


Marco Fulle - www.stromboli.net

The WMO Satellite-derived Volcanic Ash Intercomparison Activity - Capabilities and Challenges for Operational Applications

Michael Pavolonis

NOAA/NESDIS

WMO Intercomparison of Satellite-based Volcanic Ash Retrieval Algorithms within SCOPE-Nowcasting

Stephan Bojinski, WMO

Implementation: Richard Siddans and Gareth Thomas (STFC Rutherford Appleton Laboratory); Justin Sieglaff and John Cintineo (UW-CIMSS)

Planning: Elisa Carboni (Oxford), Pete Francis (UKMO), Marianne Koenig (EUMETSAT), Mike Pavolonis (NOAA), Dave Schneider (USGS), Hiroaki Tsuchiyama (JMA), Claus Zehner (ESA)

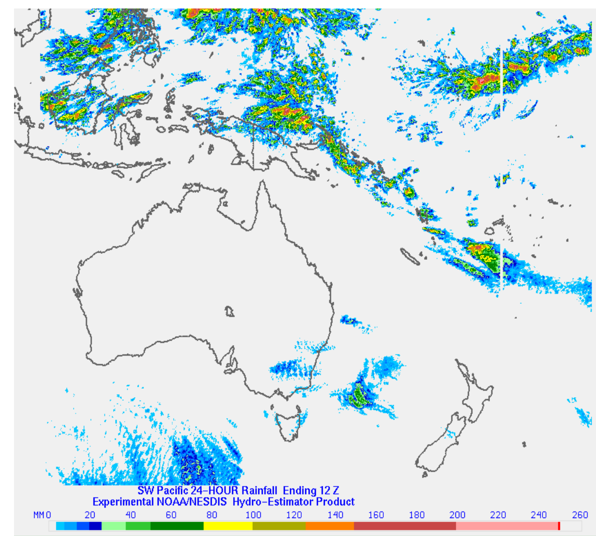
SCOPE-Nowcasting

- Sustained,
- Co-Ordinated
- Processing of
- Environmental Satellite Data for
- Nowcasting

4 Pilot Projects kicked off in 2013:

- Use of imagery/RGBs
- **Consistent Volcanic Ash products**
- Blended precipitation products
- Sand and dust monitoring

- Coordination initiative led by WMO
- Goal: To improve the use of satellite data for nowcasting applications
- Focus:
  - Use of multi-satellite data
  - Areas where satellites are dominant source of information
  - Mature science; Organized user community

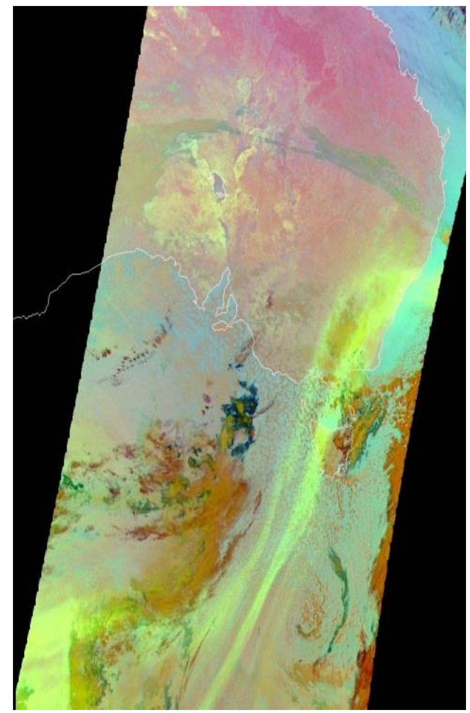


Motivation for VA Intercomparison

Value of satellite-based volcanic ash products recognized by VAACs and airlines, especially during the eruptions in the last five years, but:

- Quantifying volcanic ash parameters is difficult, but in demand;
- There is no internationally-agreed validation protocol for such products;
- Many products are available, and their strengths and weaknesses are not known or comparable,
- Many products are produced on an ad-hoc basis and not sustained or operationally available,
- There is no standard for volcanic cloud geophysical parameters endorsed by WMO.

Eyjafjallajokull (Arni Fridriksson, 17 Apr 2010)



Primary Goals of VA Intercomparison

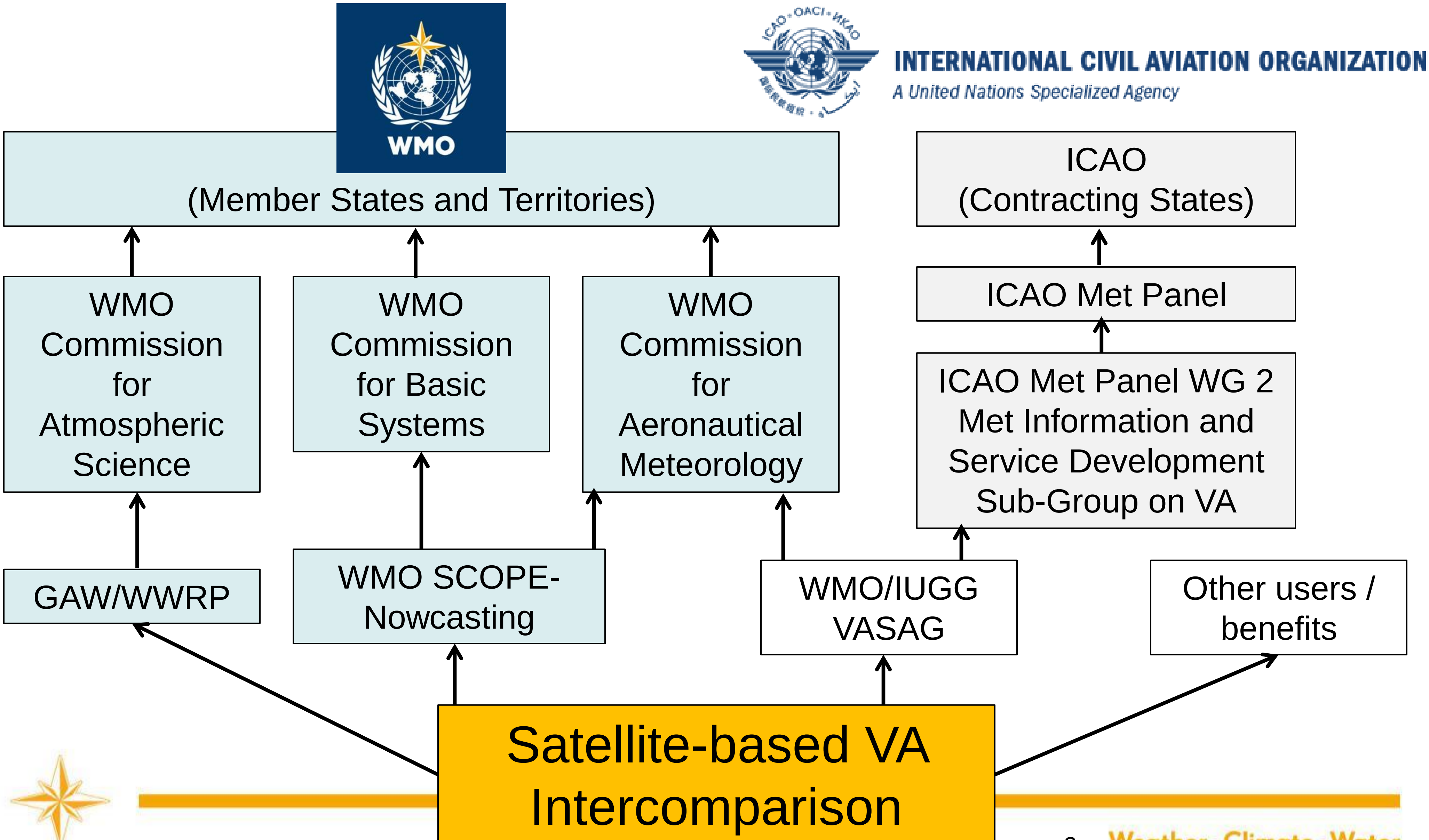
1). Quantify the differences between satellite-derived volcanic ash cloud properties derived from different techniques and sensors

