Validated Maturity Science Review For Volcanic Ash

Presented by Michael Pavolonis

Date: 2019/05/06

JPSS NOAA NASA

JPSS Data Products Maturity Definition

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.

Validated Maturity Review - Entry Criteria

- Product Requirements
- Pre-launch Performance Matrix/Waivers
- Validated 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/EDRs feedback
- Risks, Actions, Mitigations
  - Potential issues, concerns
- Path forward
- Summary

Validated Maturity Review - Exit Criteria

- Validated 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 Validated Maturity Slide Package addressing review committee's comments for:
  - Cal/Val Plan and Schedules
  - Product Requirements
  - Validated Maturity Performance
  - Risks, Actions, Mitigations
  - Path forward

VALIDATED MATURITY REVIEW MATERIAL

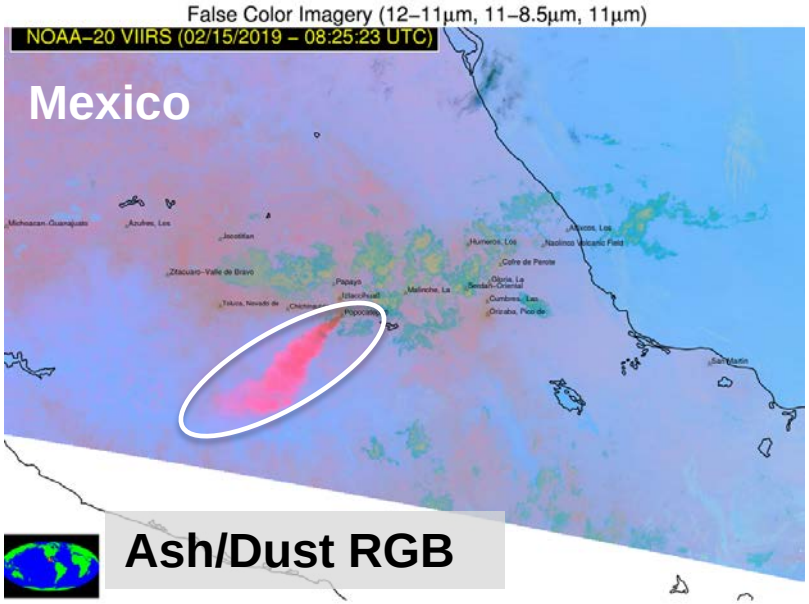
Outline

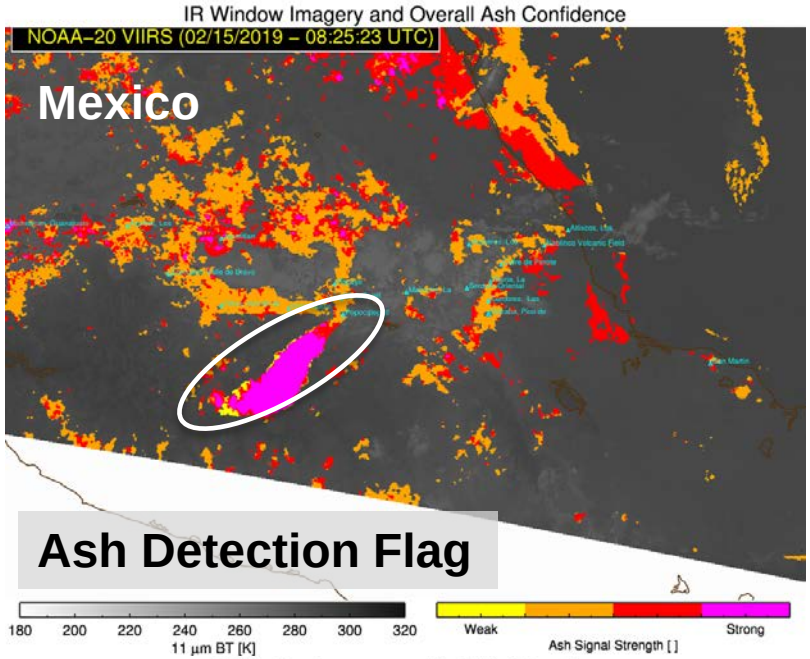
- Algorithm Cal/Val Team Members
- Product Overview/Requirements
- Evaluation of algorithm performance to specification requirements
  - Algorithm version, processing environment
  - Evaluation of the effect of required algorithm inputs
  - Quality flag analysis/validation
  - Error Budget
- User Feedback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

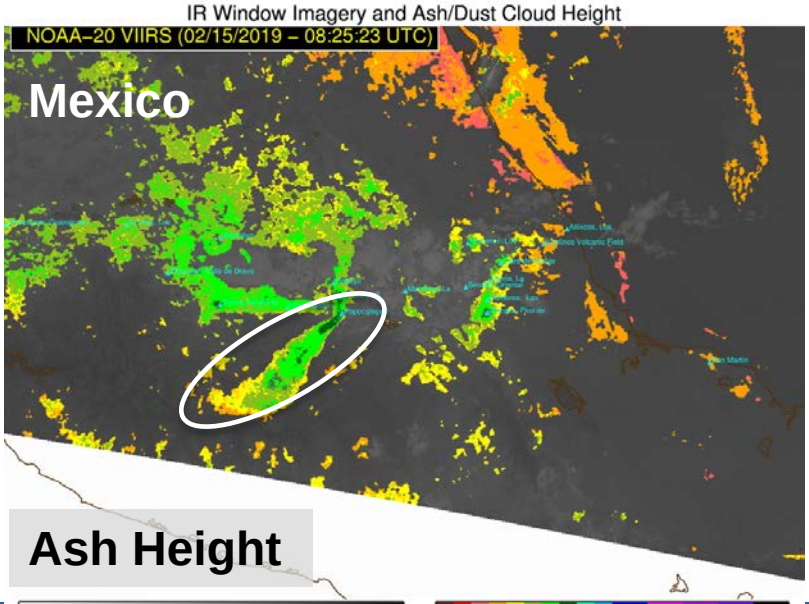
Algorithm Cal/Val Team Members

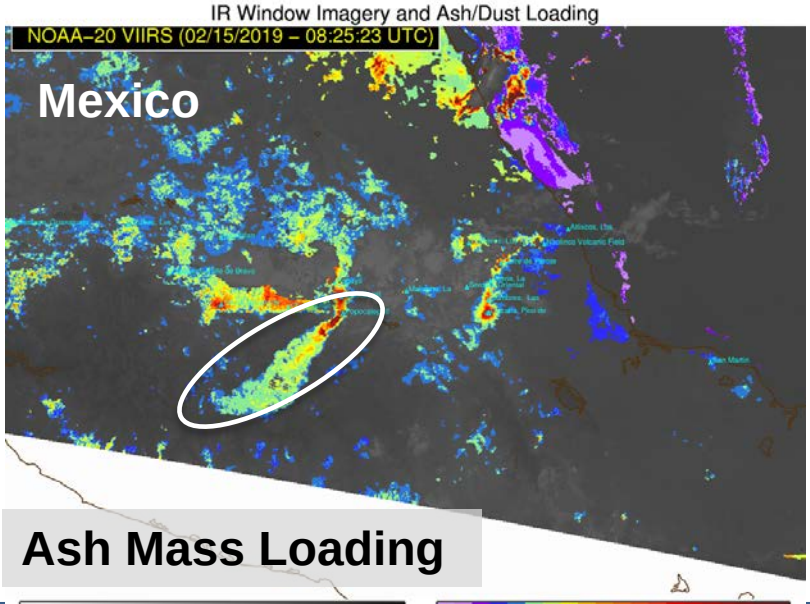
Name	Organization	Major Task
Michael Pavolonis	NESDIS/STAR	Volcanic Ash PI
Justin Sieglaff	UW-CIMSS	Algorithm development and validation
Jason Brunner	UW-CIMSS	Algorithm development and validation
William Straka	UW-CIMSS	ASSISTT integration
Hongming Qi	OSPO	Product Area Lead

NOAA-20 Volcanic Ash Products: Popocatépetl









Requirements: Volcanic Ash

Product performance requirements from JPSS L1RD supplement (threshold) versus observed/validated/JERD Vol. II

Attribute	L1RD	JERD
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

Previous Reviews

- **Beta:** no review

- **Provisional (Nov 2018)**:
  - The statistical and visual-based analyses of the 9 cases clearly show that all requirements are met, and the product has reached provisional maturity.
  - Slide 15 summarized that 9 volcanic eruptions were evaluated for this review. Represents reasonable sample of events; however it was noted that there were no major eruptions covered by NOAA-20 during the evaluation time period. All results shown are from processing on NDE I&T.
  - Obviously for validated maturity, more cases will be evaluated, including significant (high mass loading) cases.
  - Recommend the team work on comparisons to GOES-16 VA products for future reviews.
  - Recommend Mike work with Hongming Qi to get an SPSRB user request (preferably with at least one NOAA user such as VAAC/Jamie Kibler, NWS or OAR for dispersion modeling) submitted for the VOLCAT capability. There's no reason NESDIS cannot find a technical solution for implementing VOLCAT.

