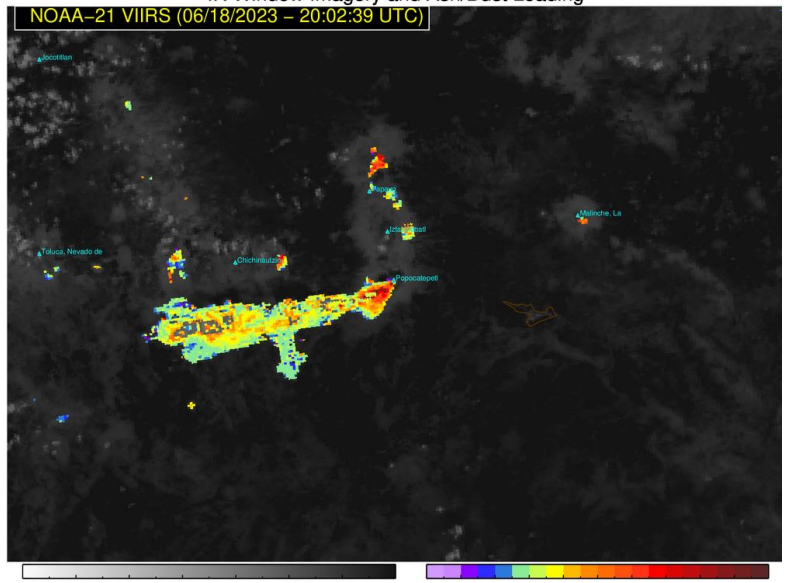
False Color Imagery (12–11µm, 11–8.5µm, 11µm)



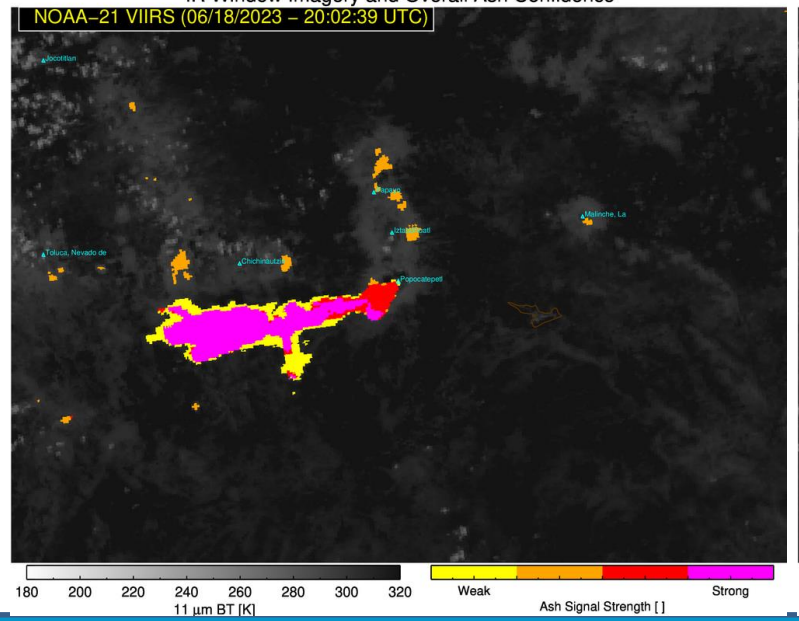
IR Window Imagery and Ash/Dust Cloud Height



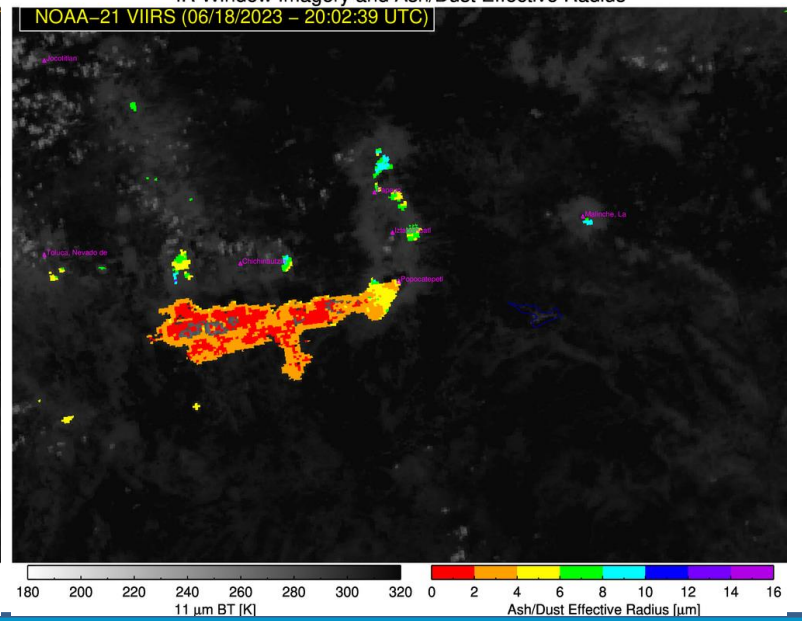
IR Window Imagery and Ash/Dust Loading



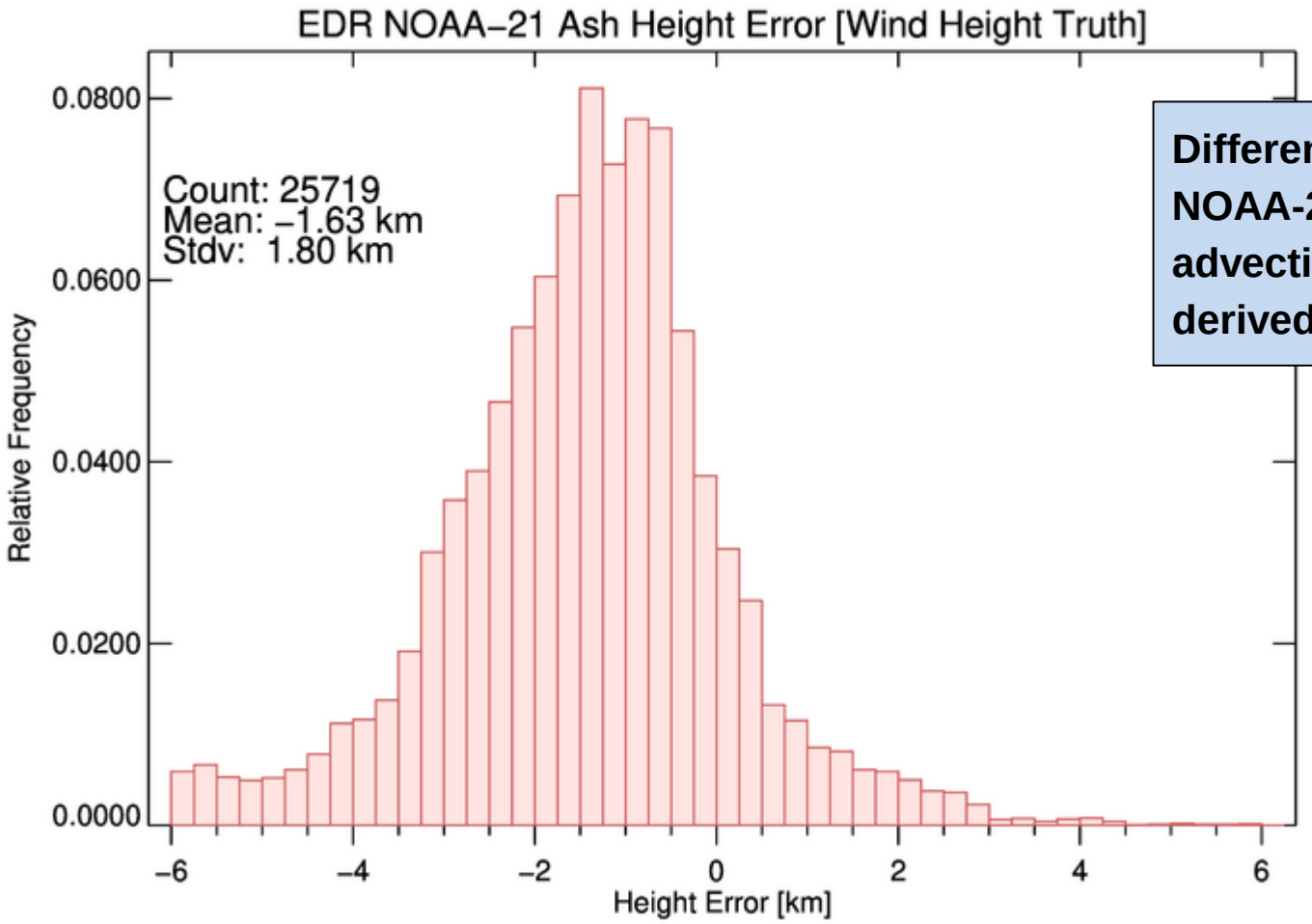
IR Window Imagery and Overall Ash Confidence