2). Establish basic product validation protocols

3). Document the general strengths and weaknesses of the different retrieval approaches

4). Provide recommendations relevant to operational usage of satellite-derived quantitative volcanic cloud products

VA Intercomparison: Need for Guidance



Intercomparison Cases

- *Eyjafallajökull (2010)*
- *Grimsvötn (2011)*
- *Sarychev Peak (2009)*
- *Kelut (2014)*
- *Puyehue-Cordón Caulle (2011)*
- *Kirishimayama (2011)*

RAL contracted by Eumetsat to host submitted datasets and perform systematic inter-comparison

Algorithm Contributions (Total: 27 (22))

SCOPE•NWC

Organization	Algorithm(s)
NOAA	SEVIRI_NOAA MODIS_NOAA
Oxford University	IASI_OXFORD TERRA_MODIS_ORAC AQUA_MODIS_ORAC
Université Libre de Bruxelles	IASI_ULB
CMA	SEVIRI_CMA
EUMETSAT	METOP-A_PMAP METOP-B_PMAP SEVIRI_EUMOP
Australian BOM	MTSAT2_BOM MODIS_BOM
DLR Germany	SEVIRI_VADUGS
SNM Argentina	MODIS_CENZARG
INGV Italy	MODIS_LUT MODIS_VPR
SRC Planeta, Russia	METOP_PLANETA
University of Bristol	BRISTOL_IASI
UK MetOffice	SEVIRI_MO AVHRR_MO

Organization	Algorithm(s)
JMA	MTSAT2_JMA MTSATIR_JMA
STFC RAL, UK	SEVIRI_ORAC_RAL TERRA_MODIS_RAL AQUA_MODIS_RAL
FMI	AATSR_FMI
NASA	MISR

"Validation" Sources

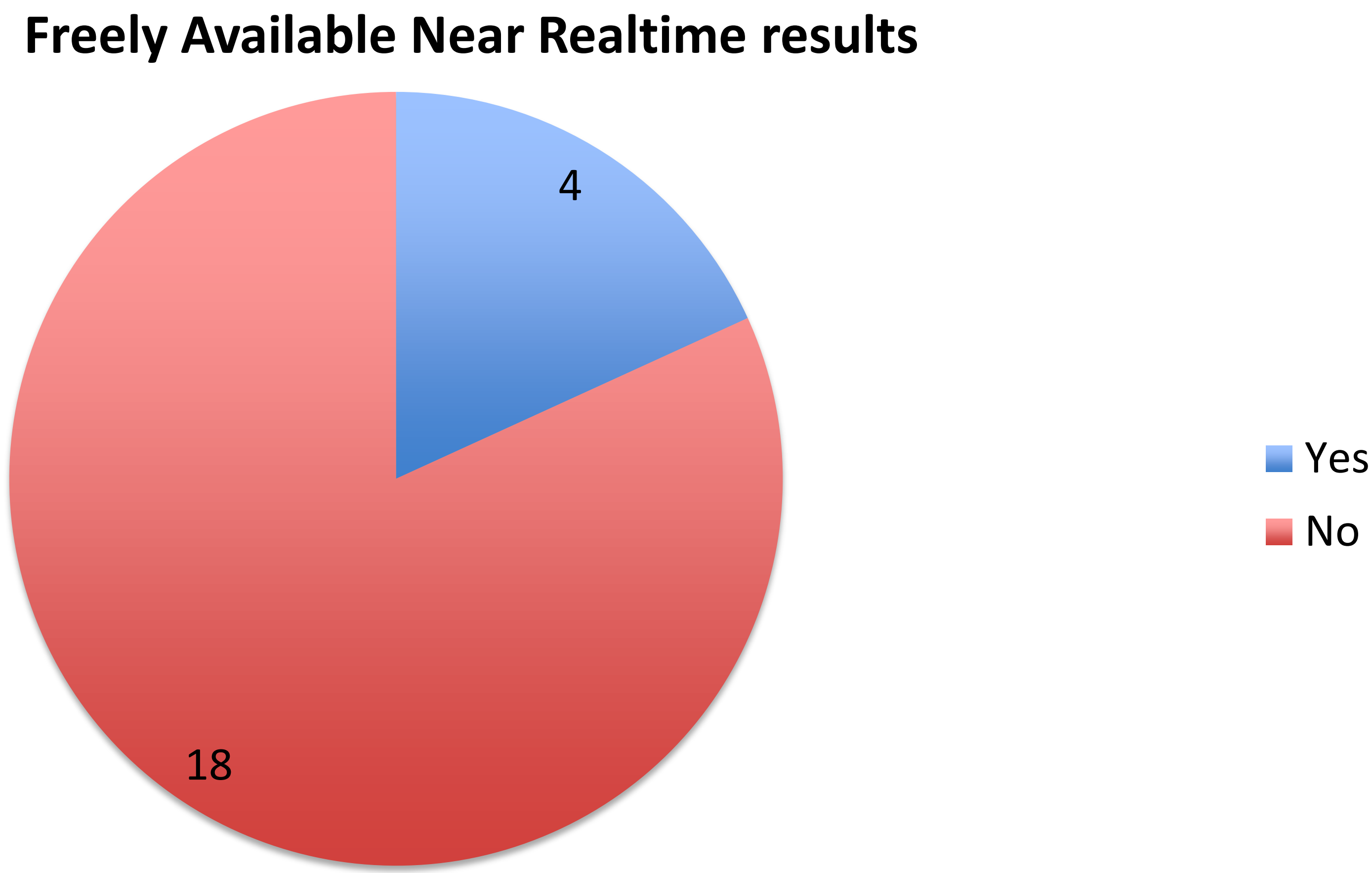
- FAAM UK Airborne lidar
- CALIPSO CALIOP
- Ground-based Lidar
- Expert assessment

Meeting Participants (Total: 33)