NDE/STAR VIIRS ECP Production Status

Algorithm	Suomi NPP	NOAA-20
August 2018 DAP February 2018 Science Code delivery (~~v2r0~~)	**STAR** Systematic production since June, 2018 **NDE** **In Ops String since Jan 2019**	**STAR** Systematic production since June, 2018 **NDE** **In Ops String since 7 March 2019**
Jan/Feb 2019 DAP August 2018 Science Code delivery (v2r1)	**Delivered to NDE in late March 2019**	**Delivered to NDE in late March 2019**
Late 2019 DAP Science Code delivery date TBD (v2r2)	**Delivery and development in progress** Delivery schedule provided by ASSISTT	**Delivery and development in progress** Delivery schedule provided by ASSISTT

Evaluation Methodology

Version of NOAA-20 volcanic ash EDR evaluated: v2r0

Algorithm changes since Provisional: none

Evaluation Methods:

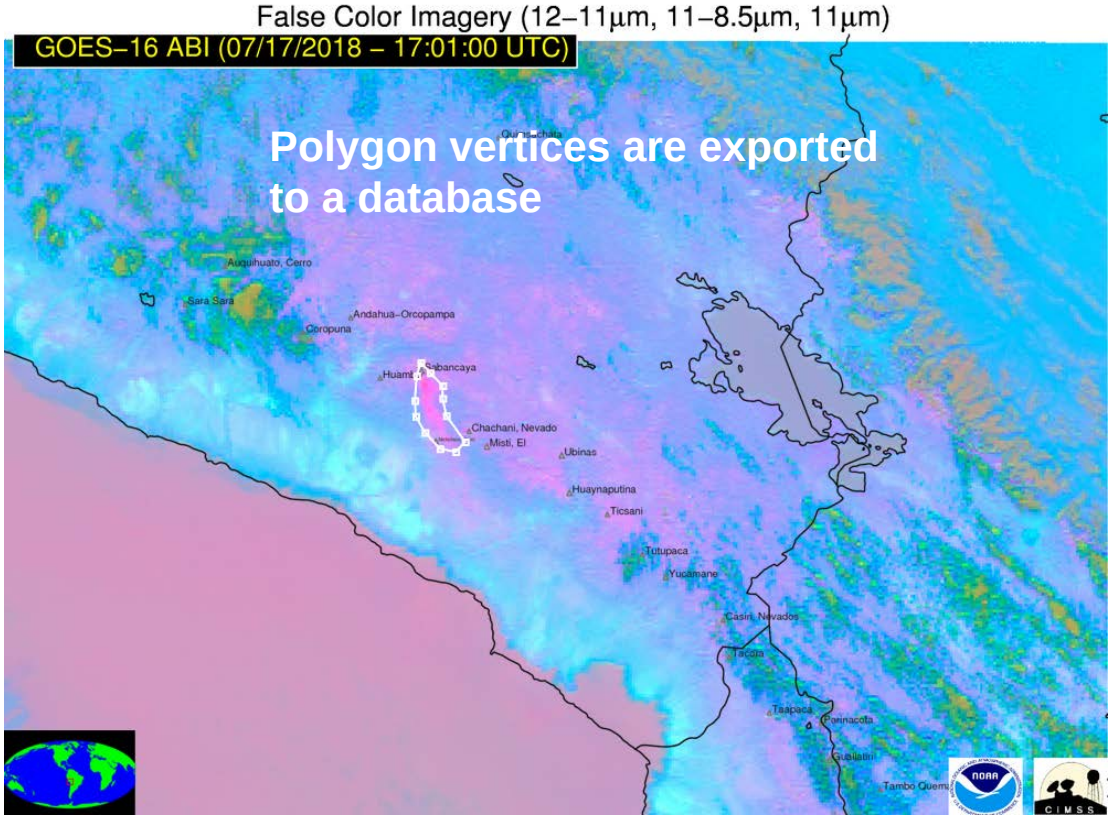
1. Evaluation of ash detection using human expert analysis
1. Validation of height and loading using advection patterns
1. Comparisons to baseline GOES-16 products
1. S-NPP vs. NOAA-20 comparisons

Eruptive Events Utilized

- 28 volcanic ash cases were identified and analyzed, totaling over 80,000 NOAA-20 VIIRS M-band pixels
- Ash clouds from a variety volcanoes were included
  - 9 Popocatepetl (Mexico)
  - 2 Dukono (Indonesia)
  - 3 Sabancaya (Peru)
  - 2 Krakatau (Indonesia)
  - 1 Merapi (Indonesia)
  - 3 Fuego (Guatemala)
  - 1 Veniaminof (Alaska)
  - 2 Karymsky (Kamchatka Peninsula)
  - 1 Bezymianny (Kamchatka Peninsula)
  - 4 Planchon-Peteroa (Chile)
- The ascending and descending nodes are sampled
- Tropical, mid, and high latitude ash clouds are sampled
- The sample of cases includes clear (over land and water) and cloudy (mainly) scenes

VALIDATION OF ASH DETECTION USING HUMAN EXPERT ANALYSIS

Manual Identification of Volcanic Ash



A web-based tool allows us to extract ash contaminated pixels using manual analysis of false color imagery

Ash Detection: Finding a Needle in a Haystack

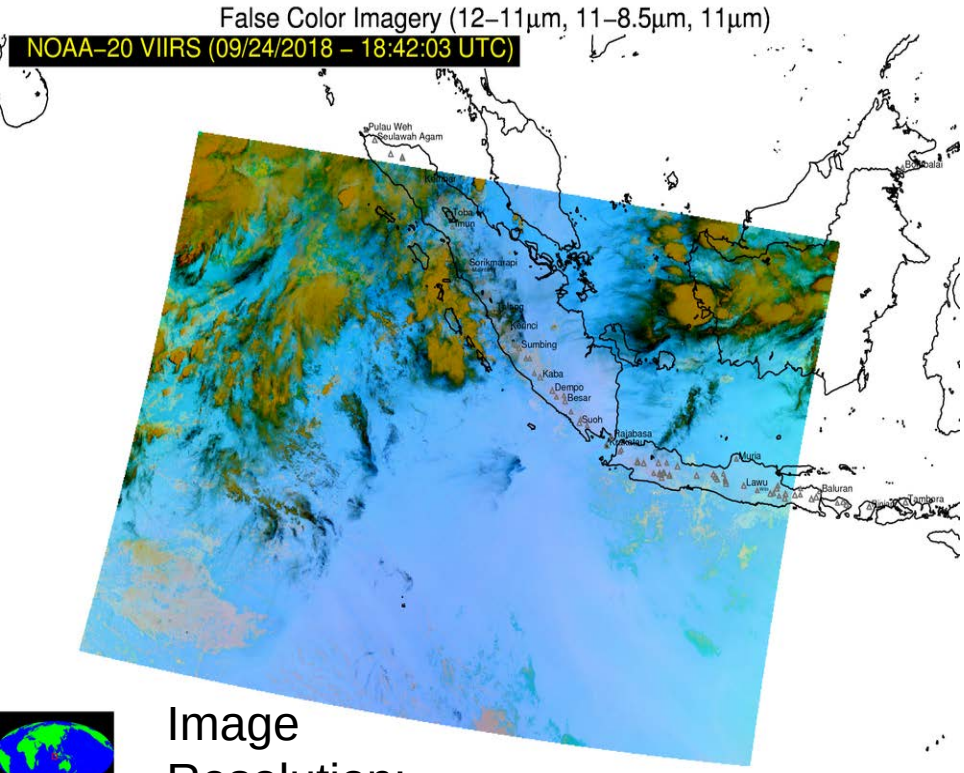
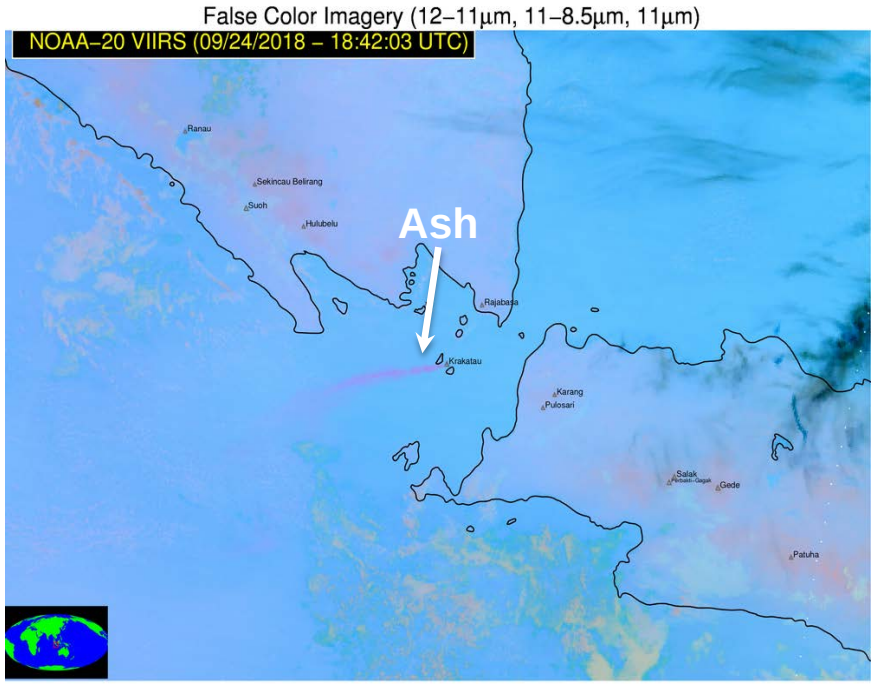