IR Window Imagery and Ash/Dust Effective Radius



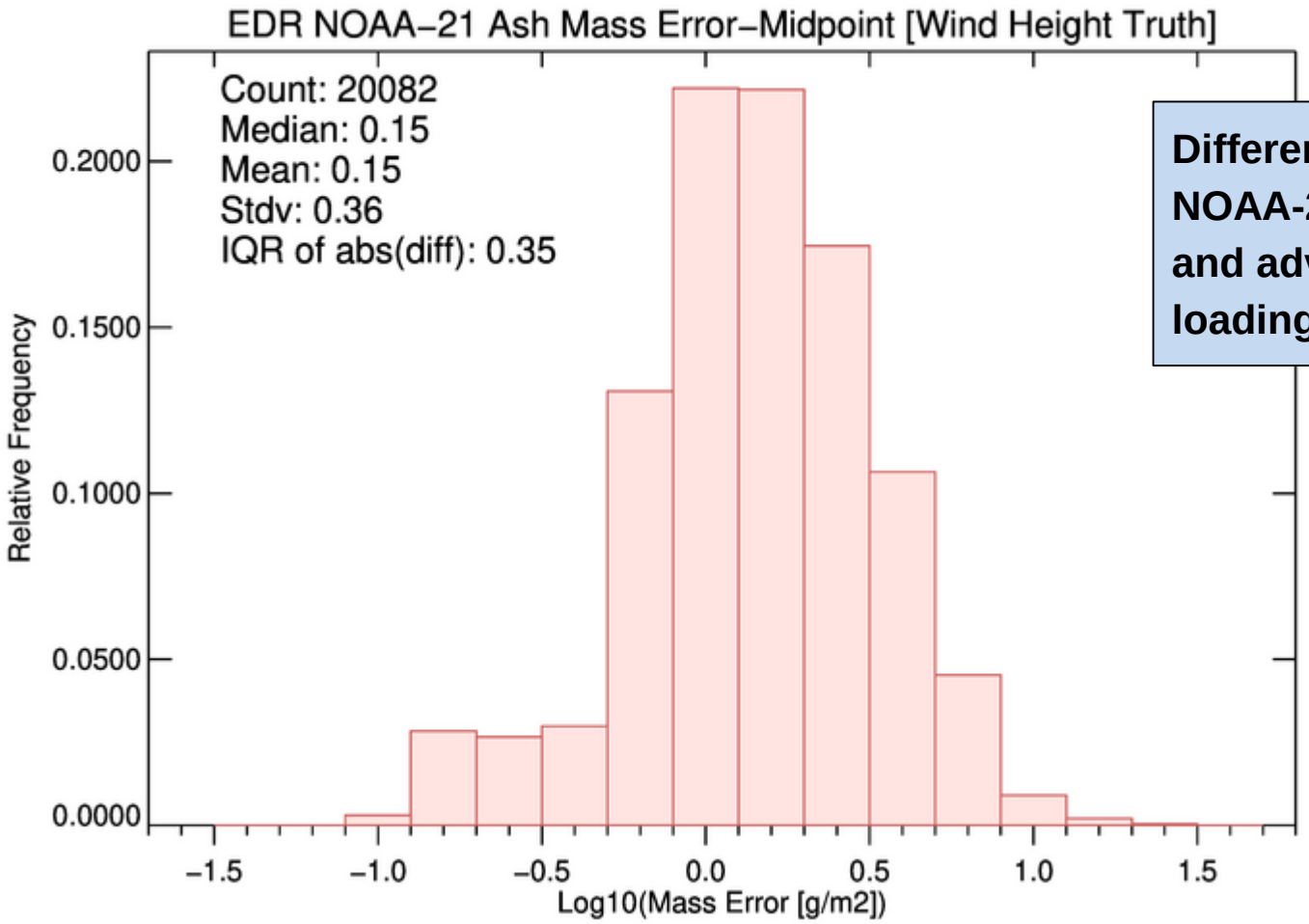
Advection Patterns: Ash Height Validation



Difference between NOAA-21 ash height and advection based height derived truth

Mean Difference (accuracy): -1.63 km (within 3 km requirement)

Advection Patterns: Ash Mass Loading Validation



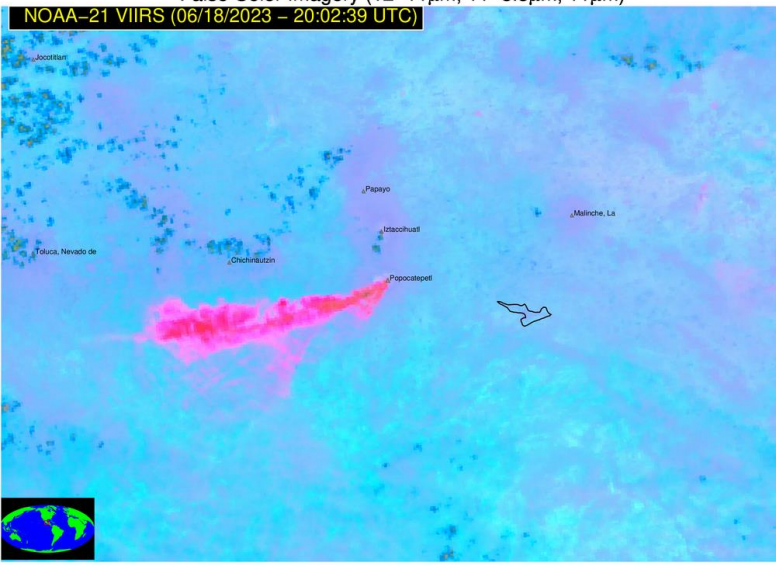
Difference between NOAA-21 mass loading and advection based loading derived truth

Median Difference (accuracy): 0.15 log10(g/m2) (within 0.60 log10(g/m2) spec)
Interquartile range (precision): 0.35 log10(g/m2) (within 0.70 log10(g/m2) spec)

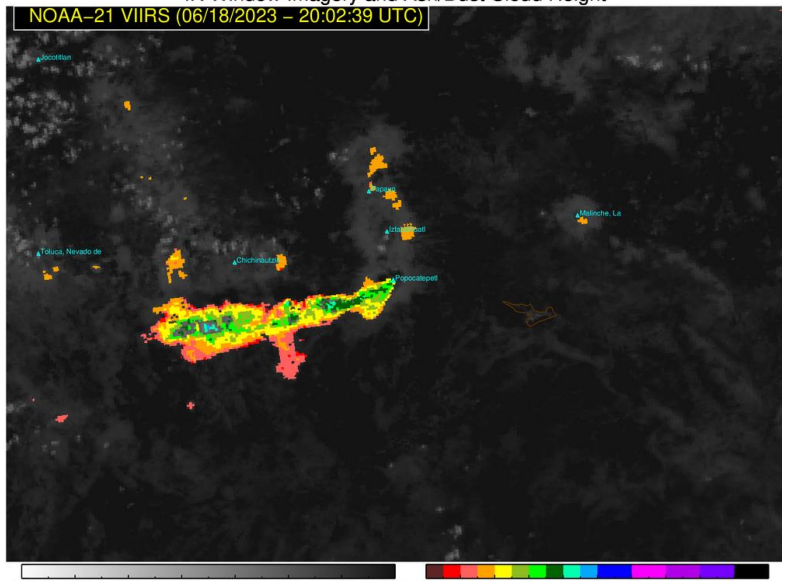
NOAA-20 and NOAA-21 Comparisons

NOAA-21 and NOAA-20 EDR Comparisons

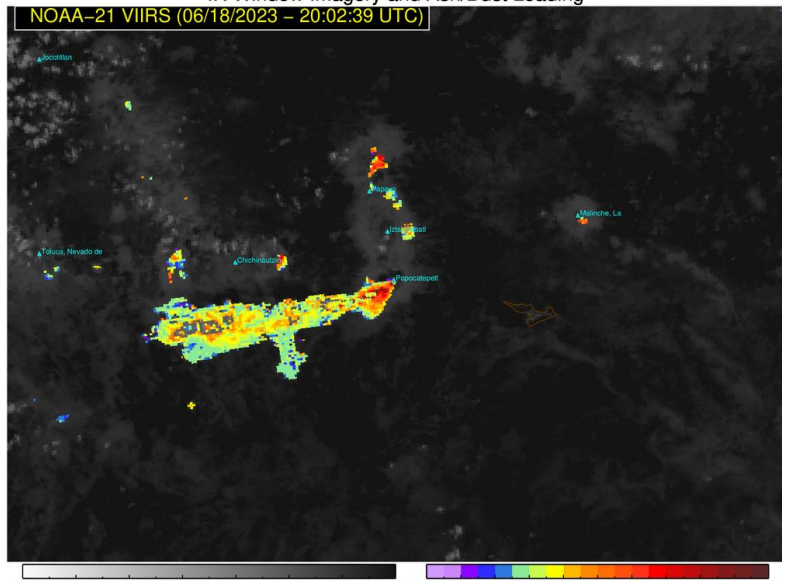
False Color Imagery (12–11μm, 11–8.5μm, 11μm)