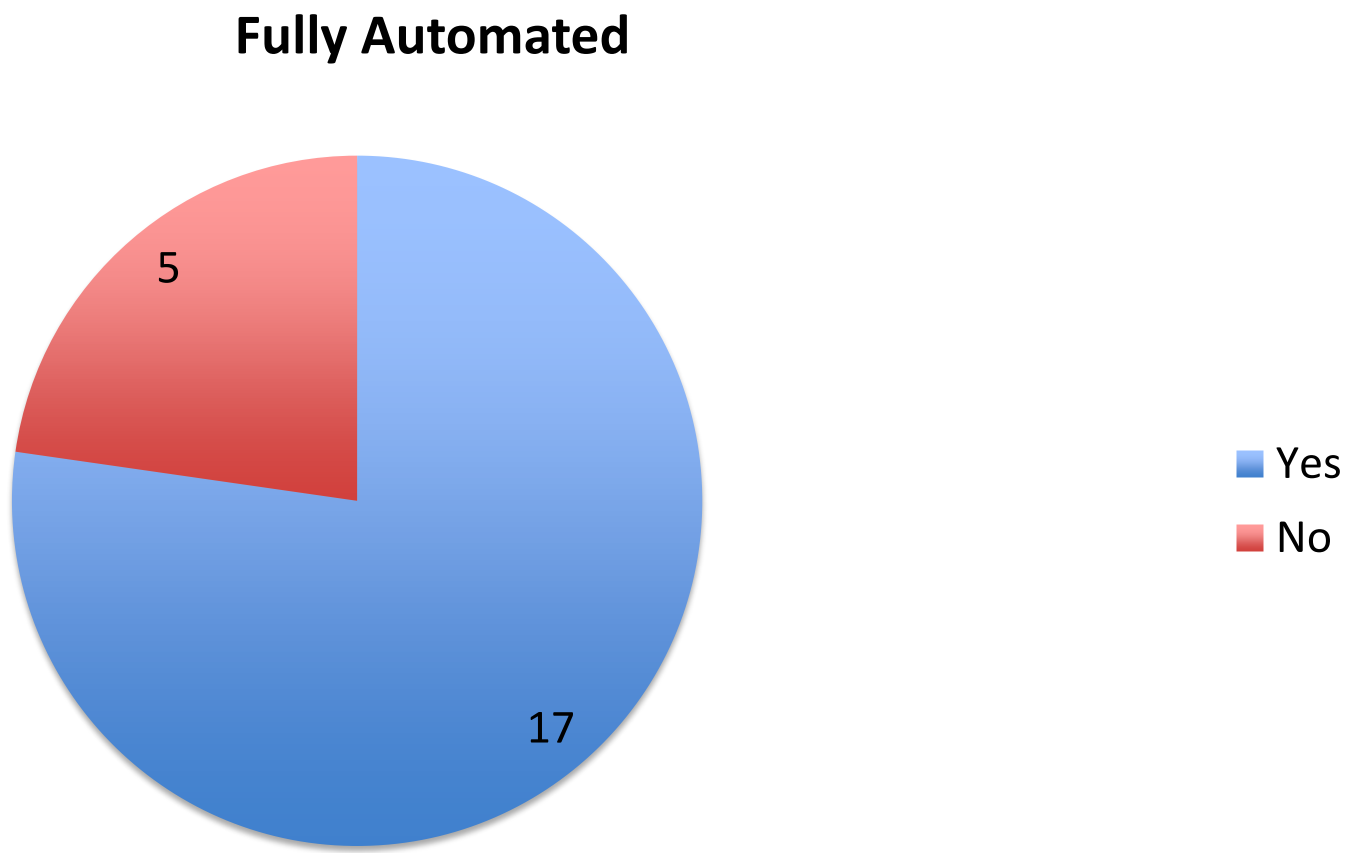
SCOPE • NWC

Country/Organization		Number of Participants	Institutions
Argentina	VAAC	1	Argentine Met Service
Australia	VAAC	1	BoM
Belgium		2	BIRA, Academia
China		1	CMA
ESA		1	----------------------------------
EUMETSAT		3	----------------------------------
Germany		2	DLR
Italy		4	INGV, Academia
Japan	VAAC	1	JMA
Republic of Korea		1	KMA
Russia		1	PLANETA
UK	VAAC	5	Met Office, RAL, Academia
USA	VAAC	10	NASA, NOAA, USGS, Academia