Image Resolution: Native/5

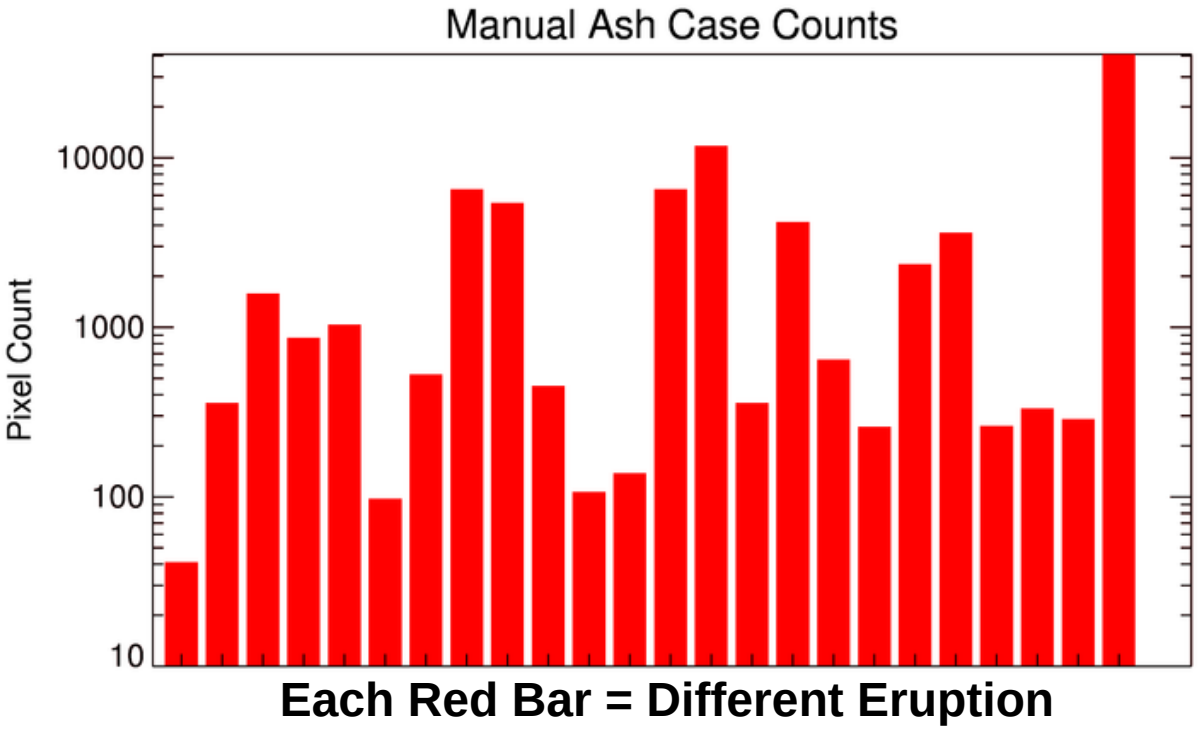
Image Resolution: Native * 1.5



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 a Haystack

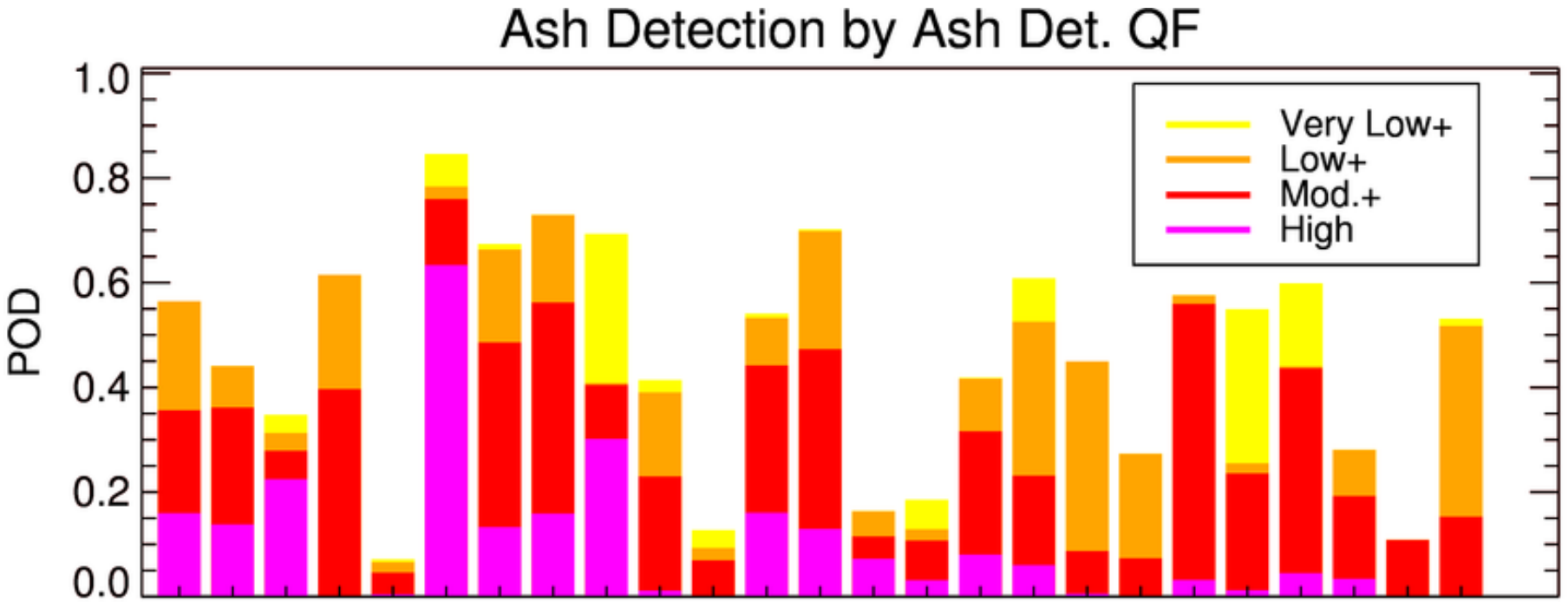
Pixel counts for a sampling of ash clouds observed by NOAA-20



Each Red Bar = Different Eruption

- 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

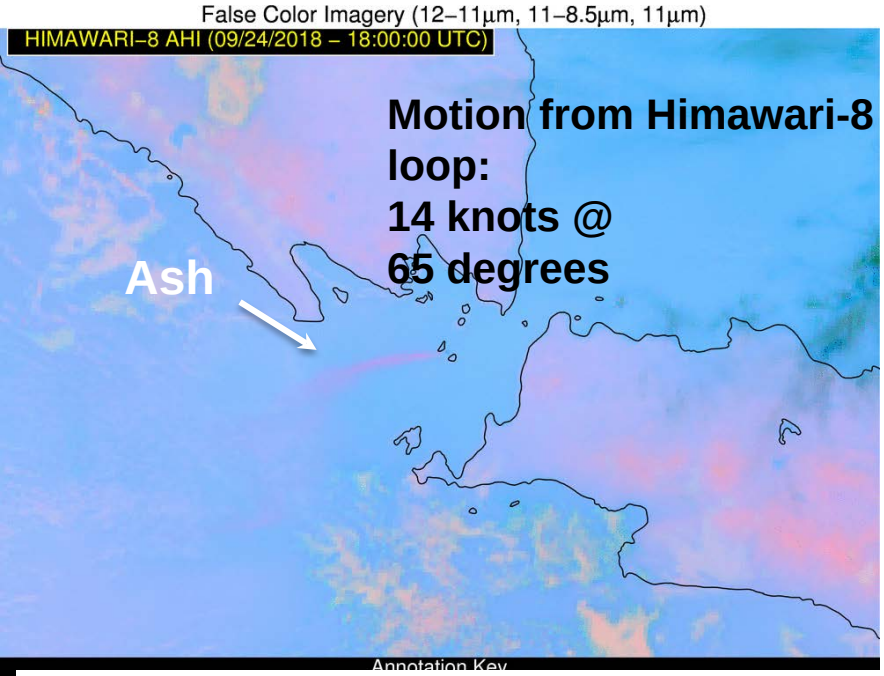
- As outlined in validation plan, given that CALIOP observations of volcanic ash, that are co-located with NOAA-20, are rare, alternative validation methods are utilized.

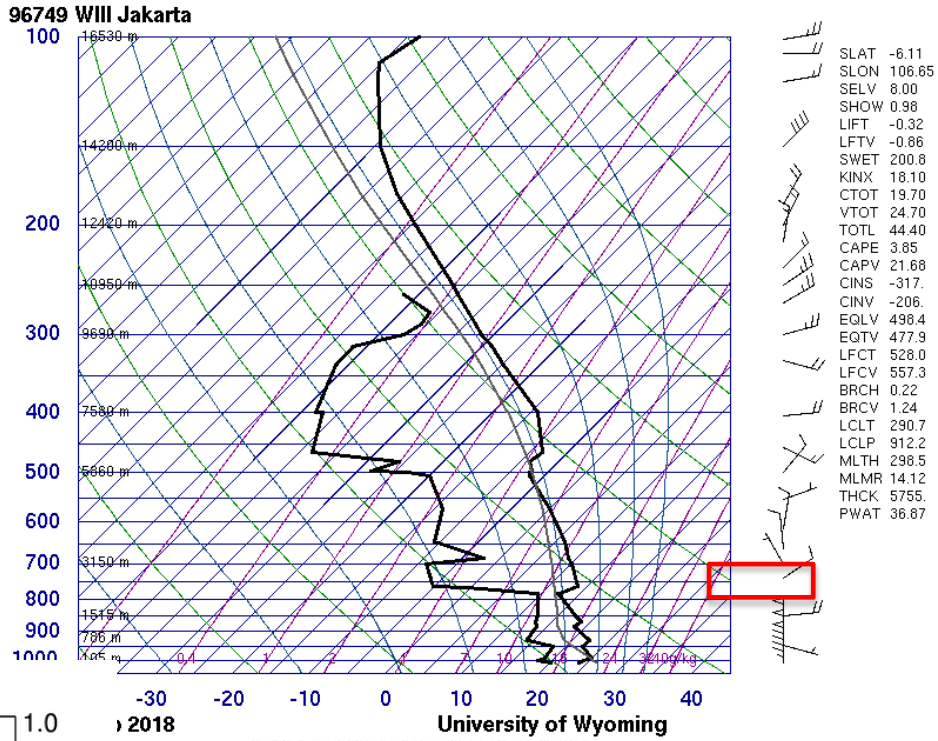
- Manual analysis of false color imagery is used to pixels that truly contain ash

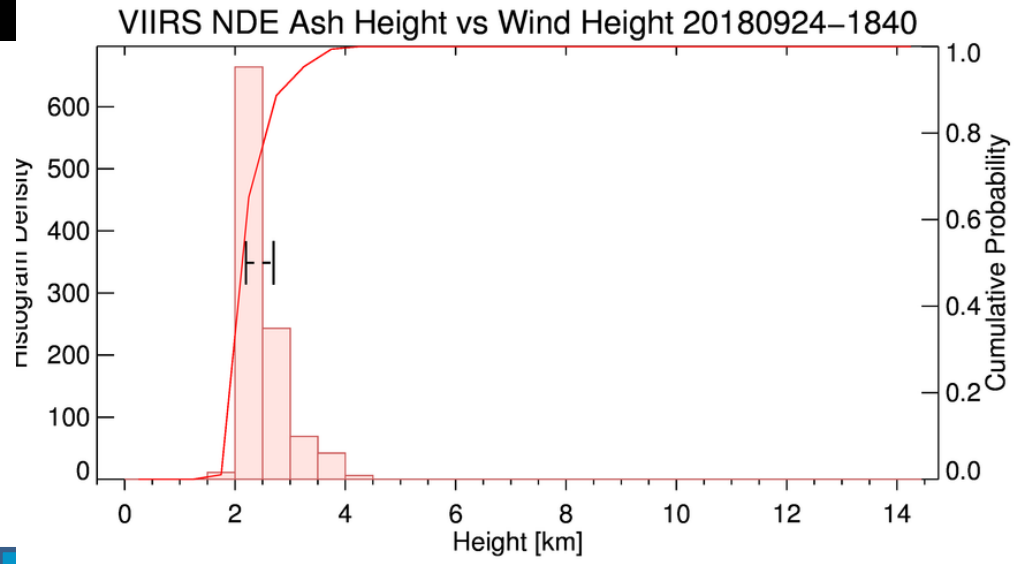
- **Ash Height:** Use false color image movies to extract ash cloud motion (speed and direction). Use nearby radiosonde to assign the satellite derived motion a height range (only cases where vertical shear is sufficient to constrain height to a ~1 km layer were used)