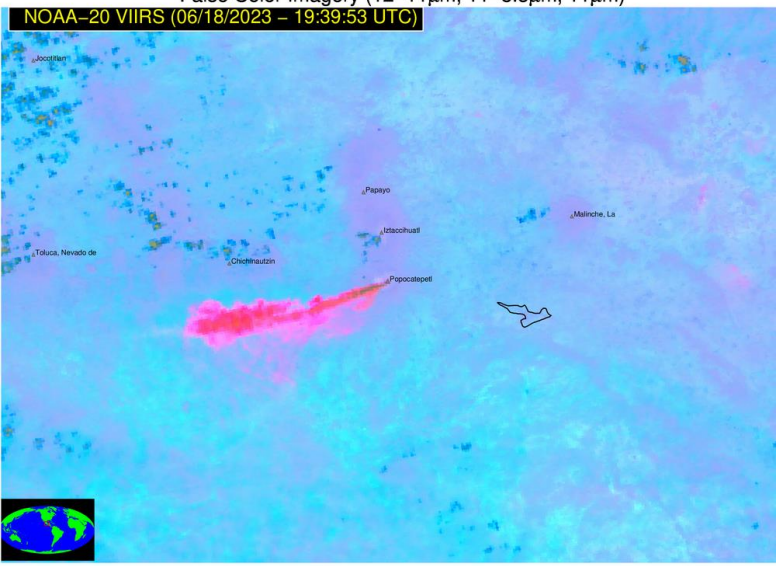
IR Window Imagery and Ash/Dust Cloud Height



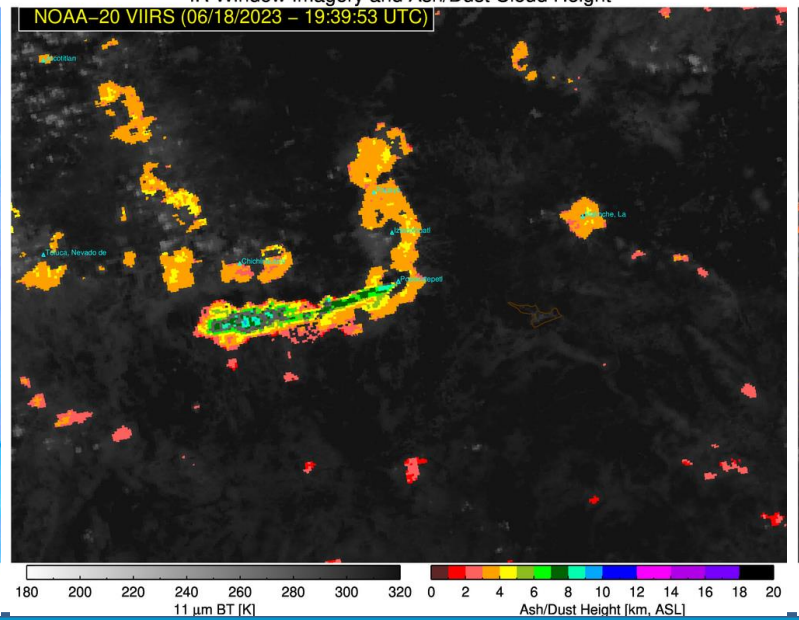
IR Window Imagery and Ash/Dust Loading



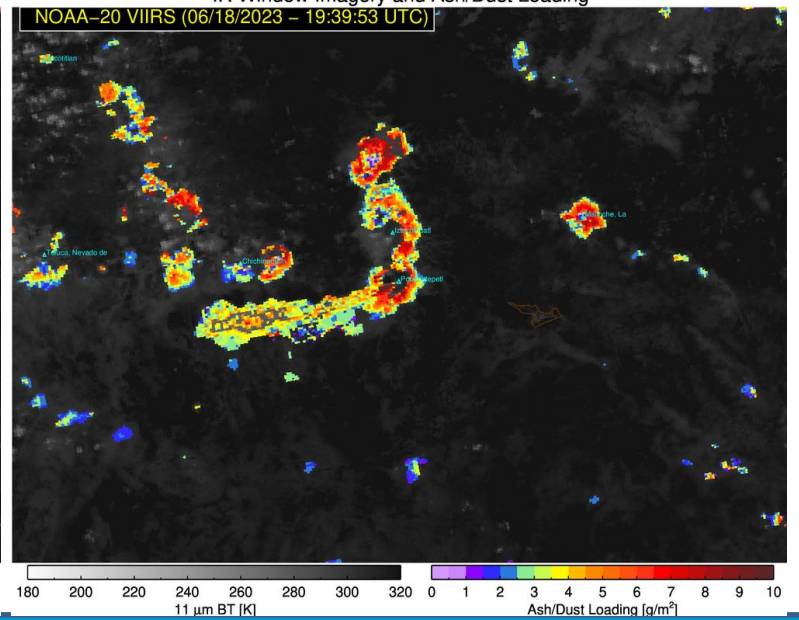
False Color Imagery (12–11μm, 11–8.5μm, 11μm)



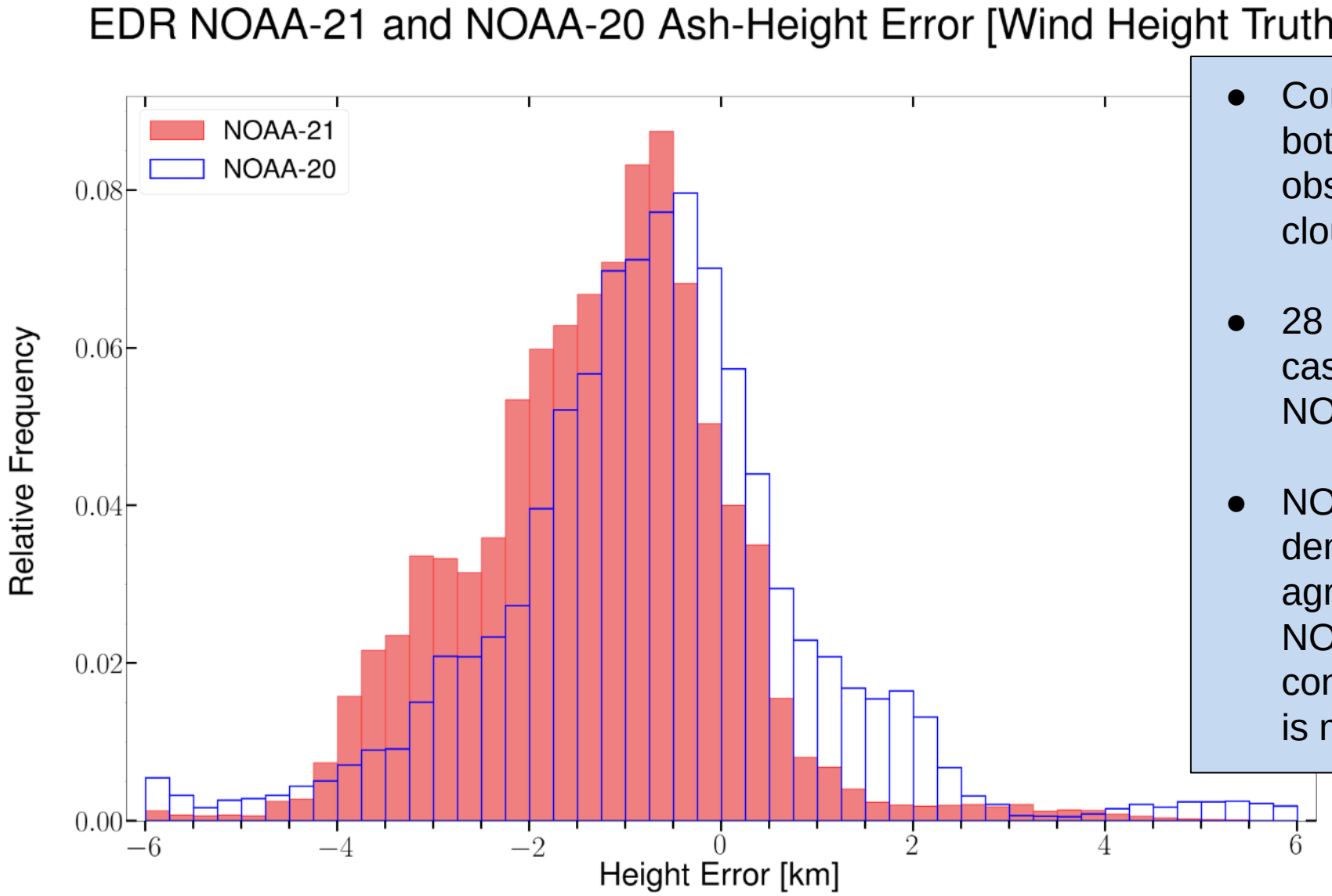
IR Window Imagery and Ash/Dust Cloud Height