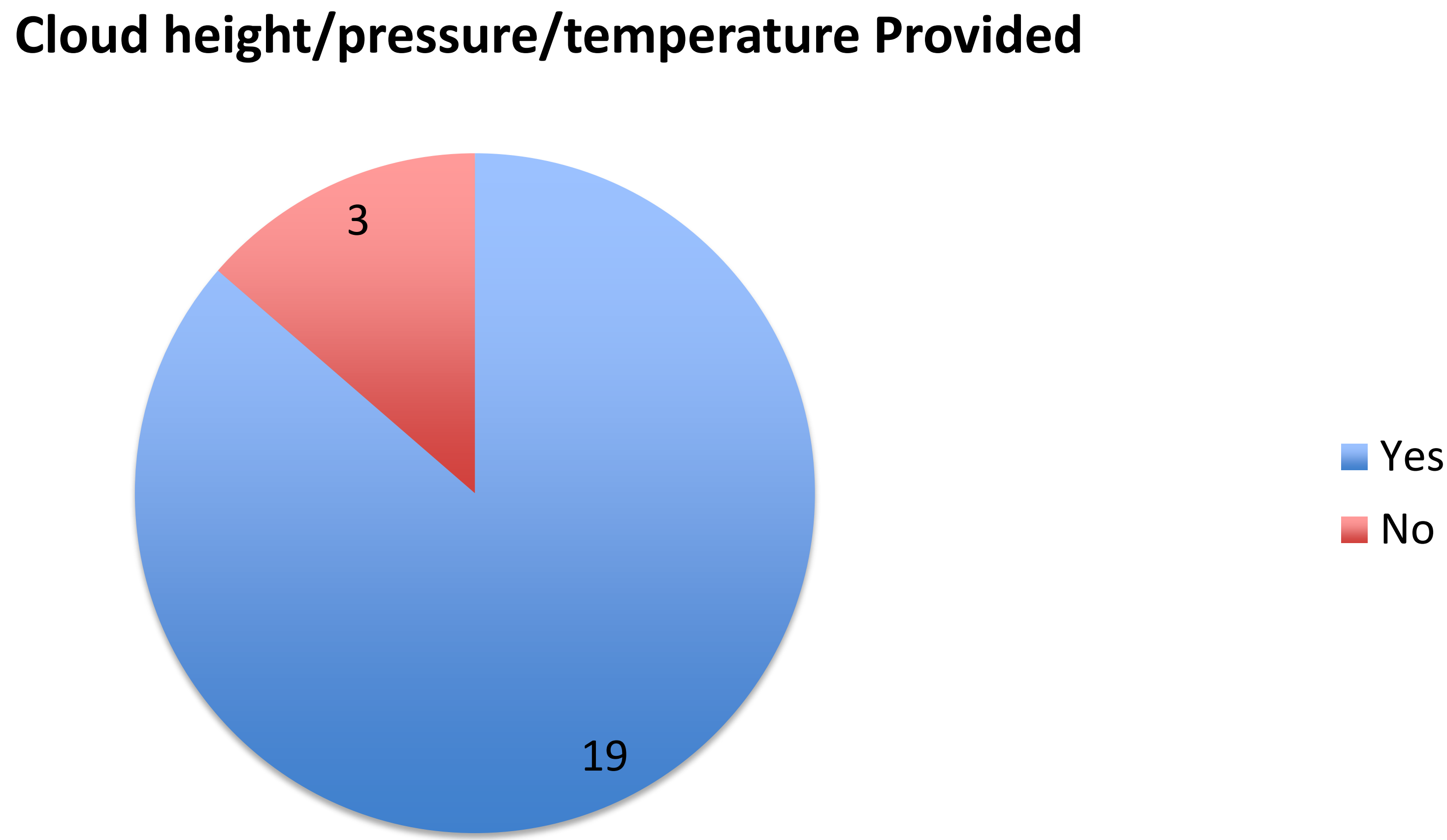
Product Availability



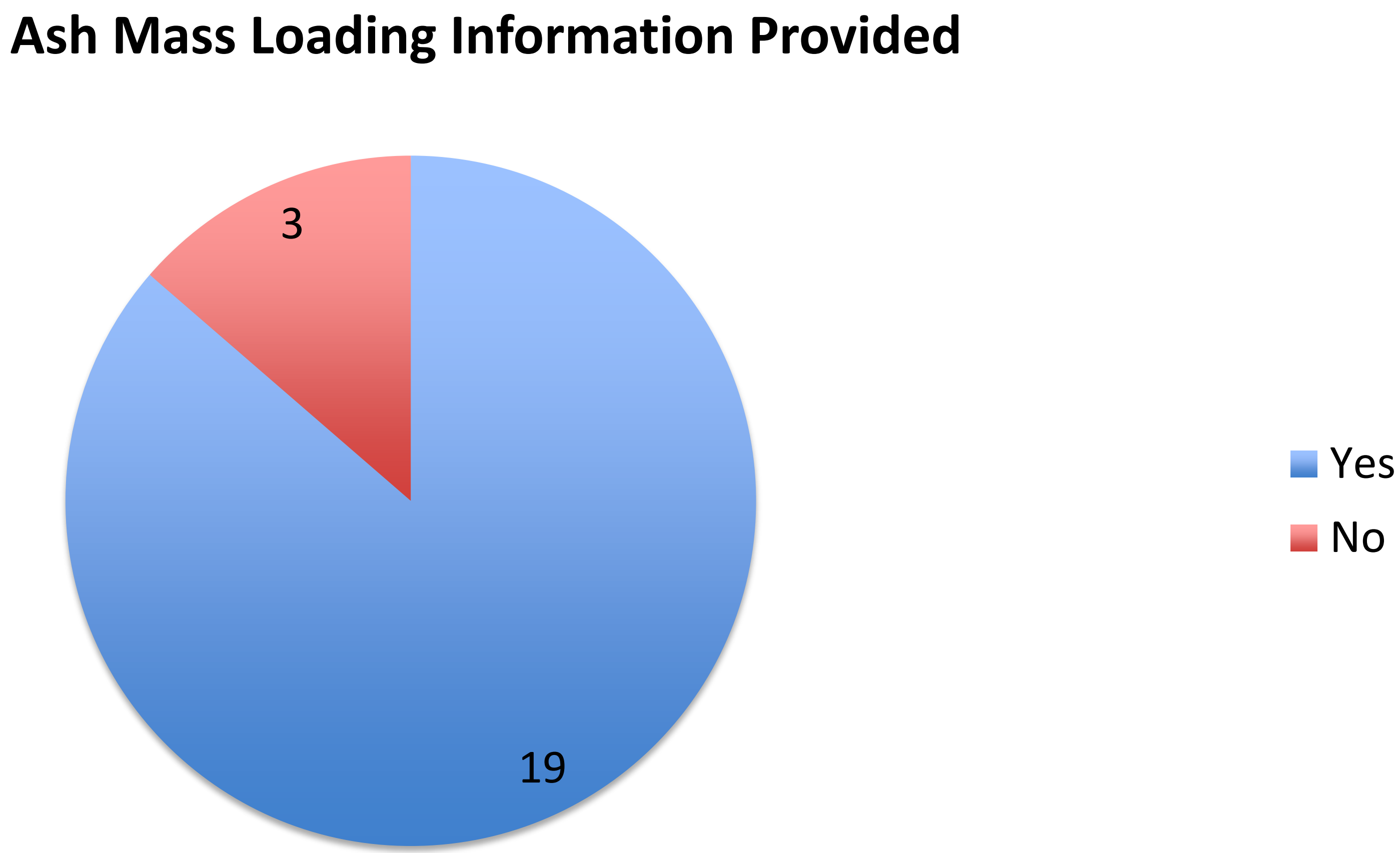
Automation



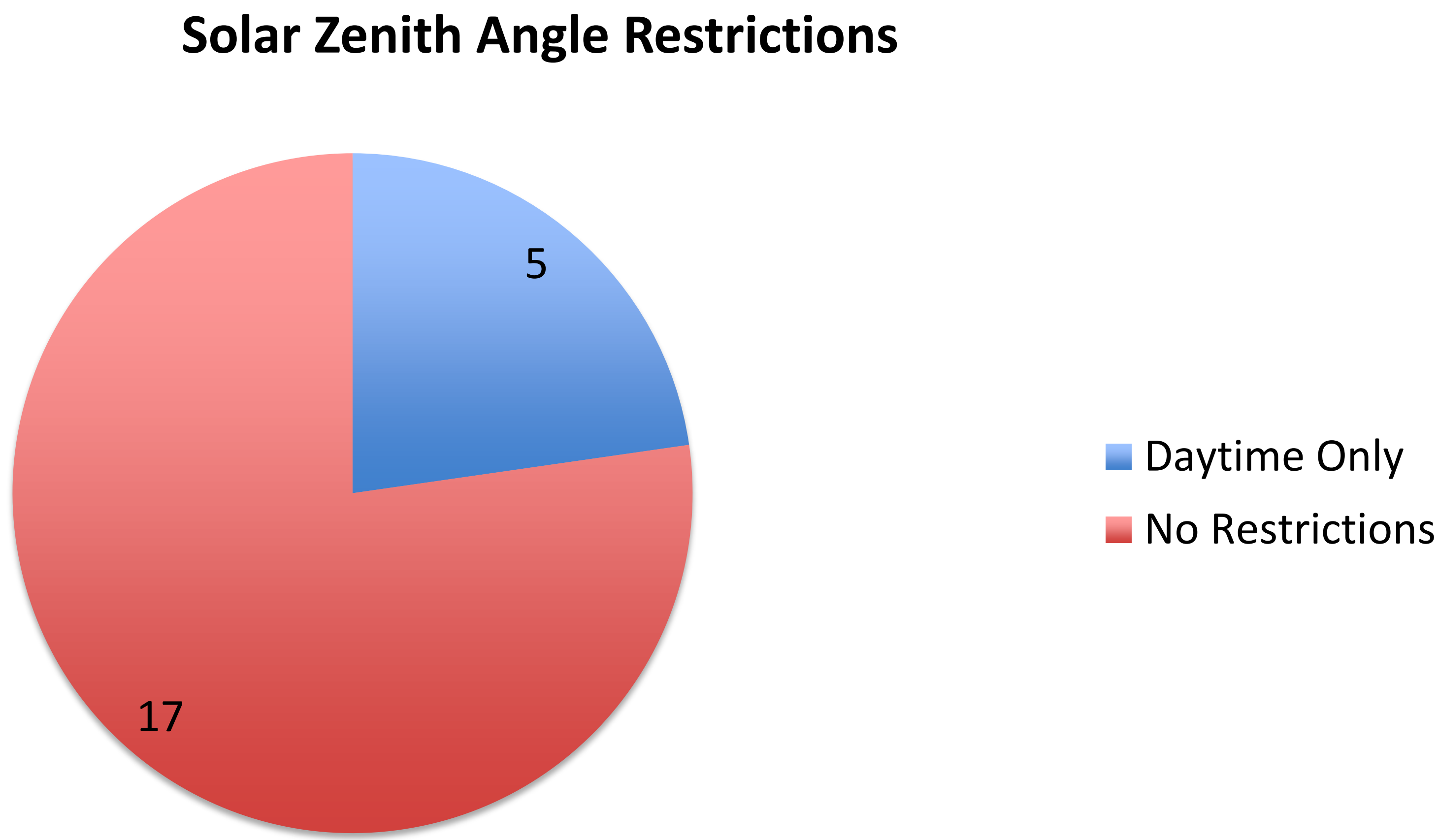
Ash Cloud Height Information



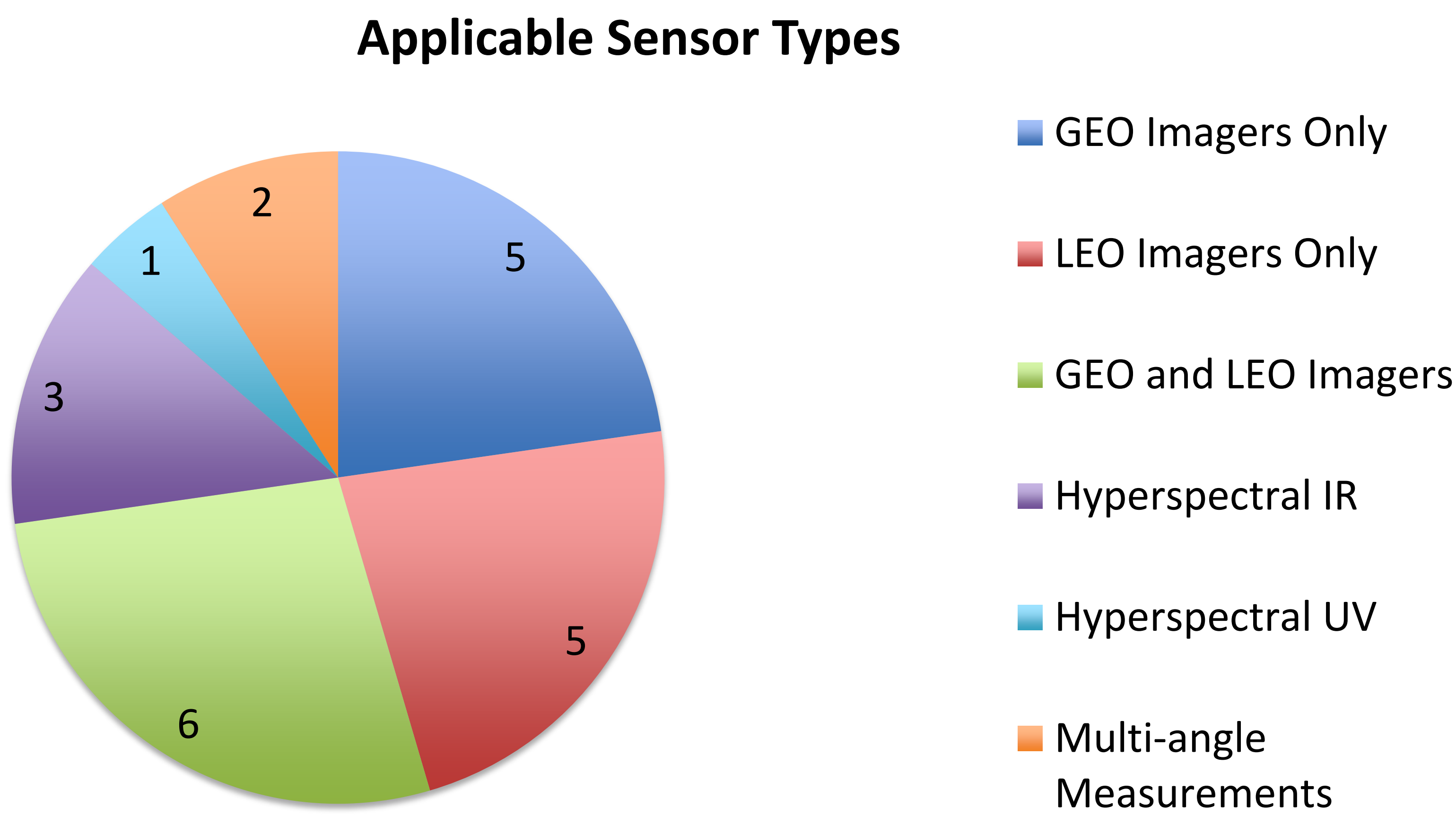
Ash Mass Loading Information



Day/night Applicability



Satellite Sensor Types



http://cimss.ssec.wisc.edu/meetings/vol_ash15/

WMO Intercomparison of Satellite-based Volcanic Ash Retrieval Algorithms Workshop

29 June - 2 July 2015
The Pyle Center
University of Wisconsin-Madison

Volcanic ash from Pavlof Volcano as photographed by astronauts aboard the International Space Station on May 18, 2013 (credit: NASA)

Venue | Program | Hotel | Register | Madison

Description of Meeting

In support of aeronautical meteorological services, WMO is sponsoring the Intercomparison of Satellite-based Volcanic Ash Retrieval Algorithms Workshop, which presents an excellent opportunity to improve the consistency of quantitative volcanic ash products from satellites. This meeting will be hosted by NOAA and Space Science and Engineering Center (SSEC) at the University of Wisconsin in Madison WI, USA, on 29 June through 2 July 2015. The volcanic ash intercomparison activity is embedded in the WMO-sponsored SCOPE-Nowcasting initiative (Sustained Coordinated Processing of Environmental Satellite Data for Nowcasting), which aims at improved rapid access to satellite data by member states, and at improved confidence in satellite products for nowcasting. The meeting in Madison is supported by the WMO Space Programme, the Aeronautical Meteorological Programme, and the Atmospheric Research and Environment Programme.