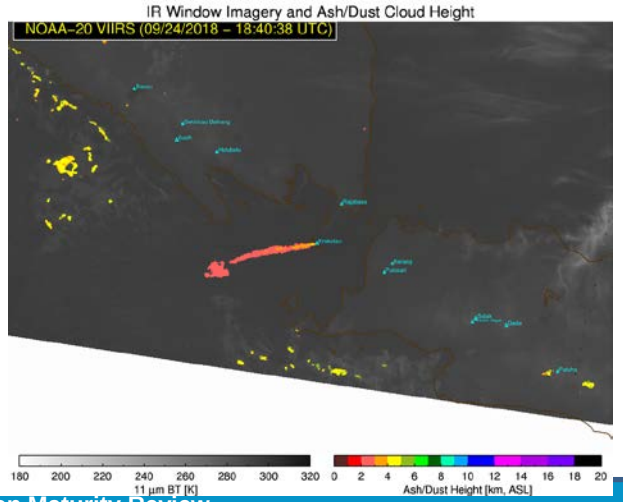
- **Ash Mass Loading:** Satellite-derived mass loading is a strong function of the assigned cloud height. Thus, the cloud motion derived height range can be used to compute a highly representative range of “truth” mass loading.

Advection Patterns

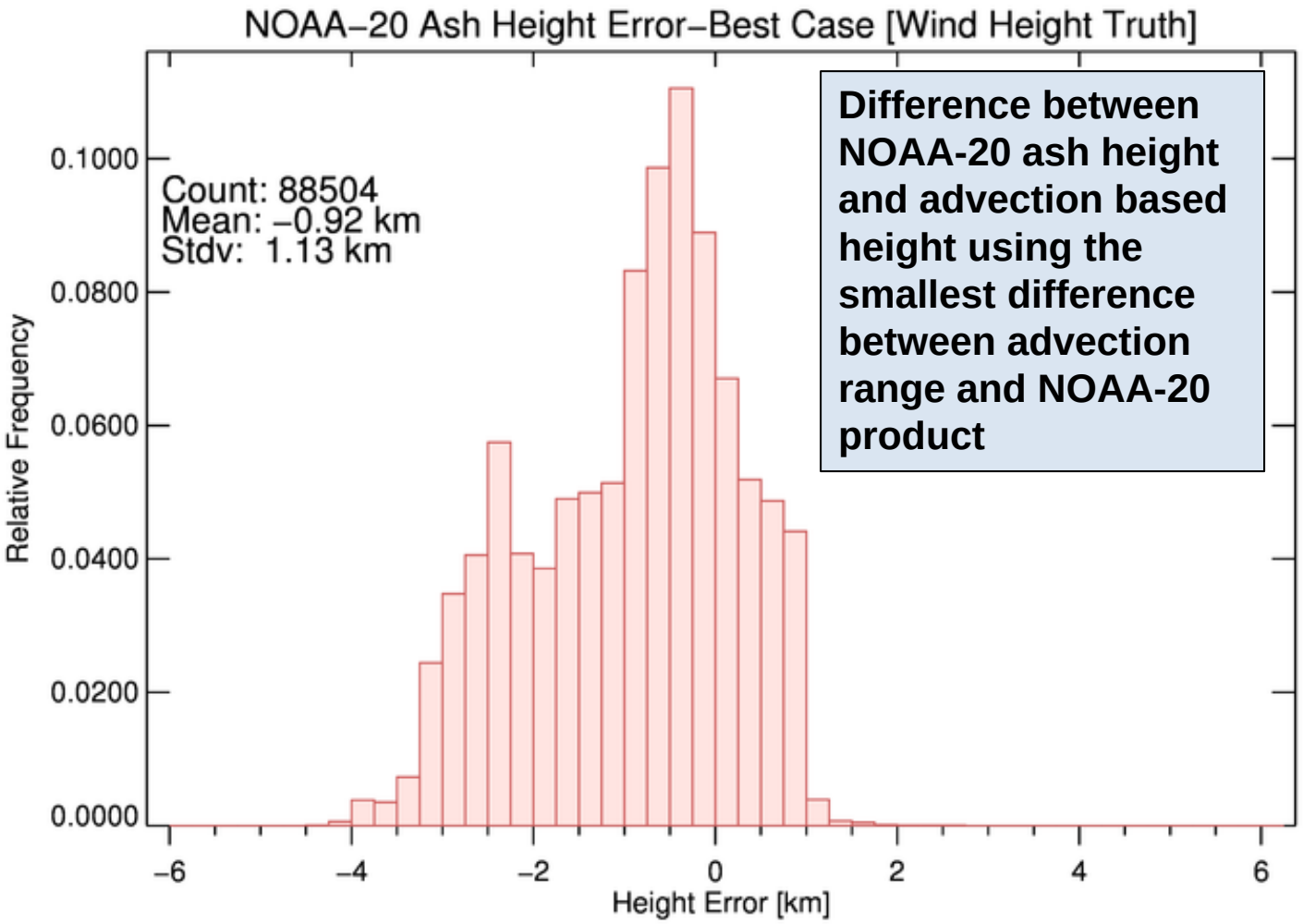






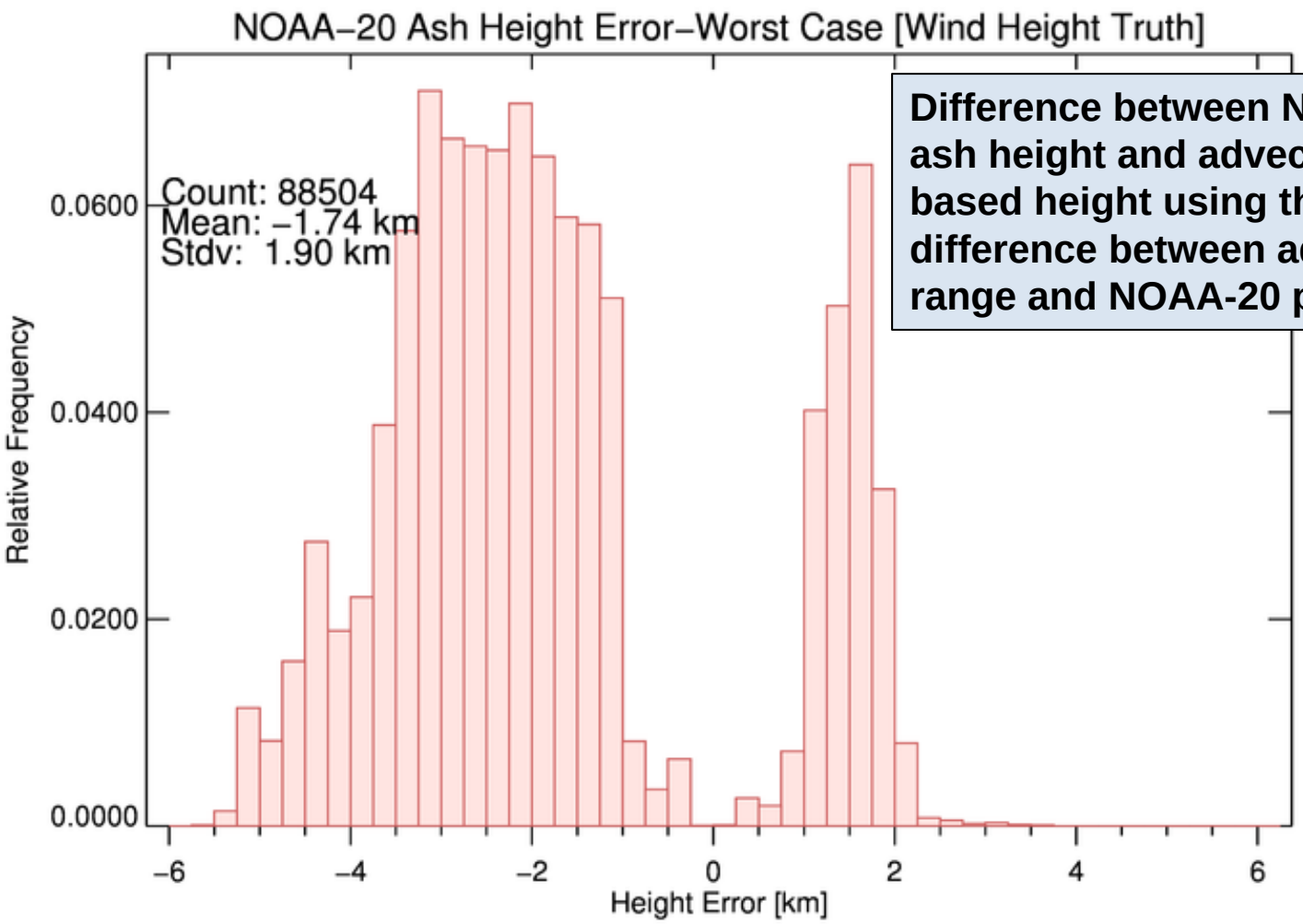


Advection Patterns: Ash Height Validation



Mean Difference (accuracy): -0.92 km (within 3 km spec)