IR Window Imagery and Ash/Dust Loading

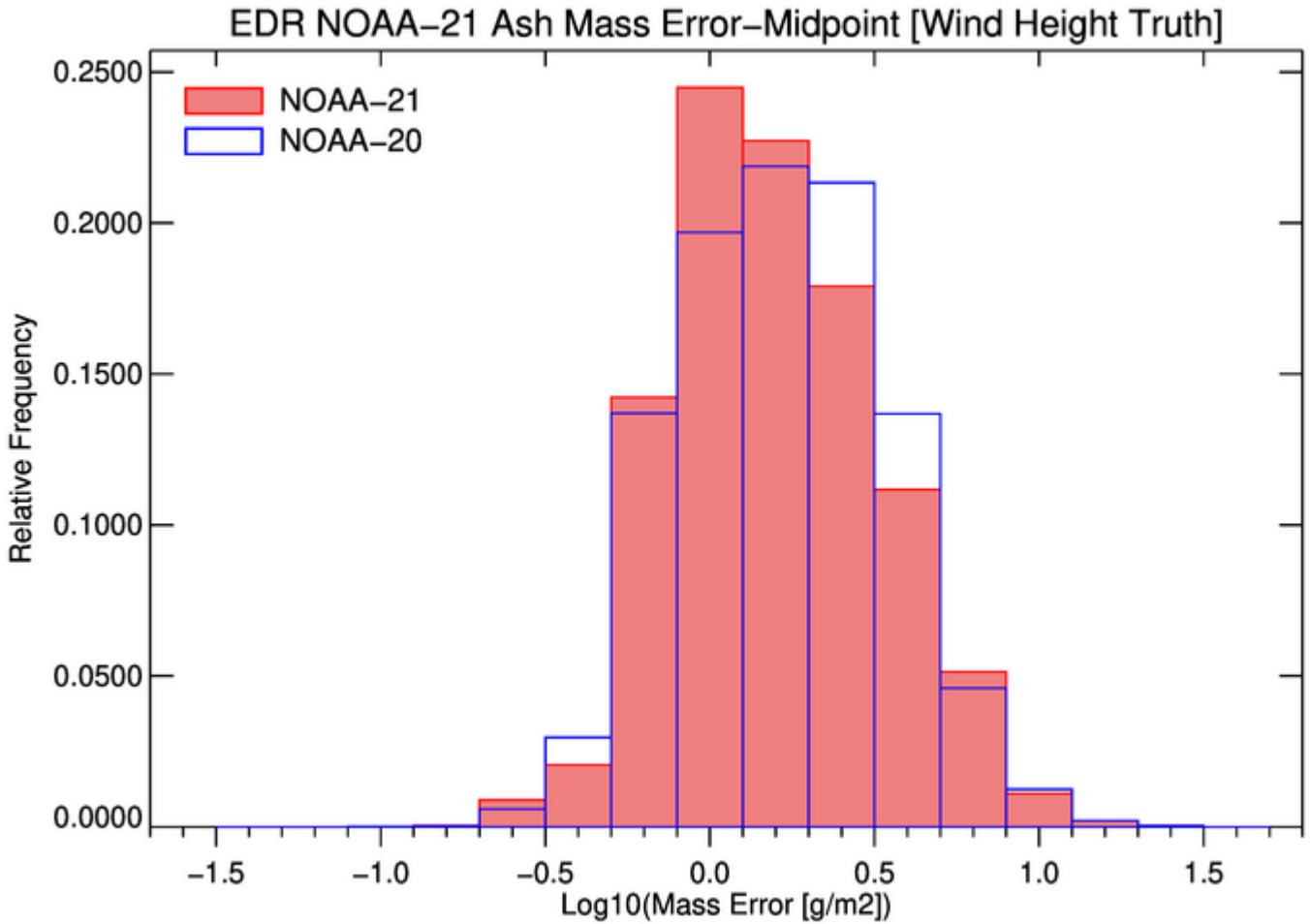


Ash Height Validation Comparison



- Comparison for cases where both NOAA-20 and NOAA-21 observed the same volcanic cloud <= 85 minutes.
- 28 of the 41 NOAA-21 EDR cases had matchups with NOAA-20.
- NOAA-21 ash height error demonstrates excellent agreement with fully validated NOAA-20 data, lends confidence the NOAA-21 EDR is meeting requirements

Ash Mass Loading Validation Comparison

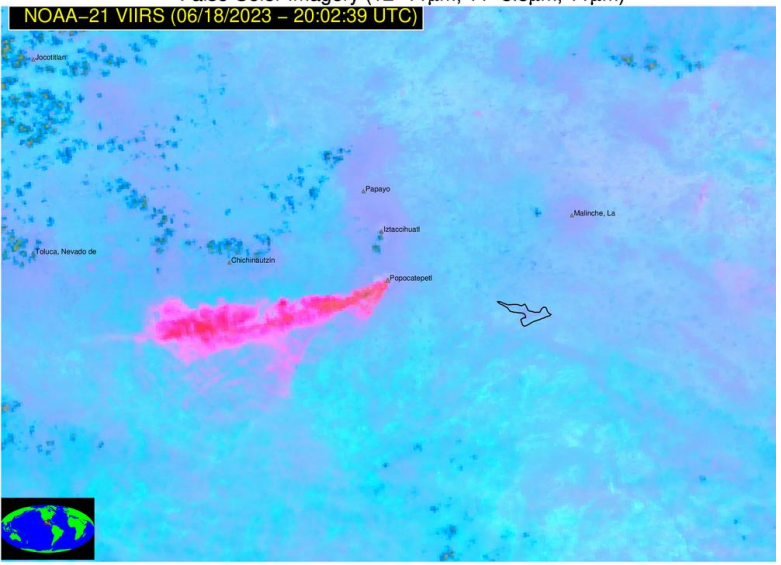


- Comparison for cases where both NOAA-20 and NOAA-21 observed the same volcanic cloud <= 85 minutes.
- 28 of the 38 NOAA-21 EDR mass cases had matchups with NOAA-20.
- NOAA-21 ash loading error demonstrates excellent agreement with fully validated NOAA-20 data, lends confidence the NOAA-21 EDR is meeting requirements

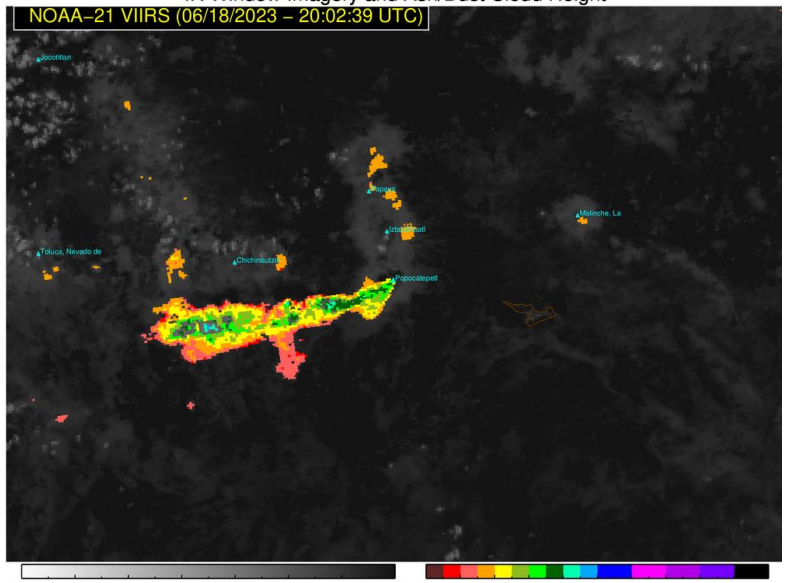
NOAA-21 Volcanic Ash EDR and VOLCAT Comparisons

NOAA-21 VOLCAT and EDR Comparisons

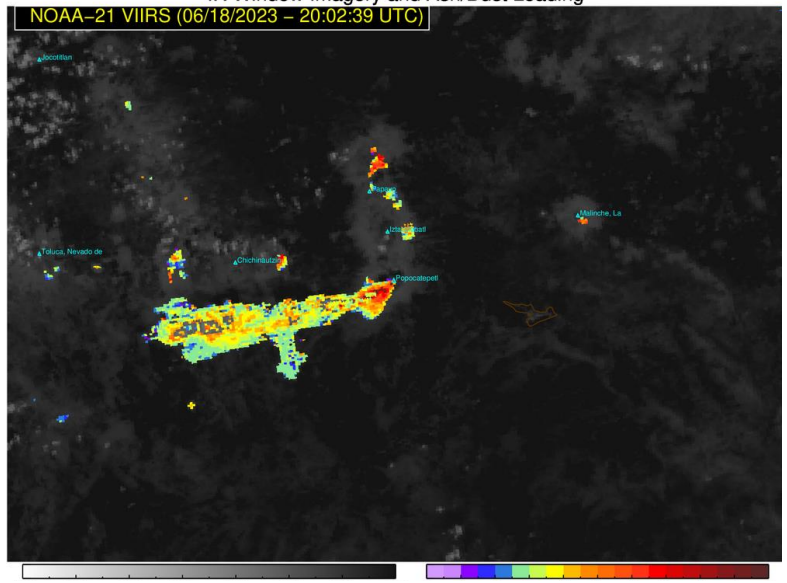
False Color Imagery (12–11μm, 11–8.5μm, 11μm)