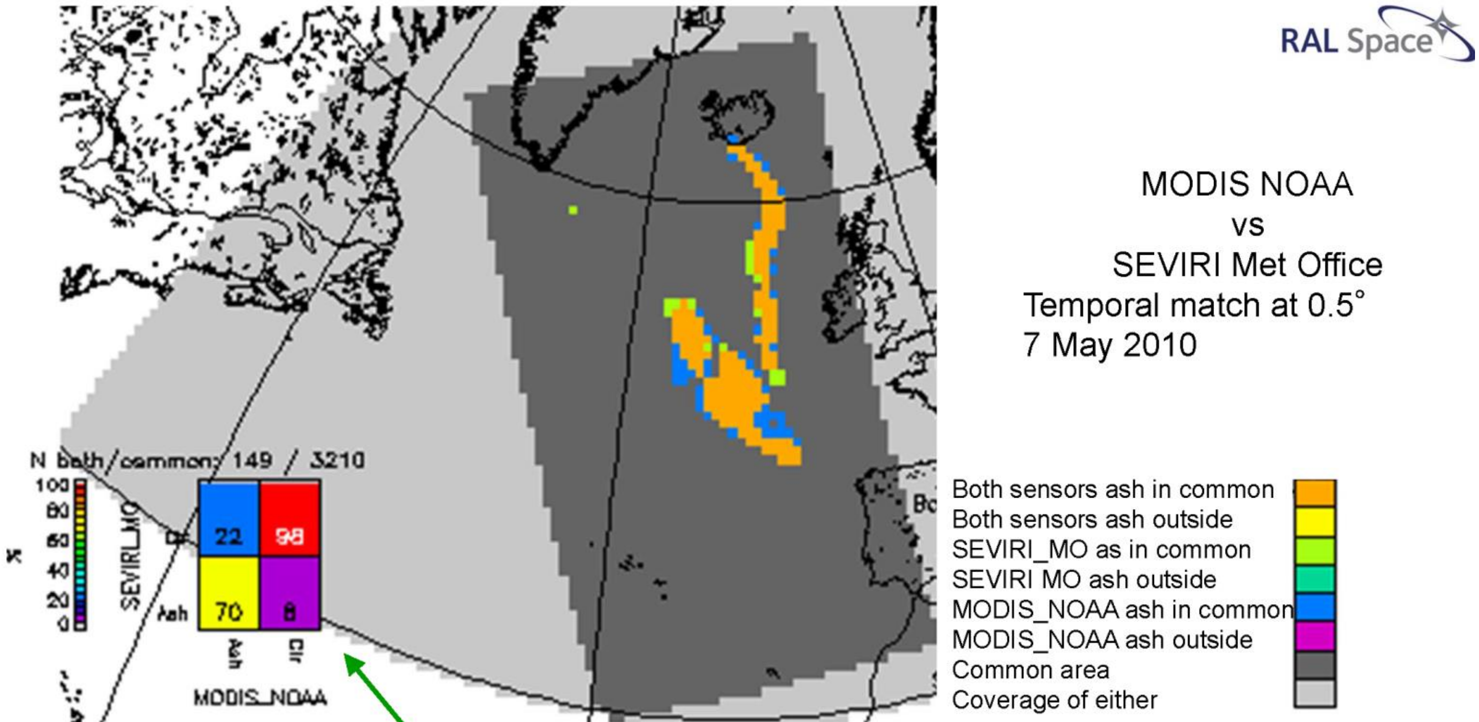
The meeting will begin at 1:00 p.m. on Monday, 29 June, and conclude at 3:00 p.m. on Thursday, 2 July 2015.

Intercomparison Meeting

29 June – 02 July, 2015

Madison, WI, USA

Analysis Method 1:
Comparisons to all other algorithms



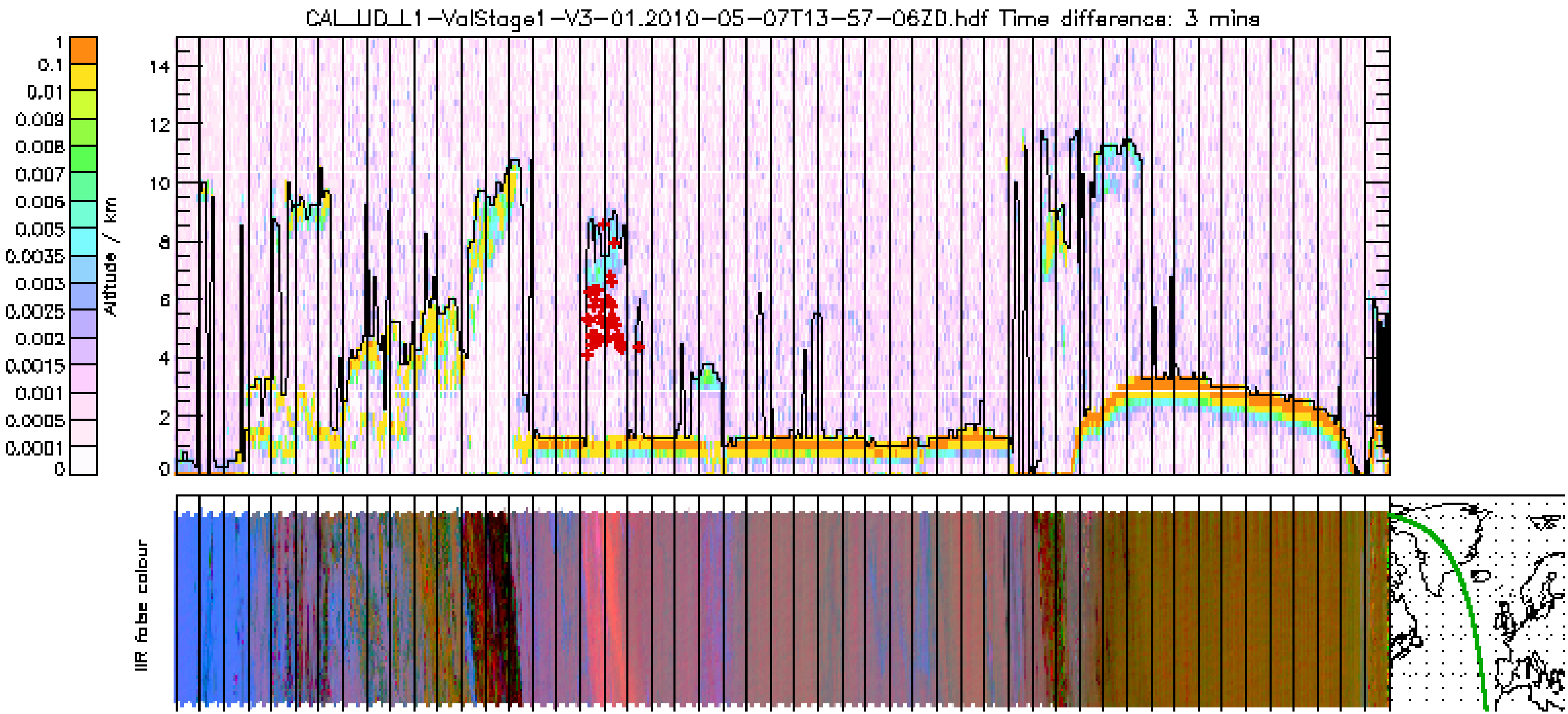
"Co-detection table"

% Sensor Y says clear/ Either sensor detects ash	% Both sensors says clear/ Either sensor says clear
% Both sensors detect ash / Either sensor detects ash	% Sensor X says clear/ Either sensor detects ash