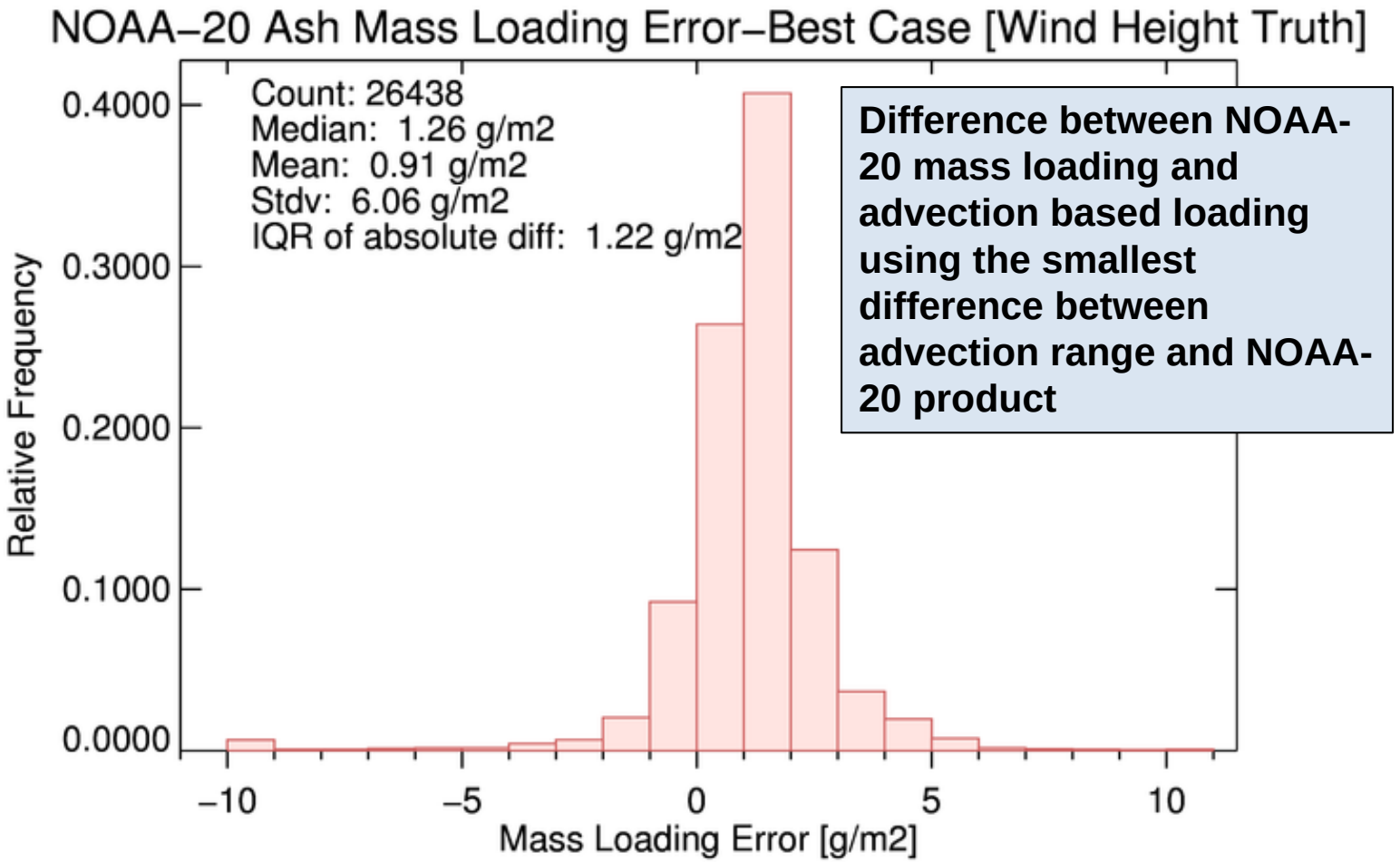
Advection Patterns: Ash Height Validation



Difference between NOAA-20 ash height and advection based height using the largest difference between advection range and NOAA-20 product

Mean Difference (accuracy): -1.74 km (within 3 km spec)

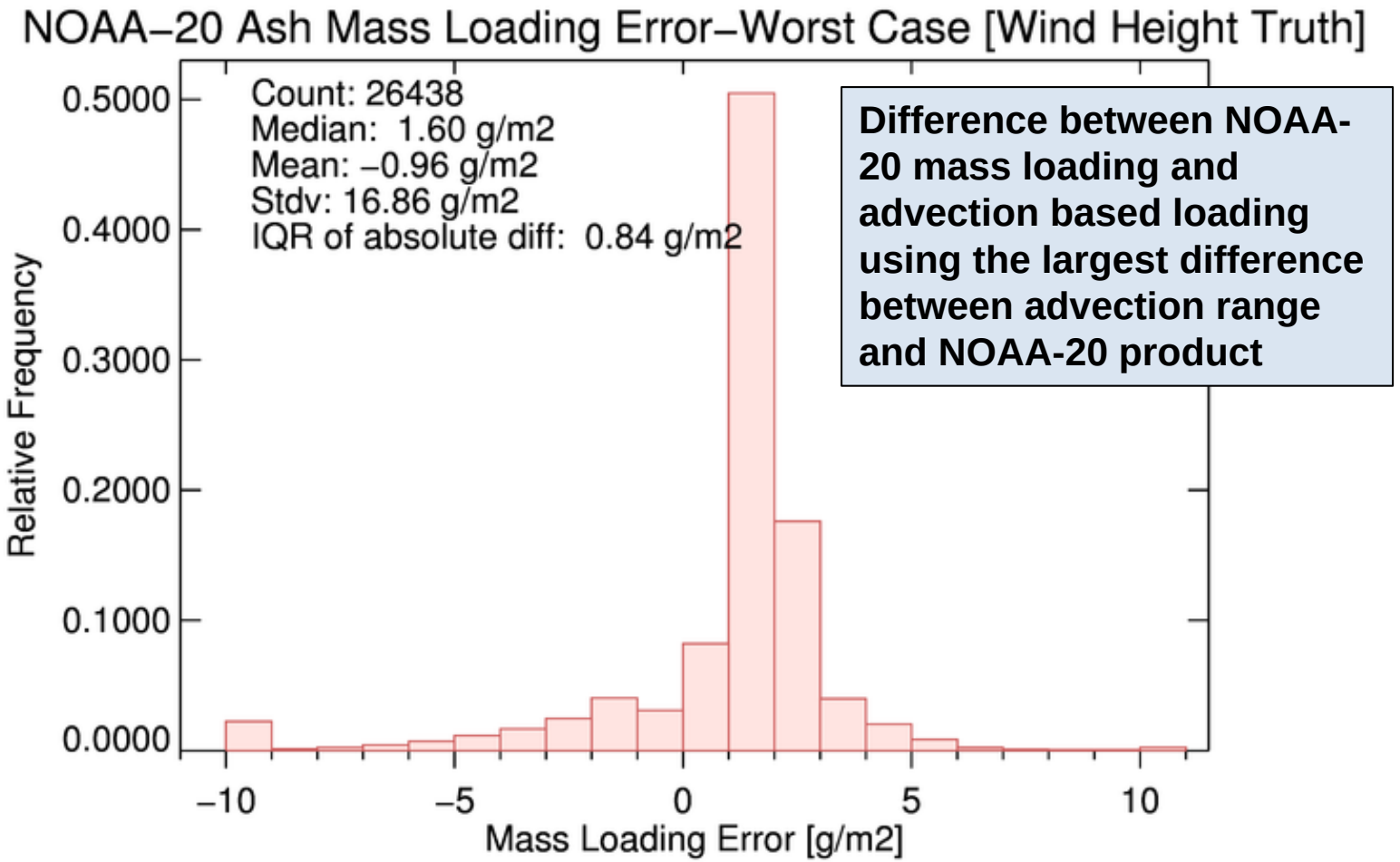
Advection Patterns: Ash Mass Loading Validation



Difference between NOAA-20 mass loading and advection based loading using the smallest difference between advection range and NOAA-20 product

Median Difference (accuracy): 1.26 g/m^2 (within 2 g/m^2 spec)
Interquartile range (precision): 1.22 g/m^2 (within 2.5 g/m^2 spec)

Advection Patterns: Ash Mass Loading Validation



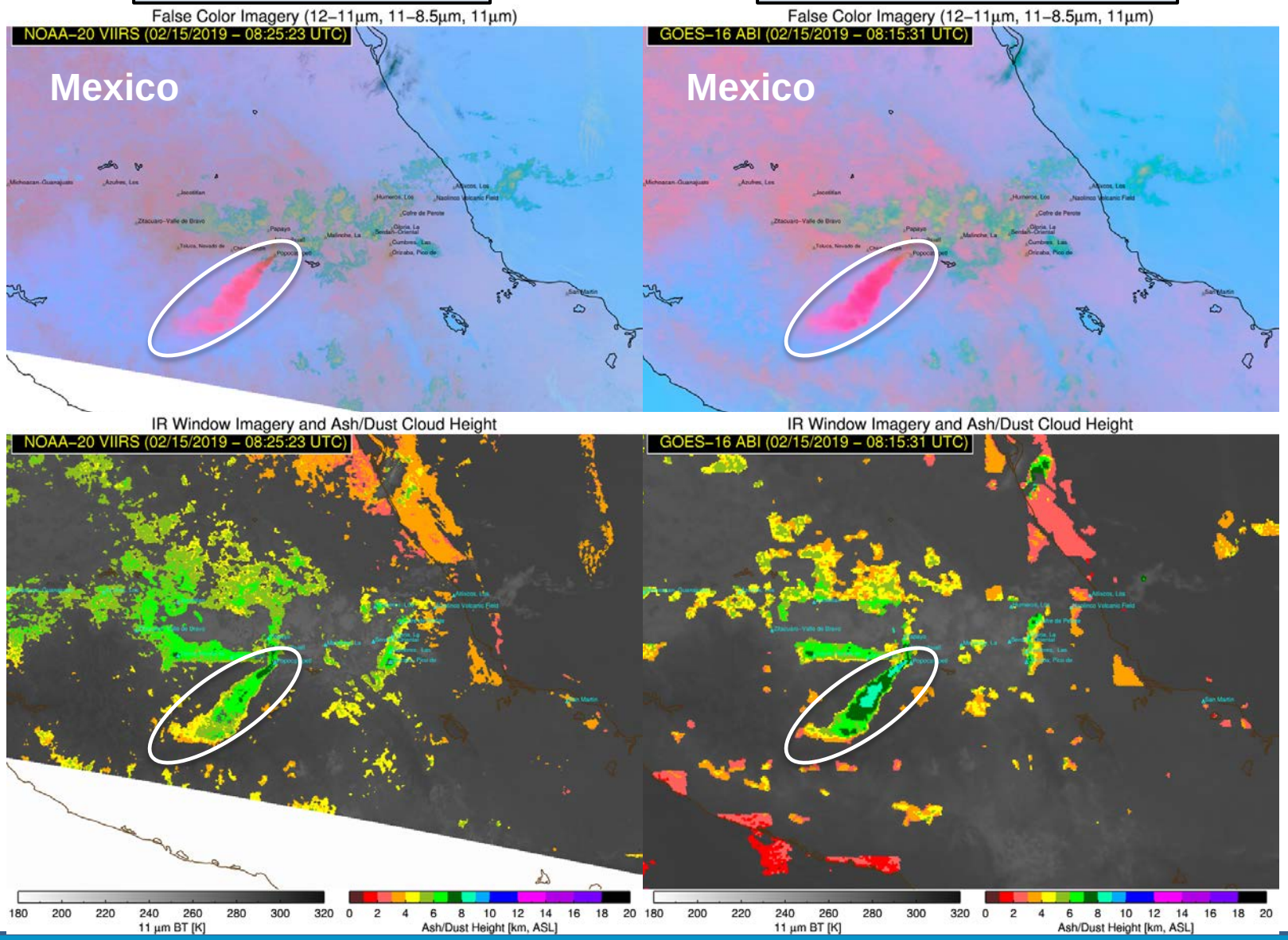
Difference between NOAA-20 mass loading and advection based loading using the largest difference between advection range and NOAA-20 product