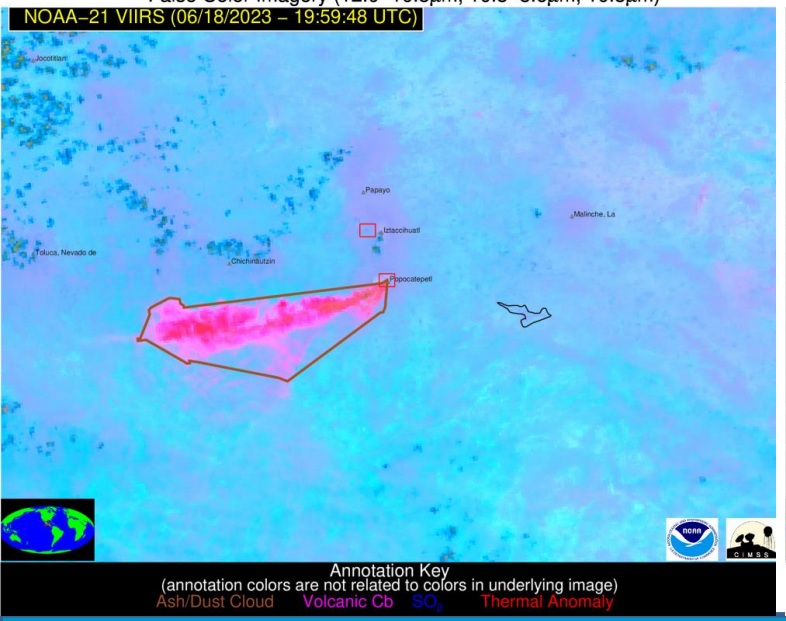
IR Window Imagery and Ash/Dust Cloud Height



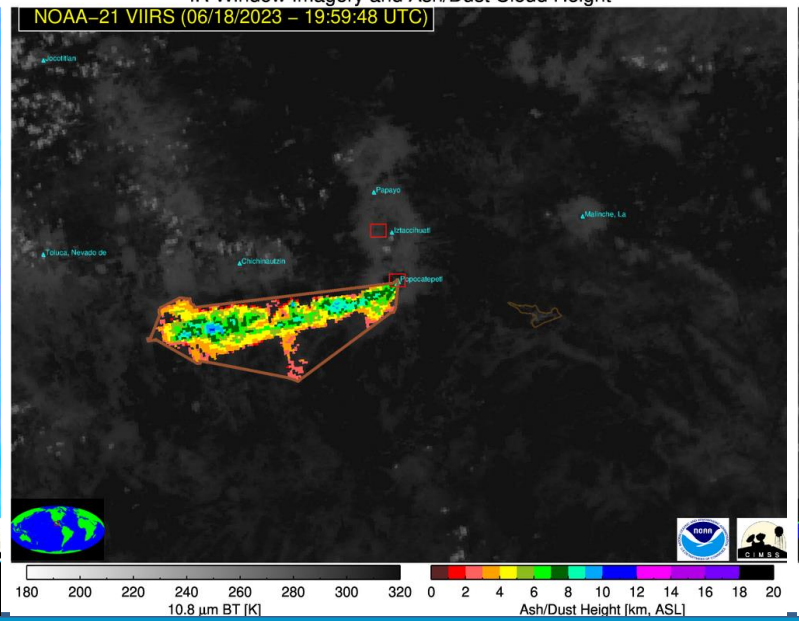
IR Window Imagery and Ash/Dust Loading



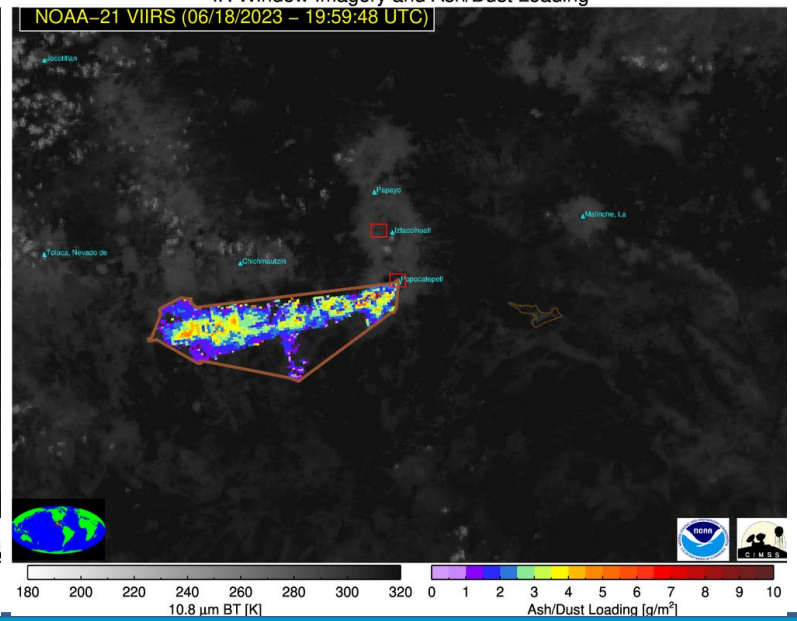
False Color Imagery (12.0–10.8μm, 10.8–8.6μm, 10.8μm)



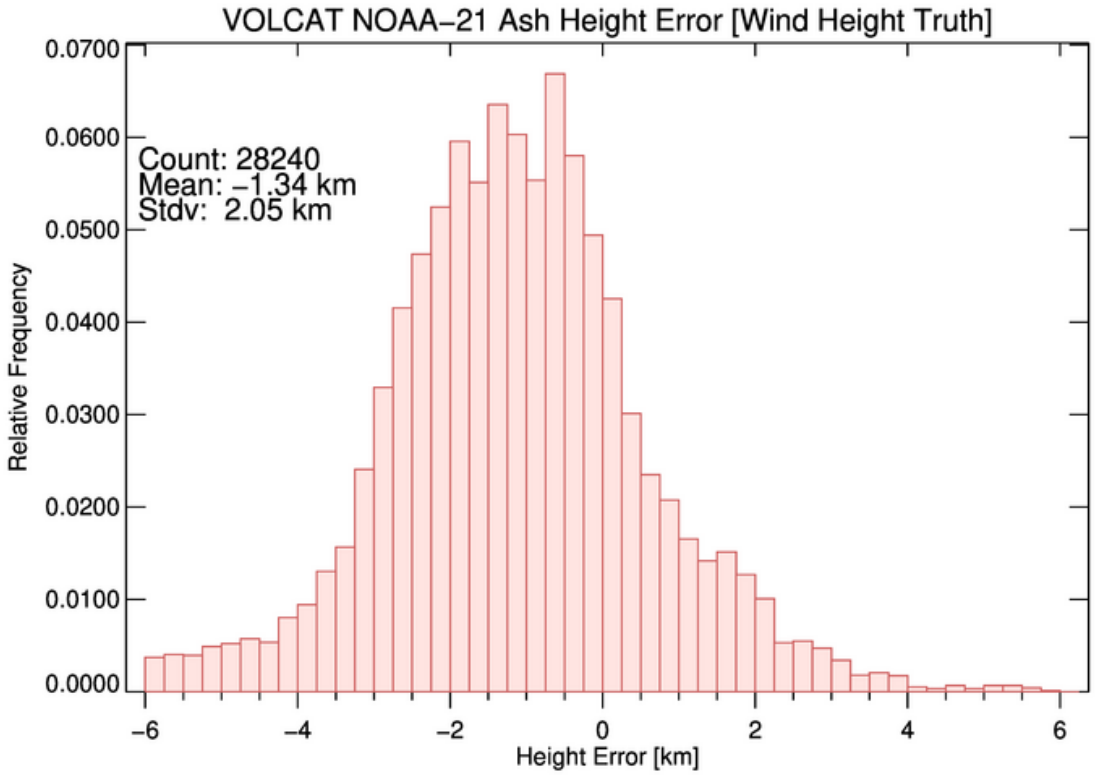
IR Window Imagery and Ash/Dust Cloud Height