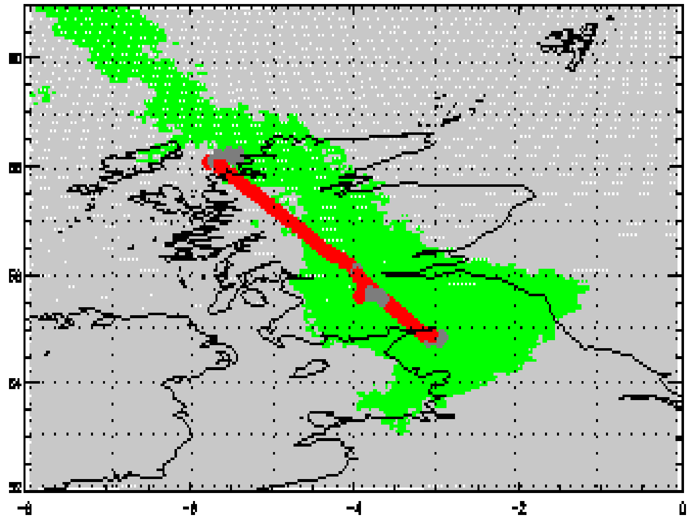
Ideally

0	100
100	0

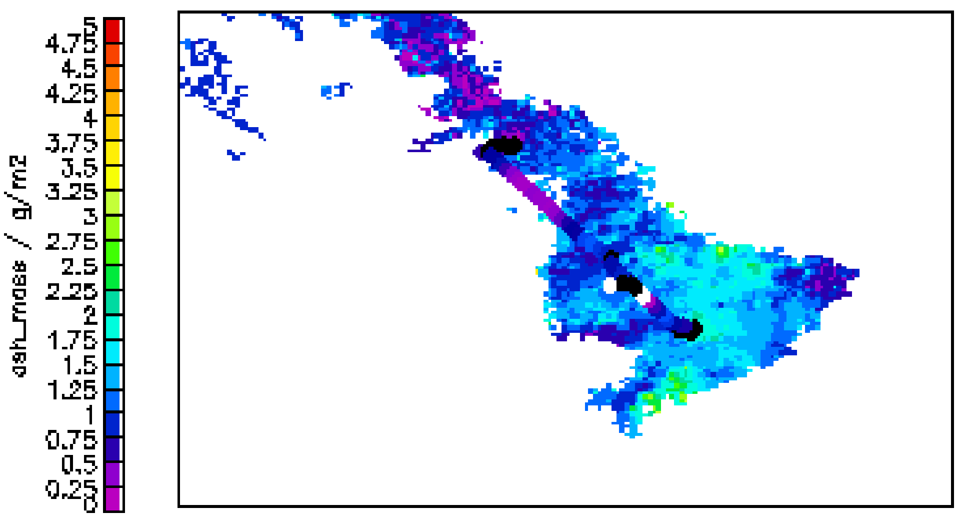
Analysis Method 2:
Comparison to Spaceborne LIDAR (CALIOP)



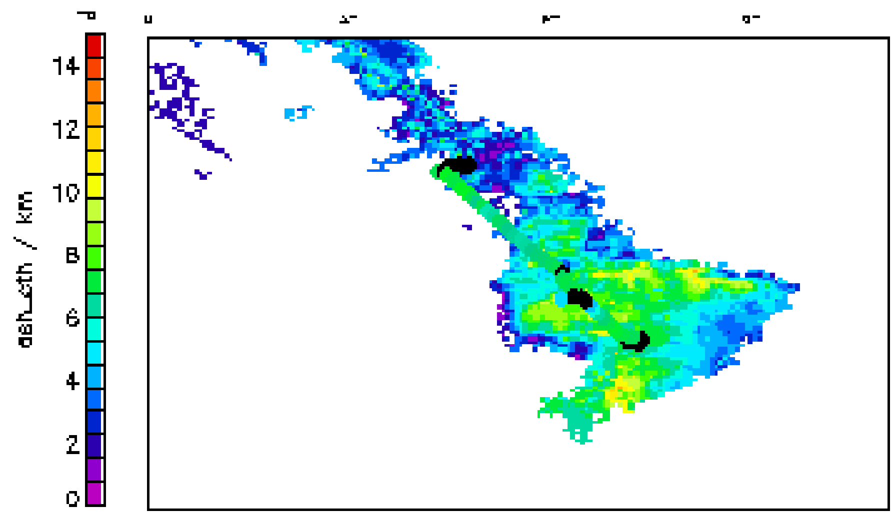
Analysis Method 3:
Aircraft Data (UKMO FAAM)