Median Difference (accuracy): 1.60 g/m^2 (within 2 g/m^2 spec)
Interquartile range (precision): 0.84 g/m^2 (within 2.5 g/m^2 spec)

COMPARISON TO GOES-16 PRODUCTS

NOAA-20 vs. GOES-16 Baseline: Ash Height

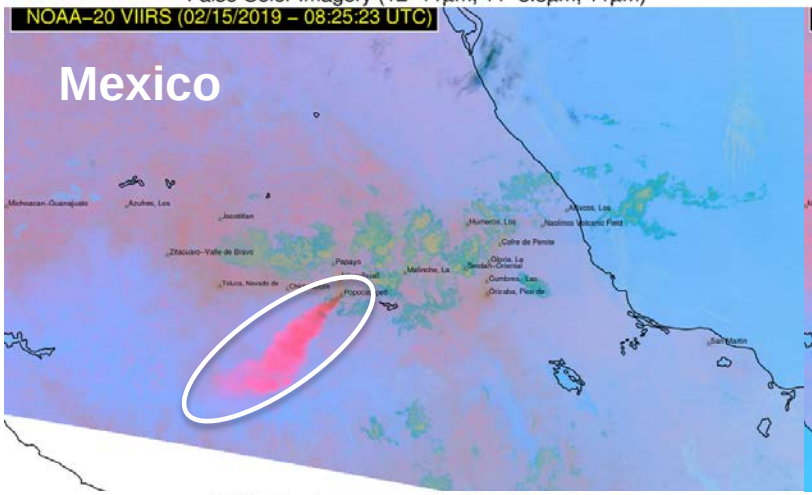
NOAA-20 EDR	GOES-16 Baseline

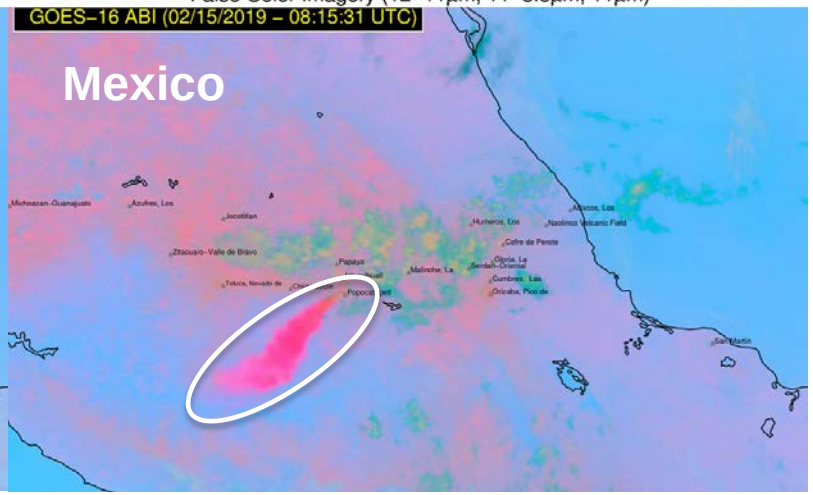


NOAA-20 vs. GOES-16 Baseline: Ash Loading

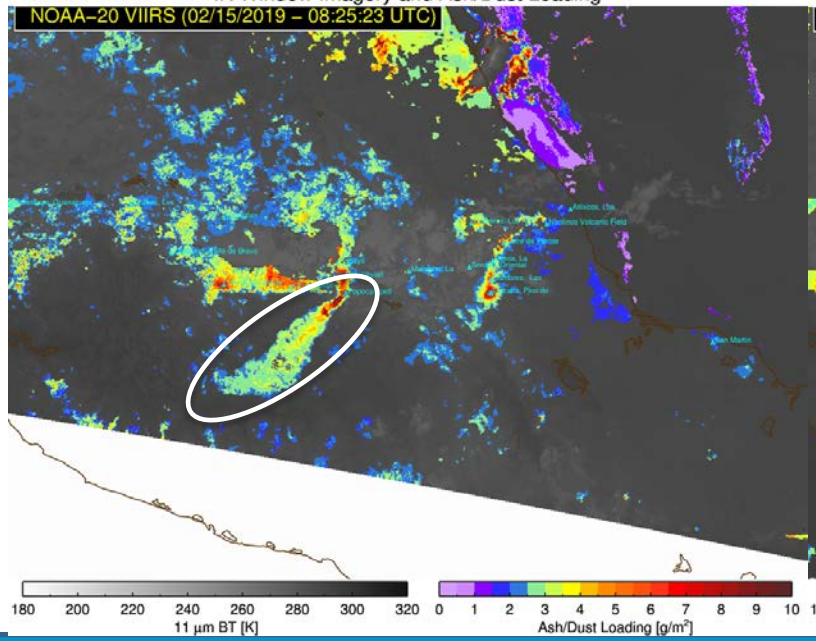
NOAA-20 EDR	GOES-16 Baseline

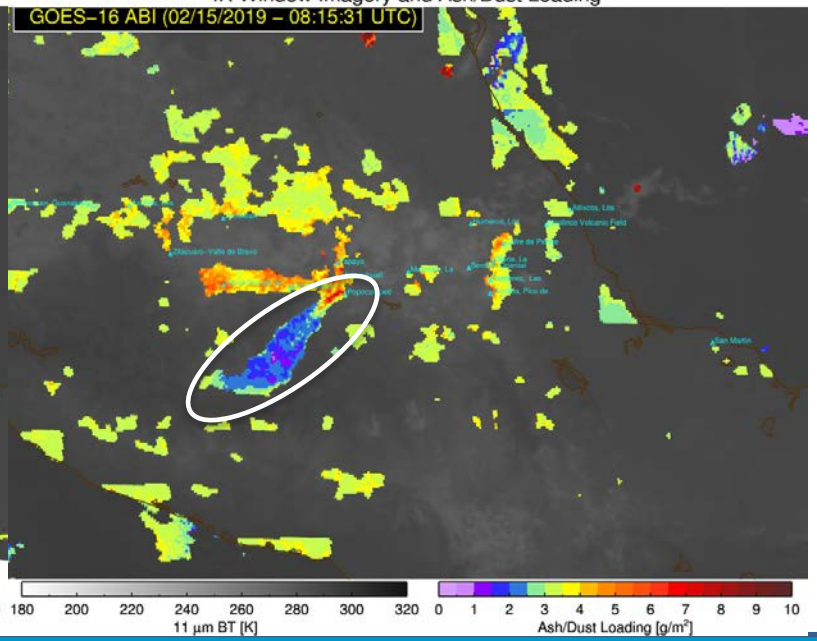
False Color Imagery (12–11μm, 11–8.5μm, 11μm)



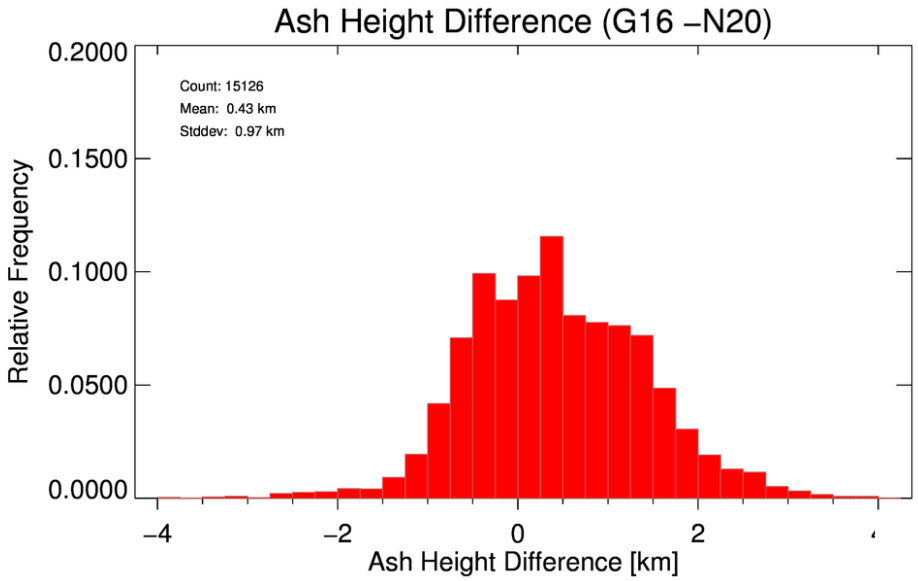


IR Window Imagery and Ash/Dust Loading



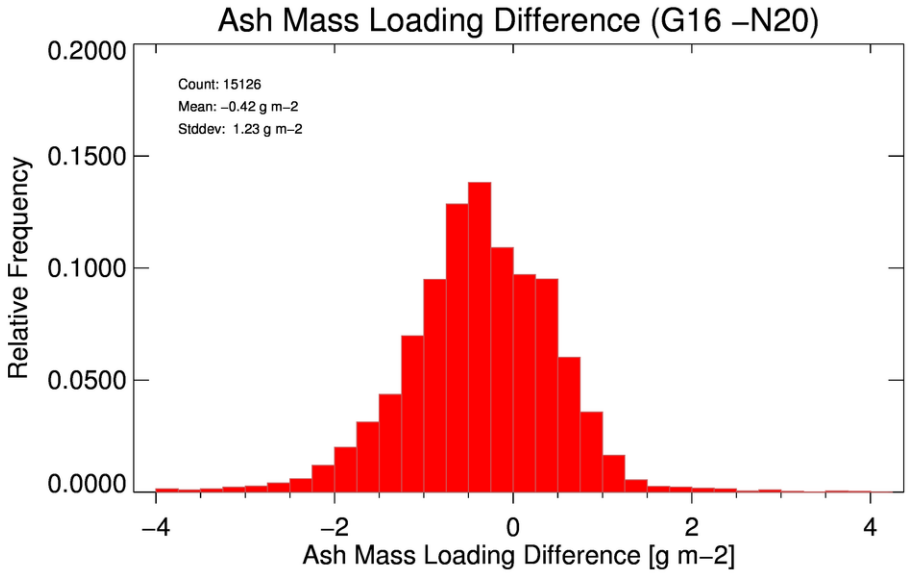


NOAA-20 vs. GOES-16 Baseline: Quantitative Comparison



- On average, the GOES-16 height is 0.43±0.97 km higher and the mass loading is 0.42±1.23 g/m^2 smaller than the NOAA-20 EDR, which is consistent with physical expectations.
- The GOES-R algorithm utilizes infrared absorption channels that increase the sensitivity to cloud height. These channels are not available on VIIRS.