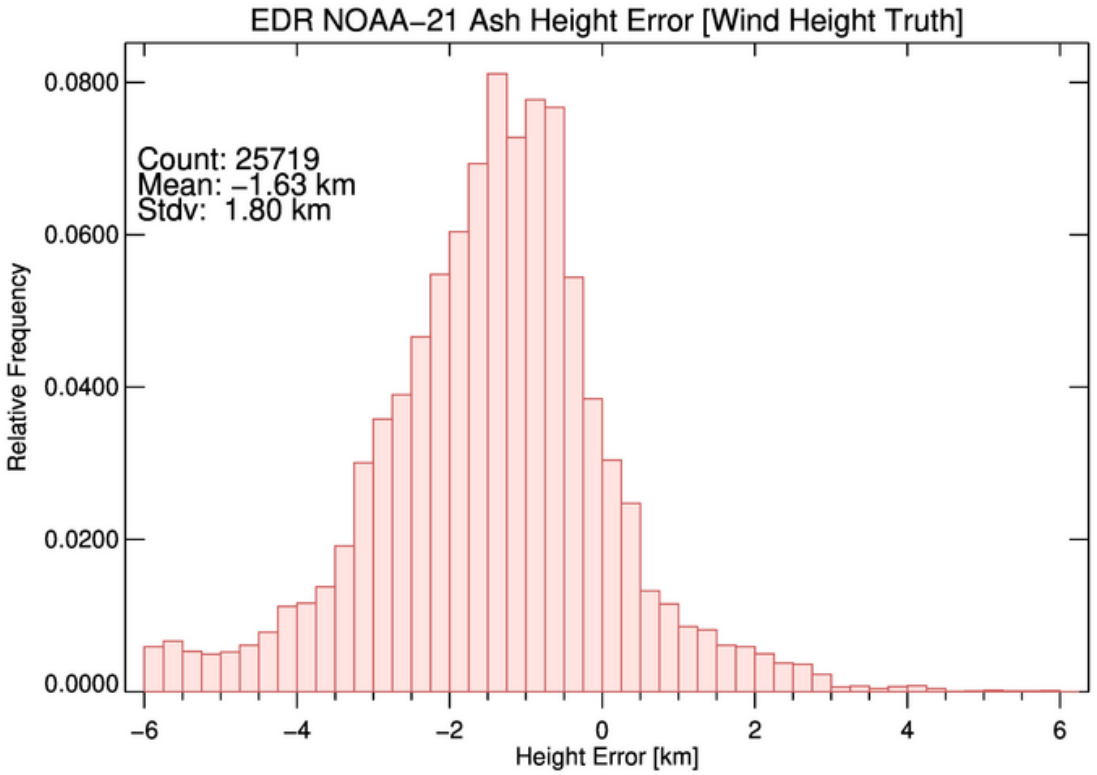
IR Window Imagery and Ash/Dust Loading



Ash Height VOLCAT vs. EDR Validation Comparison



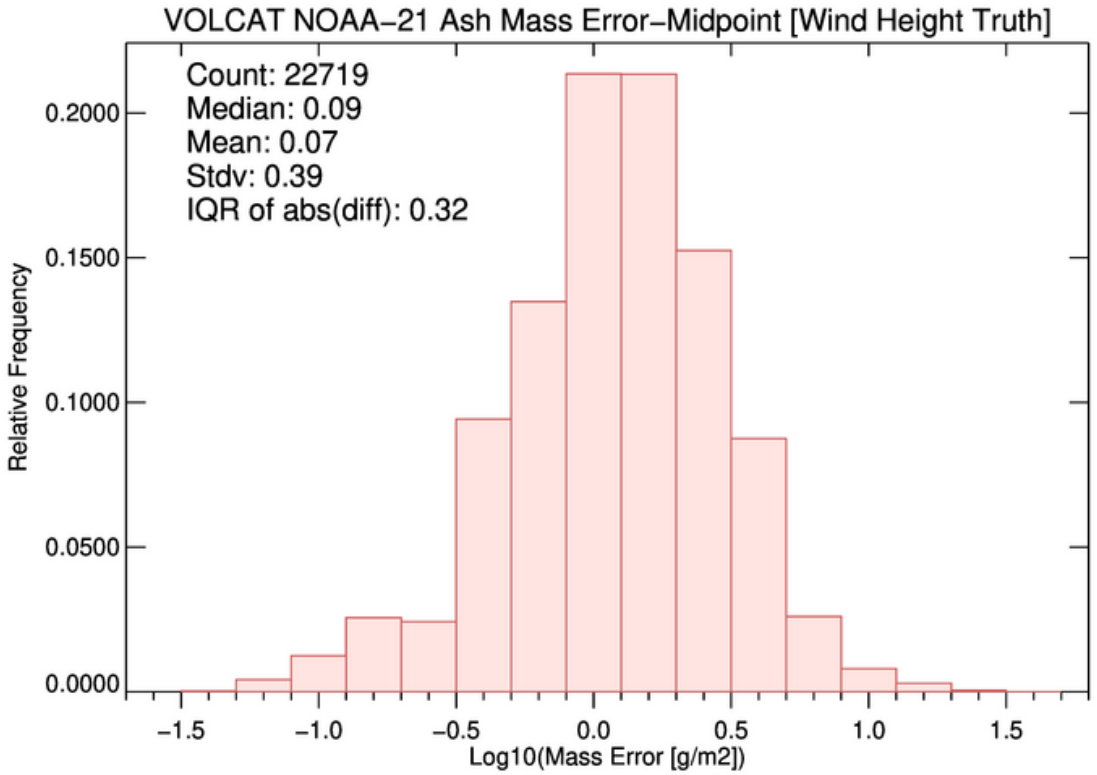
VOLCAT



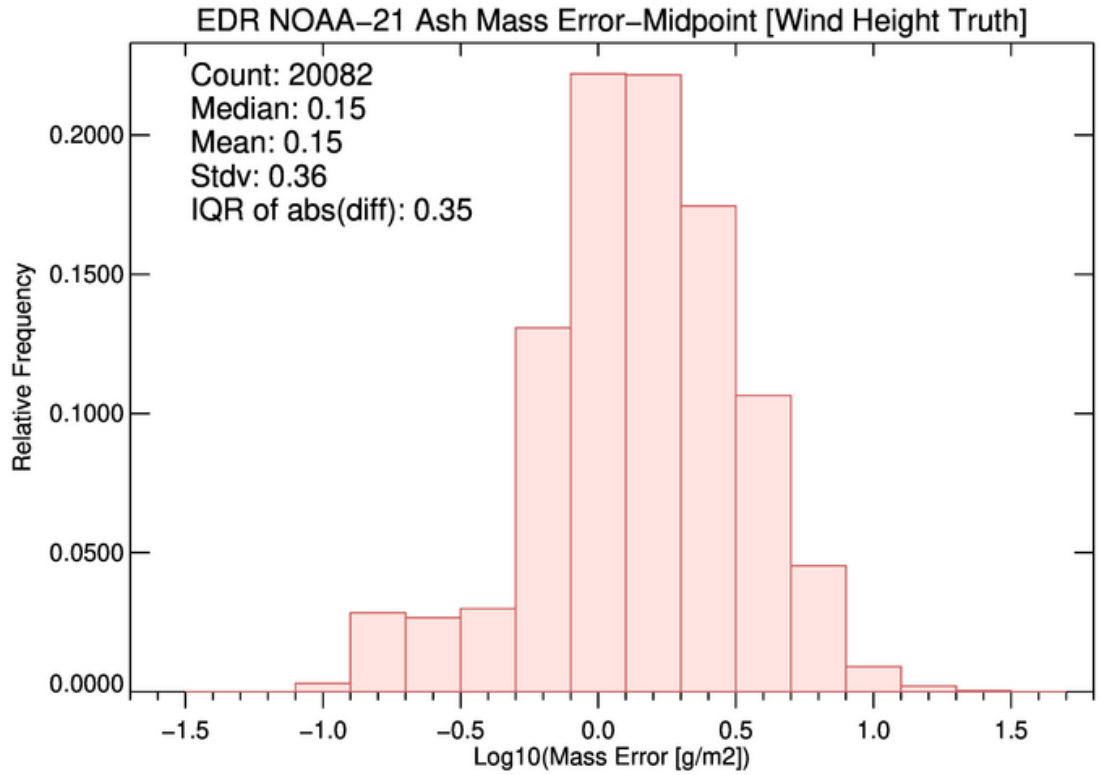
EDR

- NOAA-21 EDR ash height has been shown to be meeting specifications, VOLCAT output for the same cases is shown to have reduced ash height errors.