Based on radiative closure, the higher the retrieved cloud height, the smaller the retrieved mass loading (all else being equal).

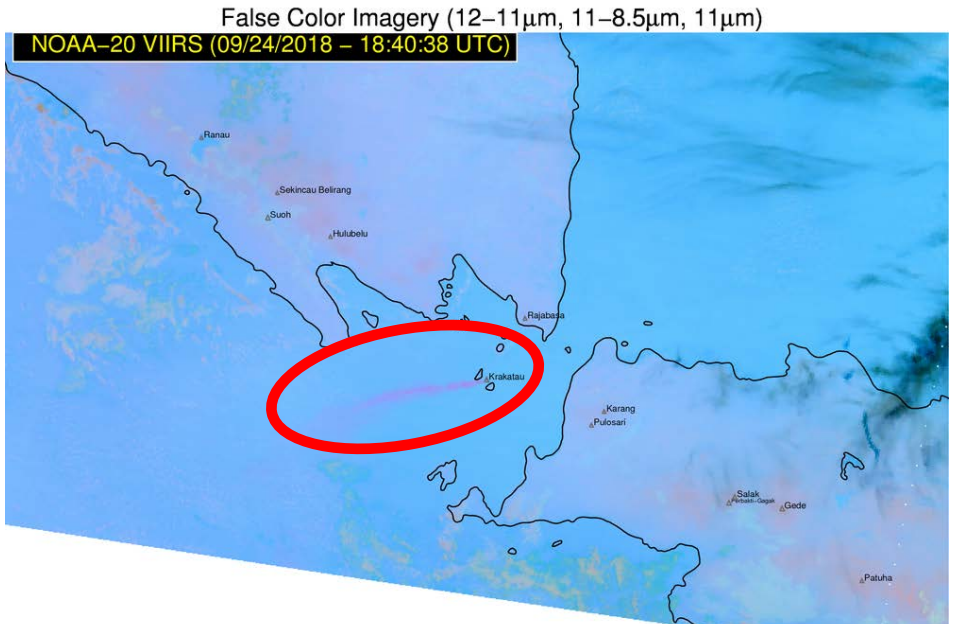


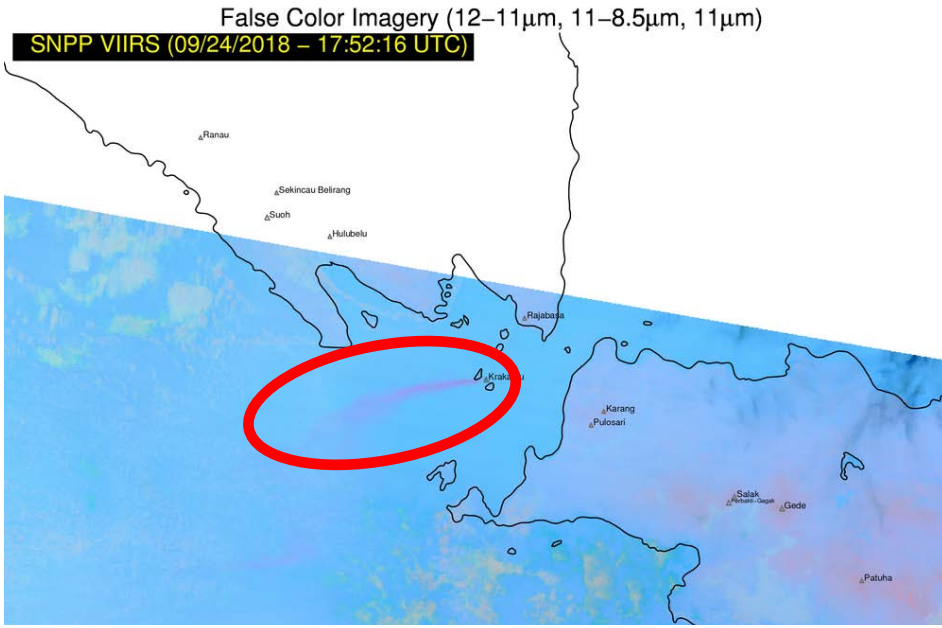
S-NPP AND NOAA-20 COMPARISON

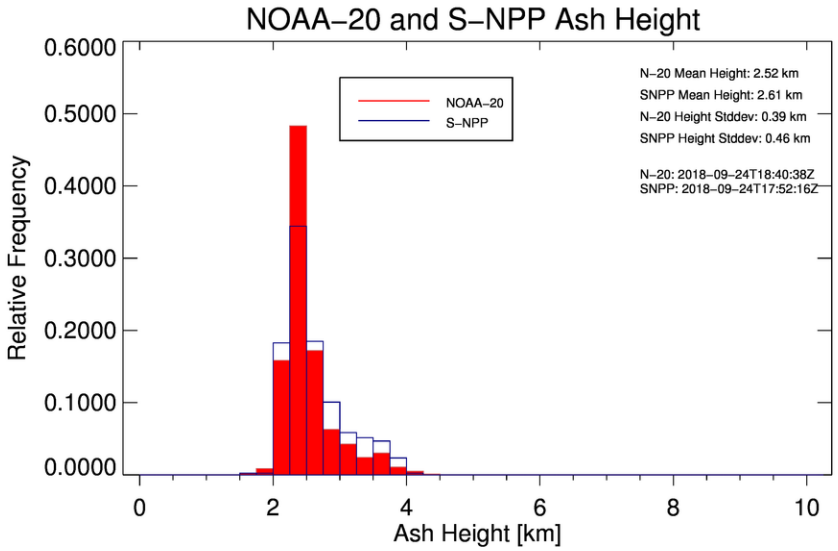
S-NPP and NOAA-20 Comparison

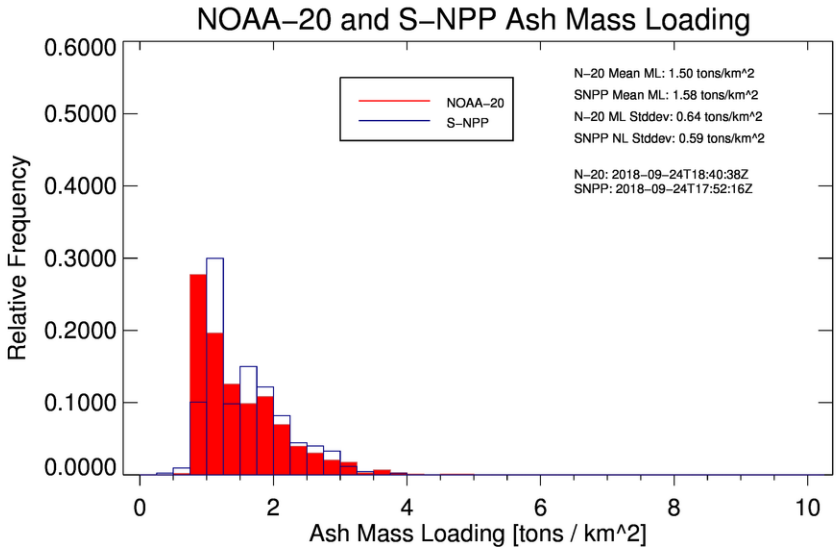
- S-NPP and NOAA-20 orbits are separated by approximately 50 minutes
- 22 cases were chosen for comparisons where both datasets were available and not at the extreme limb of the imager
- Results should be consistent, but not identical due to changes in volcanic clouds over 50 minutes and viewing angle differences between S-NPP and NOAA-20

S-NPP vs. NOAA-20: Example

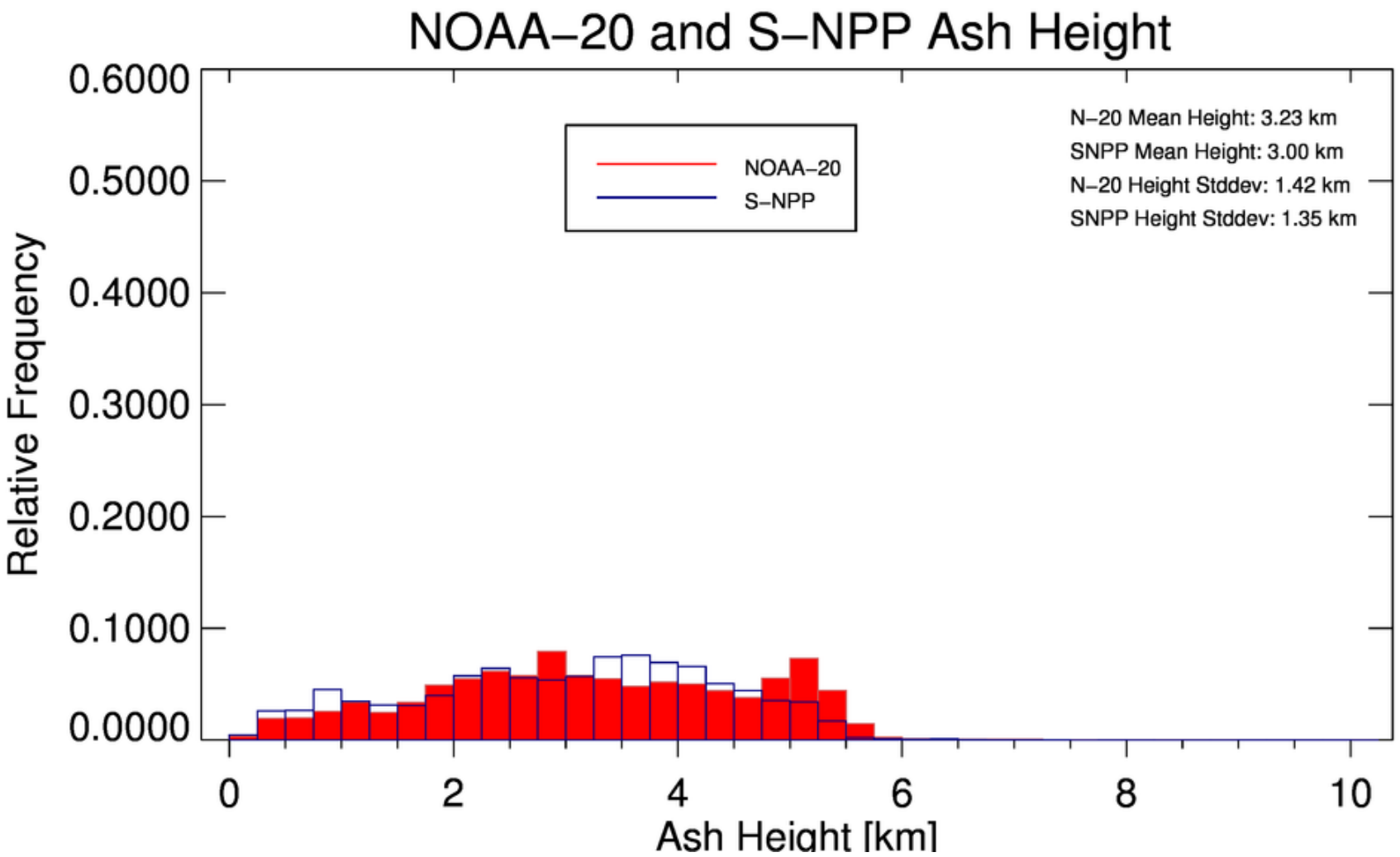




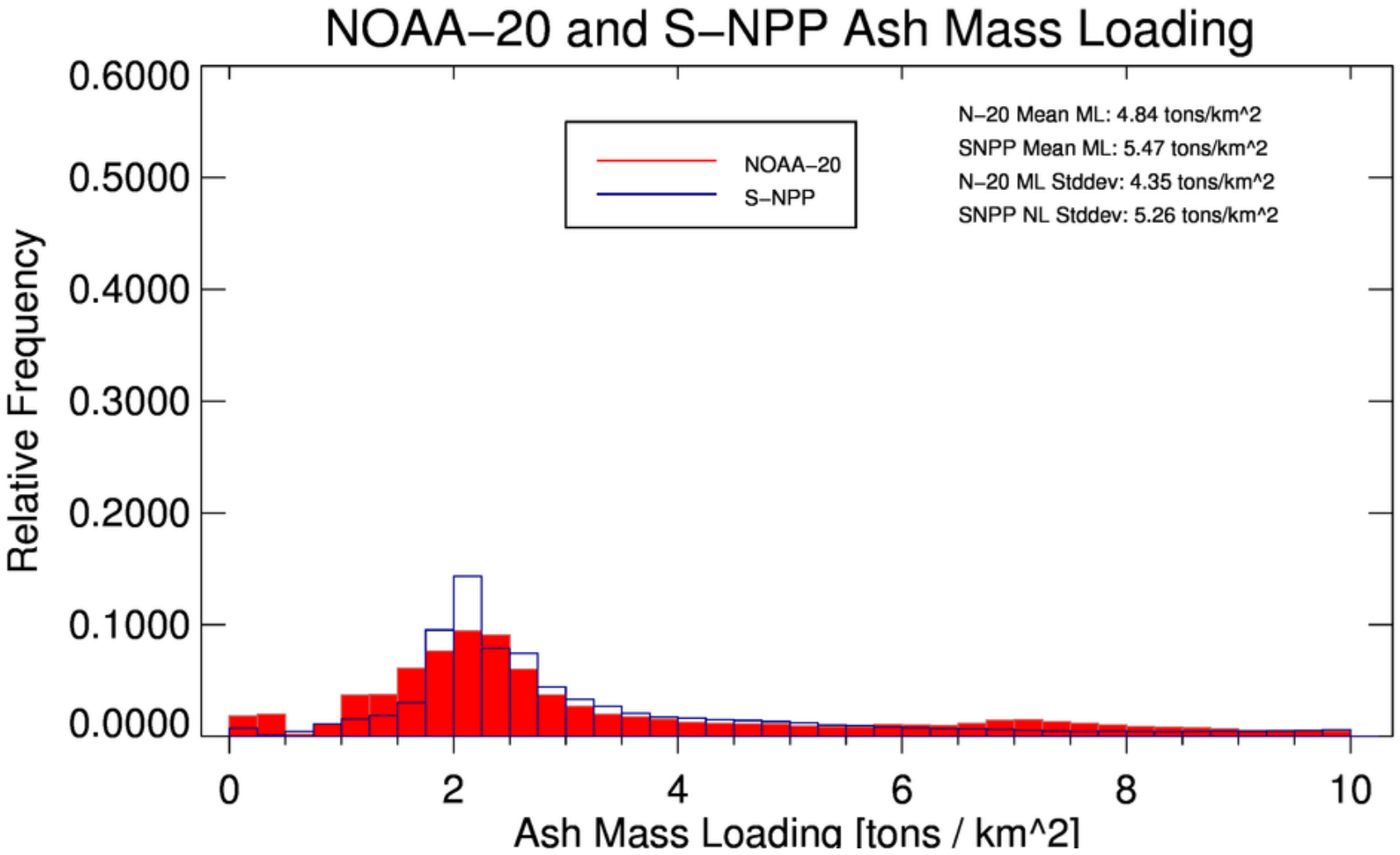




S-NPP vs. NOAA-20: Bulk Stats – Ash Height



S-NPP vs. NOAA-20: Bulk Stats – Ash Mass Loading



Evaluation of Required Algorithm Inputs

- **Primary sensor data:** VIIRS M14, M15, and M16
  - No issues
  - Performance is consistent with S-NPP (no threshold changes were needed)

- **Ancillary data:** GFS fields drive the required clear sky radiative transfer model
  - The FV3 was evaluated and the correlation with the heritage GFS based results was > 0.97
  - The transition to FV3 should not be an issue

Error Budget

Attribute Analyzed	JERD Threshold	S-NPP Performance (previous analysis)	NOAA-20 Performance (analysis reported here)	Meet Requirement ?	Additional Comments
Height: Accuracy	3 km	1.9 km	0.92 – 1.74 km	Yes	Low bias
Loading: Accuracy	2 ton/km^2	1.1 ton/km^2	1.26 – 1.60 ton/km^2	Yes	High bias
Loading: Precision	2.5 ton/km^2	1.4 ton/km^2	0.84 – 1.22 ton/km^2	Yes	

The enterprise volcanic ash algorithm meets the established requirements.

User Feedback

Name	Organization	Application	User Feedback - User readiness dates for ingest of data and bringing data to operations
Jamie Kibler	NESDIS/OSPO/ SAB	Support for Washington Volcanic Ash Advisory Center operations	VOLCAT is strongly preferred
Jeff Osiensky	NWS/AAWU	Support for Anchorage Volcanic Ash Advisory Center operations	VOLCAT is strongly preferred
ARL	OAR/ARL	Support for volcanic ash dispersion and transport forecasting	VOLCAT is strongly preferred

Downstream Product Feedback

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

No downstream usage

Risks, Actions, and Mitigations

Identified Risk	Description	Impact	Action/Mitigation and Schedule
Missing Granules	Numerous missing granules limited validation opportunities	None	Closed: This issue was fixed, leaving sufficient time to perform the full validation analyses
Lack of Lidar Data	Lidar observations of volcanic ash, coincident with NOAA-20, are extremely rare	Low (does not prevent spec from being met)	Other methods of validation have been employed
Situational Performance	NOAA-20 has yet to observe a major stratospheric eruption with a long-lived ash cloud	Low (does not prevent spec from being met)	New eruptions will continue to be analyzed

Documentation

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)	As requested

Check List - Validated Maturity

Validated Maturity End State	Assessment
Product performance has been demonstrated over a large and wide range of representative conditions (i.e., global, seasonal).	Yes
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.	Yes
Product analyses are sufficient for full qualitative and quantitative determination of product fitness-for-purpose.	Yes
Product is ready for operational use based on documented validation findings and user feedback.	Yes
Product validation, quality assurance, and algorithm stewardship continue through the lifetime of the instrument	Yes

Conclusion

- Cal/Val results summary:
  - Team recommends algorithm validated maturity
    - An advection based validation analysis and comparisons to S-NPP indicate that the NOAA-20 volcanic ash products meet the accuracy specifications
    - The JPSS volcanic ash algorithm does not represent the latest state of the science. Users are cautioned that the JPSS volcanic ash products were not designed for advanced applications such as eruption alerting and integration with dispersion models.

Path Forward

- The VIIRS volcanic ash EDR was introduced to ensure continuity with GOES-R product requirements

- The Enterprise Algorithm is very similar to the GOES-R baseline algorithm, which was the first automated algorithm of its kind when it was first developed in 2007-2010

- Since 2010, far more sophisticated algorithms have been developed within the VOLcanic Cloud Analysis Toolkit (VOLCAT)

- VOLCAT is a stand-alone multi-sensor application that not only addresses the GOES-R and JPSS ash product requirements, but also introduces new capabilities such as eruption alerting

- We continue to seek an R2O path for VOLCAT that overcomes issues associated with mission stove piping and can accommodate its unique processing requirements. VOLCAT, as is, can be implemented into operations, as the Japanese Meteorological Agency, the Australian Bureau of Meteorology, and the New Zealand Met Service (*in Amazon cloud*) have successfully transitioned VOLCAT to operations