Ash Mass Loading VOLCAT vs. EDR Validation Comparison



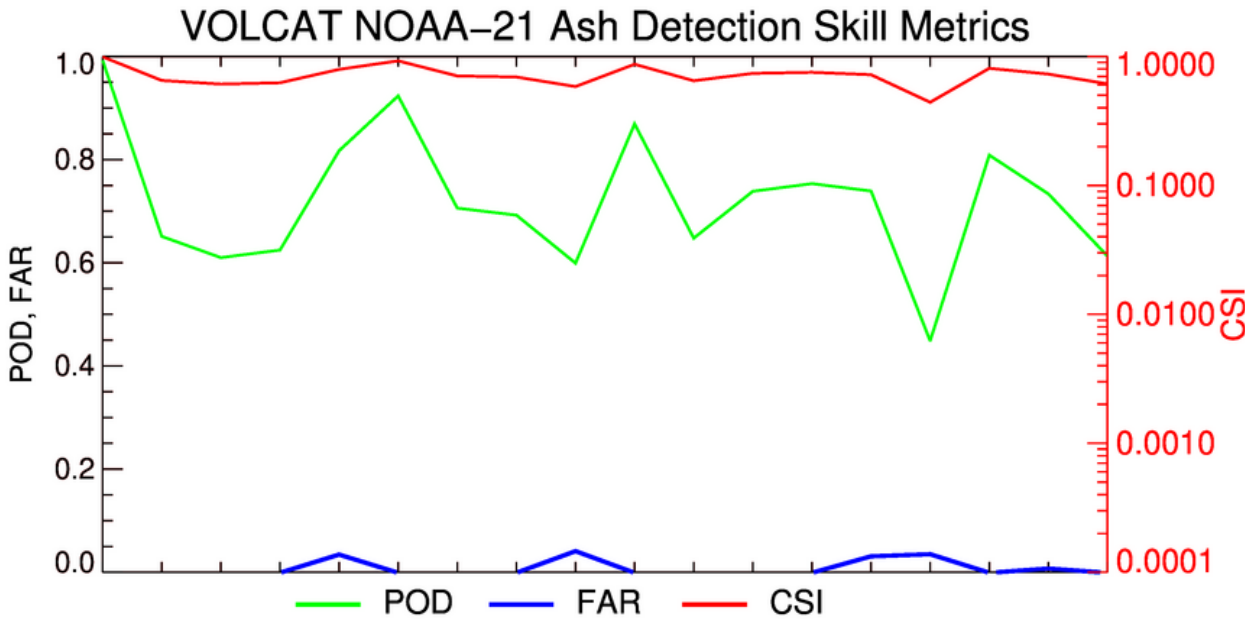
VOLCAT



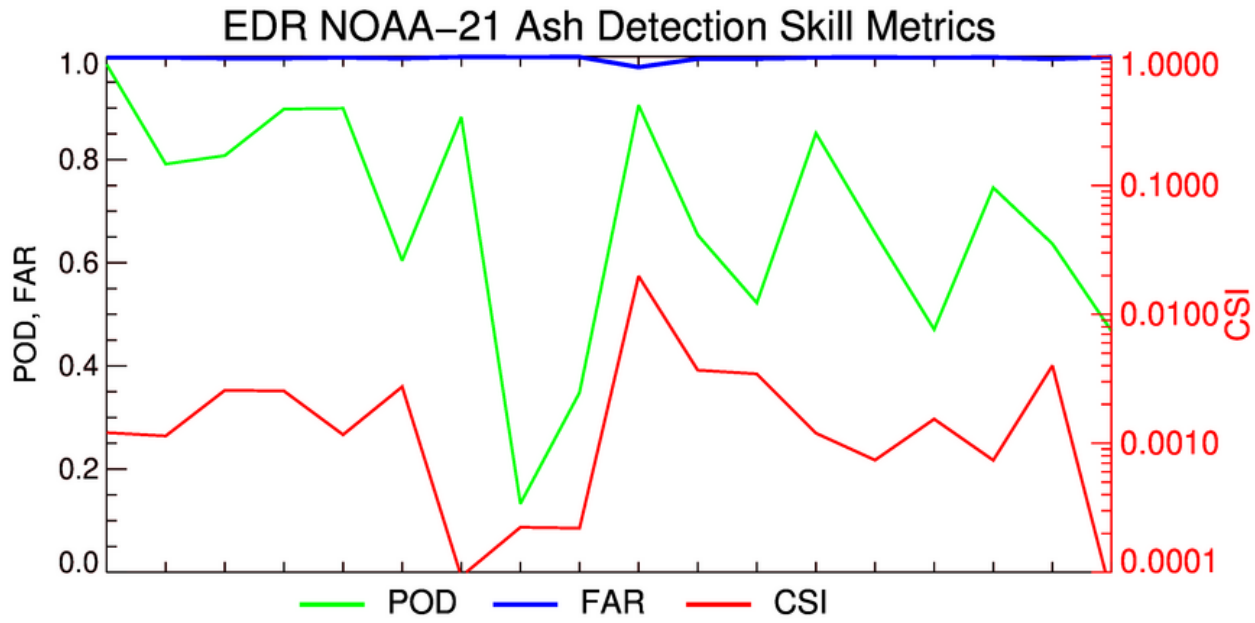
EDR

- NOAA-21 EDR ash mass loading has been shown to be meeting specifications, VOLCAT output for the same cases is shown to have reduced ash mass loading errors.

VOLCAT vs. EDR Ash Detection Skill



VOLCAT



EDR

- EDR algorithm reflects volcanic ash detection approach without sophisticated methods for reducing false positives (spectrally there is significant overlap between volcanic ash clouds and some meteorological clouds)
- VOLCAT approach utilizes sophisticated spatial and machine learning techniques to maintain high probability of detection but with significantly lower false alarm rate.
- VOLCAT Critical Skill Index (CSI) is **2-3 orders of magnitude higher** than EDR approach

Error Budget (1 slide)

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.

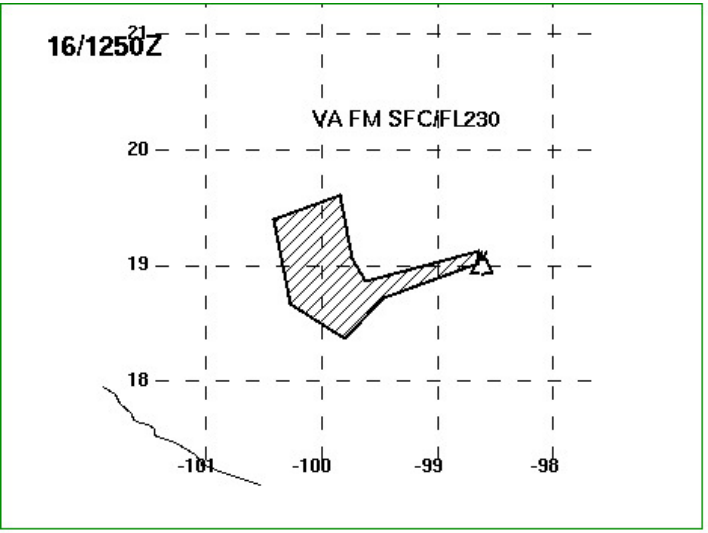
Attribute Analyzed	DPS	Requirement/ Threshold	Pre-Launch Performance	On-orbit Performance			Meet Requirement?	Additional Comments
				NOAA-21	NOAA-20	S-NPP		
Accuracy (Height)		3.0 km	n/a	-1.63	-1.33	-1.90	Yes	Low bias (consistent with other)
Accuracy (Mass Load)		2.0 ton / km^2	n/a	0.99	1.43	1.10	Yes	High bias (consistent with other)
Precision (Mass Load)		2.5 ton / km^2	n/a	1.54	1.02	1.40	Yes	

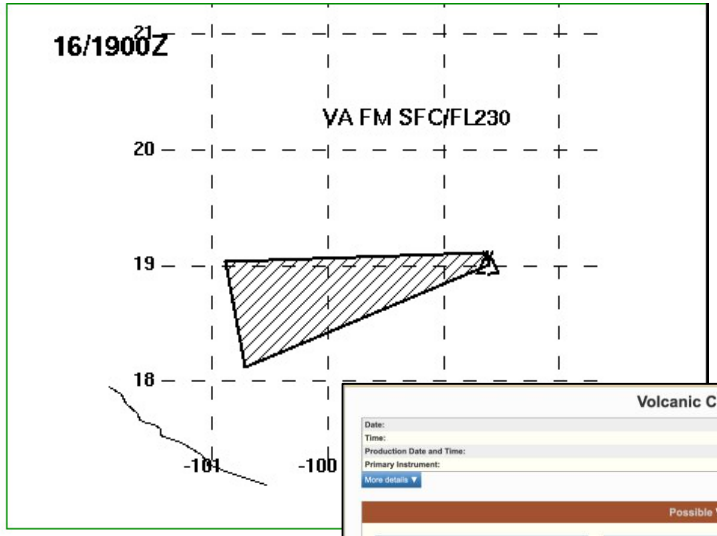
User Feedback

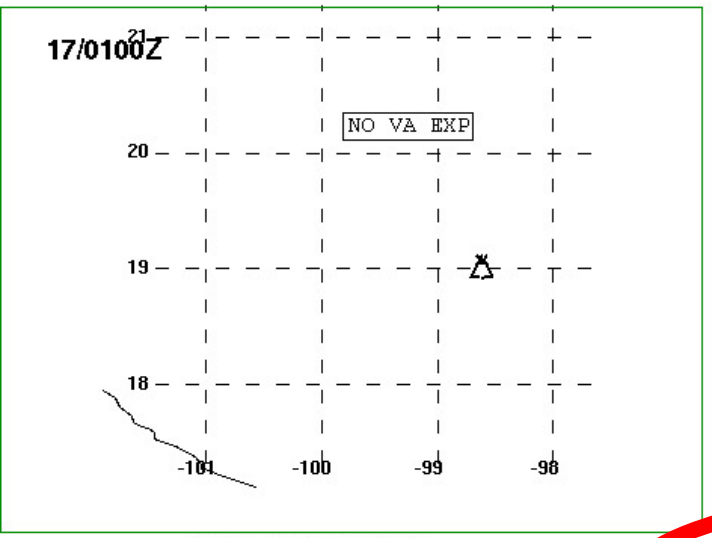
Name	Organization	Application	User Feedback - User readiness dates for ingest of data and bringing data to operations

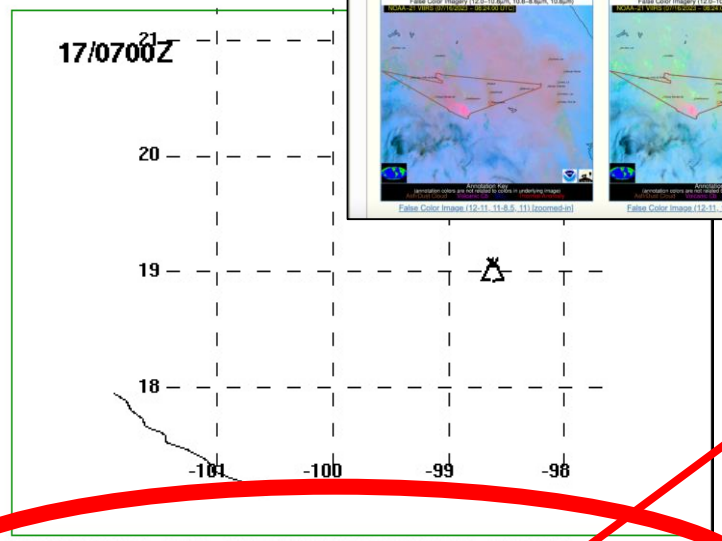
- Volcanic ash end-users (e.g., NOAA/NWS VAACs and NOAA HYSPLIT group) have indicated their preference for VOLCAT products.
- Analogous GOES-R Volcanic Ash product was retired and there are no known users of current product.
- VOLCAT produces similar retrieval fields (e.g., ash height, ash mass loading–comparisons shown previously), but VOLCAT has sophisticated methodology to significantly eliminate false positives. Additionally, VOLCAT allows for volcano eruption alerting, tracking and characterization of volcanic ash properties, and thermal anomaly detection and characterization, etc.
- VOLCAT transition to operations project is in-progress, this JPSS Volcanic Ash EDR will be retired upon the completion of the VOLCAT transition to operations.

Example of VOLCAT usage by Washington VAAC



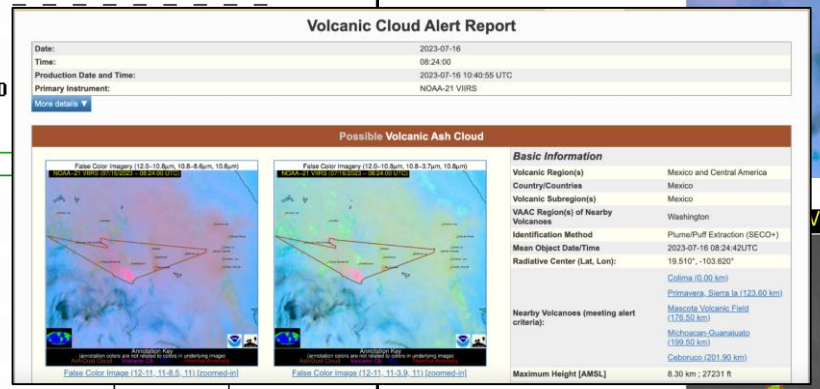




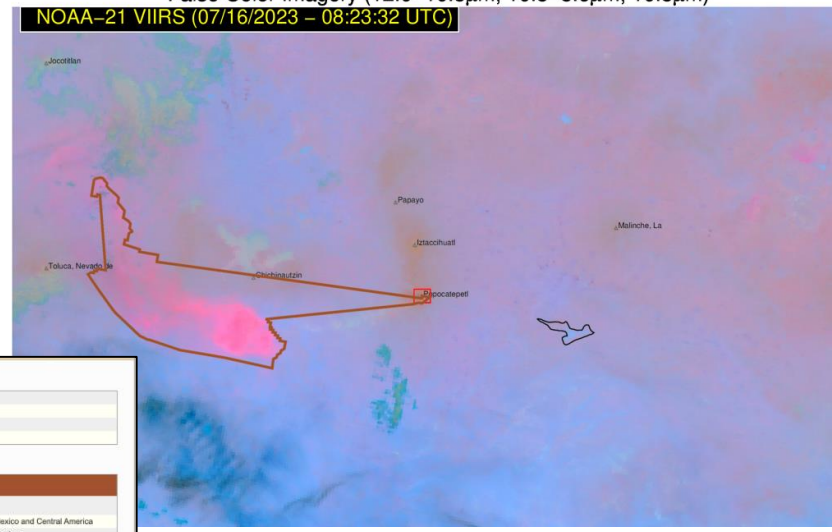


VOLCANIC ASH ADVISORY
DTG: 20230716/1306Z
VAAC: WASHINGTON
VOLCANO: POPOCATEPETL 341090
AREA: MEXICO
SUMMIT ELEV: 17693 FT (5393 M)
ADVISORY NR: 2023/844

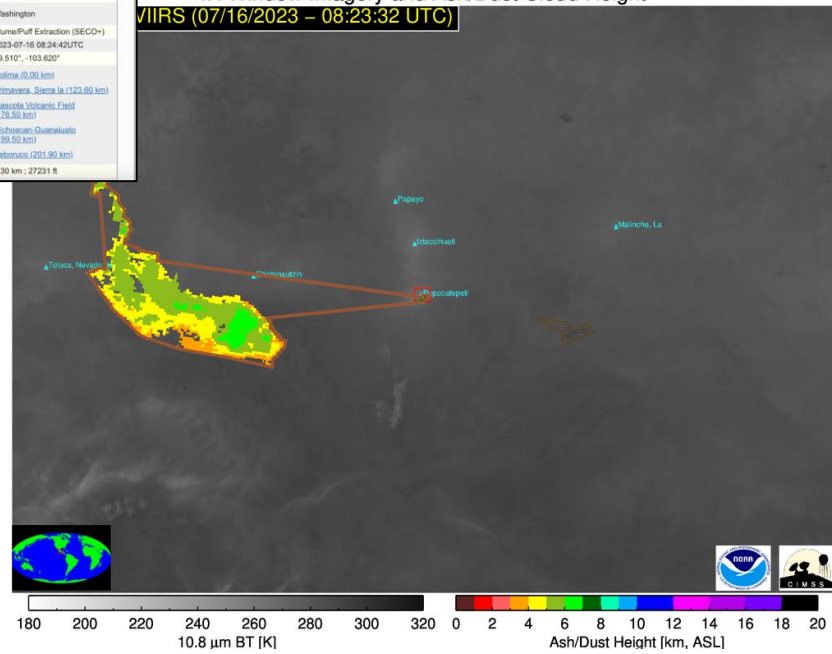
INFO SOURCE: GOES-16. WEBCAM. NWP MODELS. VOLCAT.
ERUPTION DETAILS: LGT VA EMS
RMK: LGT VA EMS OBSD IN SAT AND WEBCAM. VA CLDS EXTD APPX
100NMI WSW OF SUMMIT. VOLCAT ALERT RECEIVED. NWP MDL FCST
LTLCG THRU T+6HRS. ...ZENG
NXT ADVISORY: WILL BE ISSUED BY 20230716/1900Z



False Color Imagery (12.0–10.8μm, 10.8–8.6μm, 10.8μm)



IR Window Imagery and Ash/Dust Cloud Height



Downstream Product Feedback

Algorithm	Product	Downstream Product Feedback - Reports from downstream product teams on the dependencies and impacts
Aerosol Detection	Smoke/Dust/Volcanic Ash	Verified NOAA-21 Volcanic Ash EDR is working as expected

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
Lack of Lidar Data	Lidar observations of volcanic, coincident with NOAA-21 are extremely rare, further CALIOP mission has reached end-of-life.	Low (spec can still be met)	Other validation methods have been employed.
Situational Performance	NOAA-21 has yet to observe a major stratospheric eruption with a long-lived ash cloud.	Low (spec can still be met)	New eruptions will be analyzed.

Documentations (Check List, 1 slide)

Science Maturity Check List	Yes ?
ReadMe for Data Product Users	N21 readme pending results of 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
Regular Validation Reports (at least annually) (Demonstrates long-term performance of the algorithm)	As requested

Check List - Provisional Maturity

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 select locations, periods, and associated ground truth or field campaign efforts.	**Yes** Slides 17-34
Product analysis is sufficient to communicate product performance to users relative to expectations (Performance Baseline).	**Yes** Slide 35
Documentation of product performance exists that includes recommended remediation strategies for all anomalies and weaknesses. Any algorithm changes associated with severe anomalies have been documented, implemented, tested, and shared with the user community.	**Yes**
Product is ready for operational use and for use in comprehensive cal/val activities and product optimization.	**Yes** Slides 35, 41

Conclusion

- Cal/Val results summary:
  - Science Team recommends algorithm Provisional maturity
    - The advection pattern validation and NOAA-20 comparisons give us confidence the Volcanic ash algorithm is meeting specifications with the limited validation dataset included in this Provisional review.
    - **The science team recommends Provisional status at this time.**

Path Forward

- Continue to sample annual cycle and further geographic variety for NOAA-21 VIIRS volcanic cloud observations in preparation for full maturity review.
- In addition to techniques shown in this presentation, should any independent validation observations become available we will use those datasets for additional validation.
- VOLCAT is the long-term plan (for all satellite sensors, including JPSS) and transition to NESDIS operations is proceeding.