Ash mass

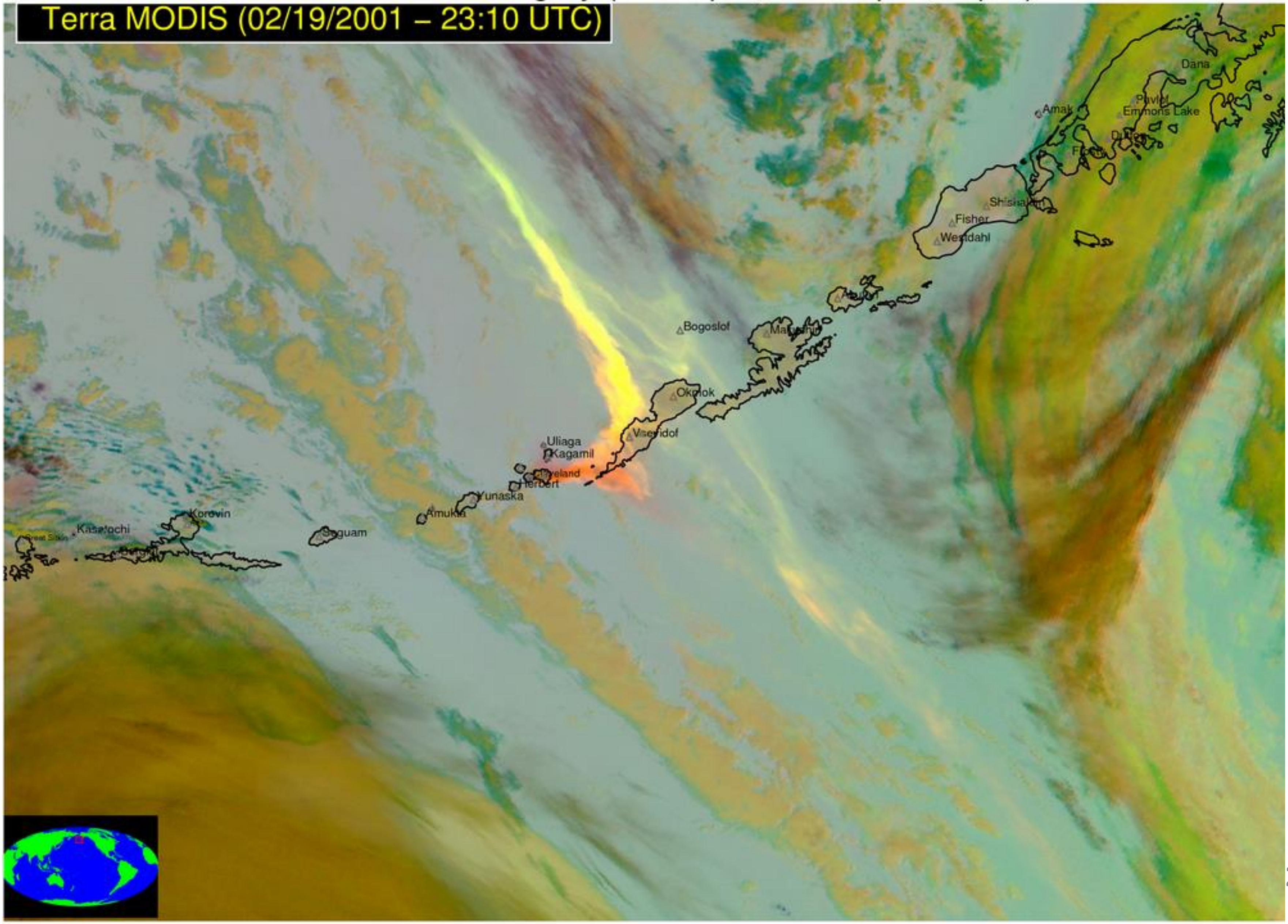


Ash height



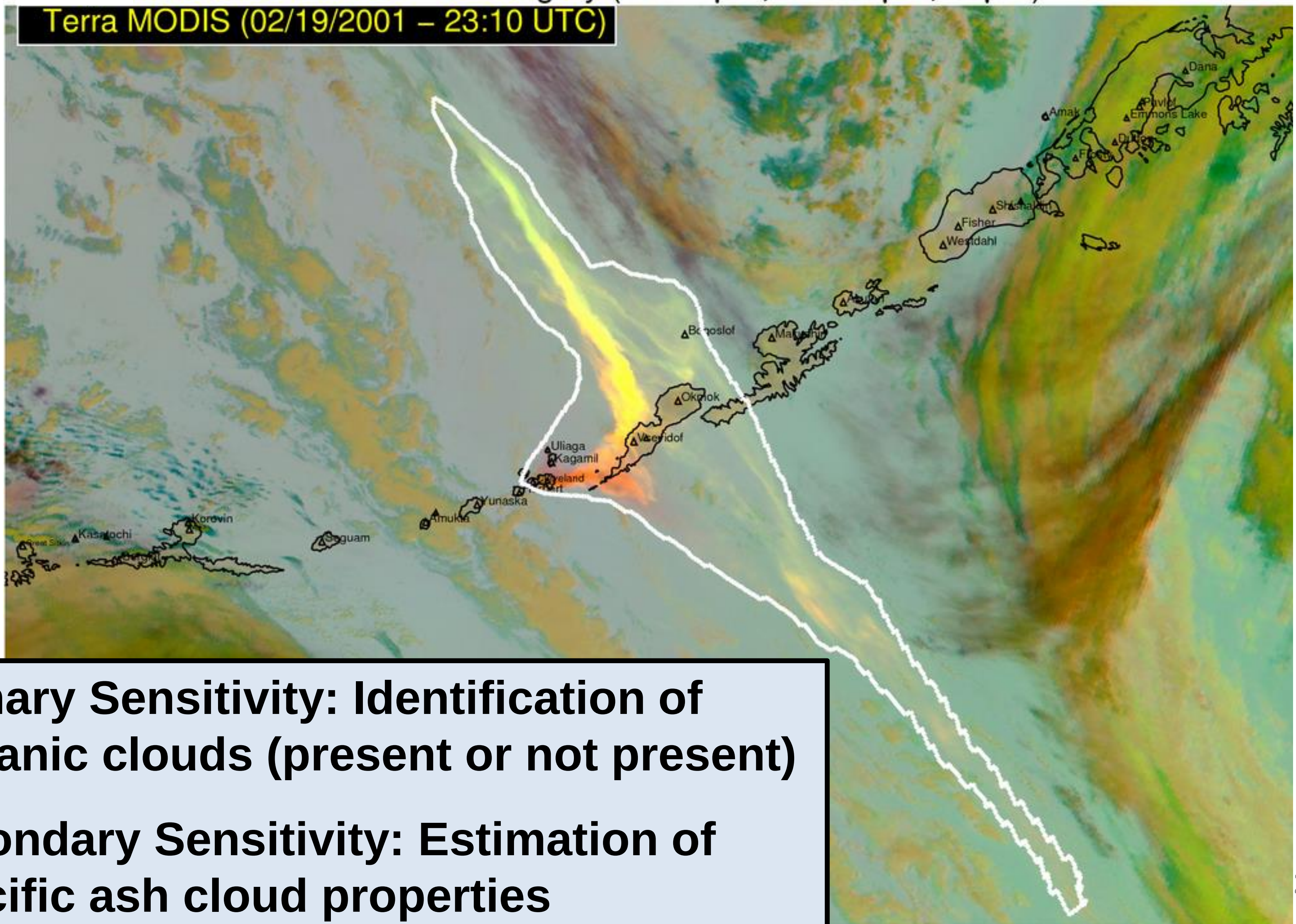
Major Conclusion 1: Primary vs. Secondary Sensitivity

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



Major Conclusion 1: Primary vs. Secondary Sensitivity

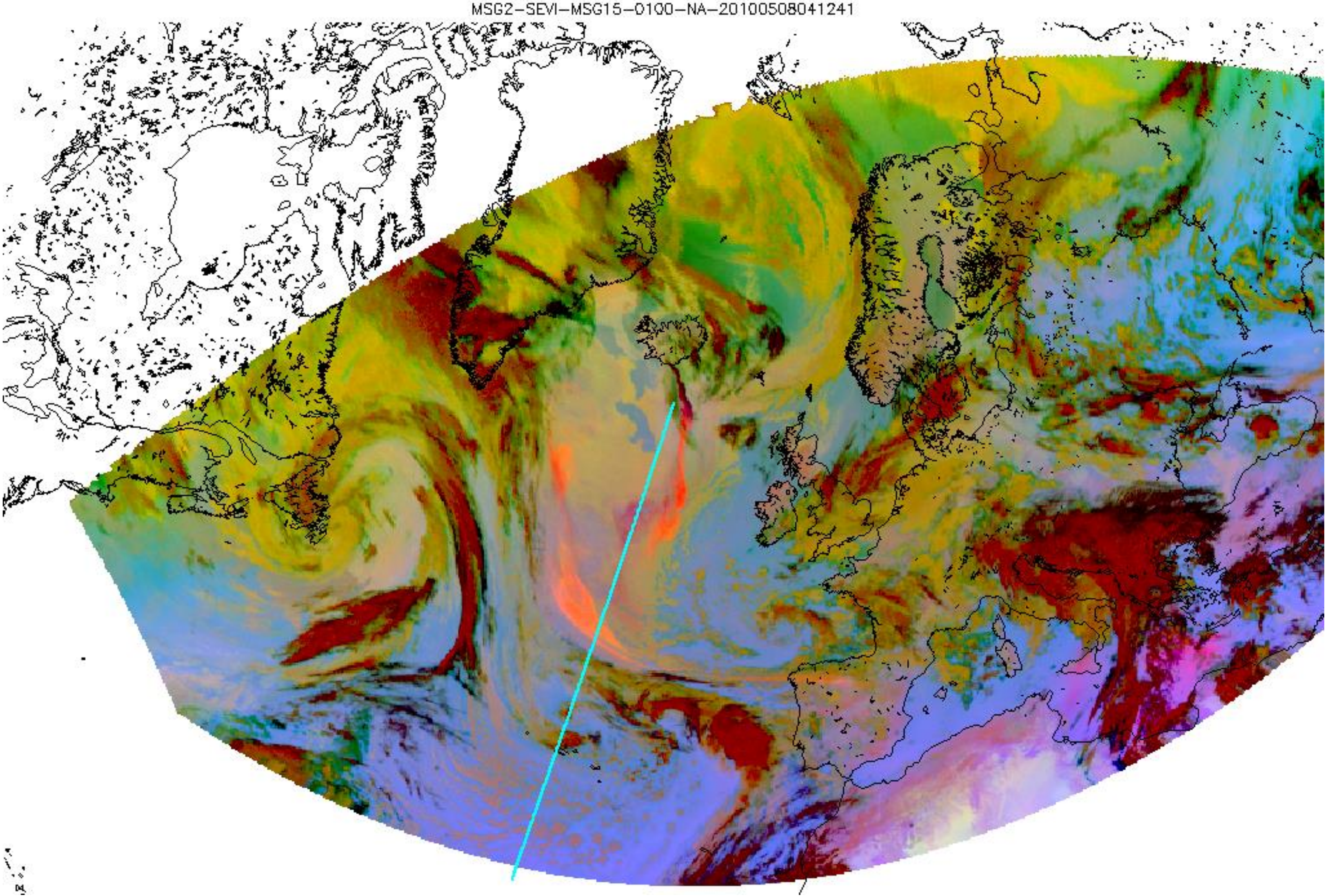
False Color Imagery (12–11μm, 11–8.5μm, 11μm)



Primary Sensitivity: Identification of volcanic clouds (present or not present)

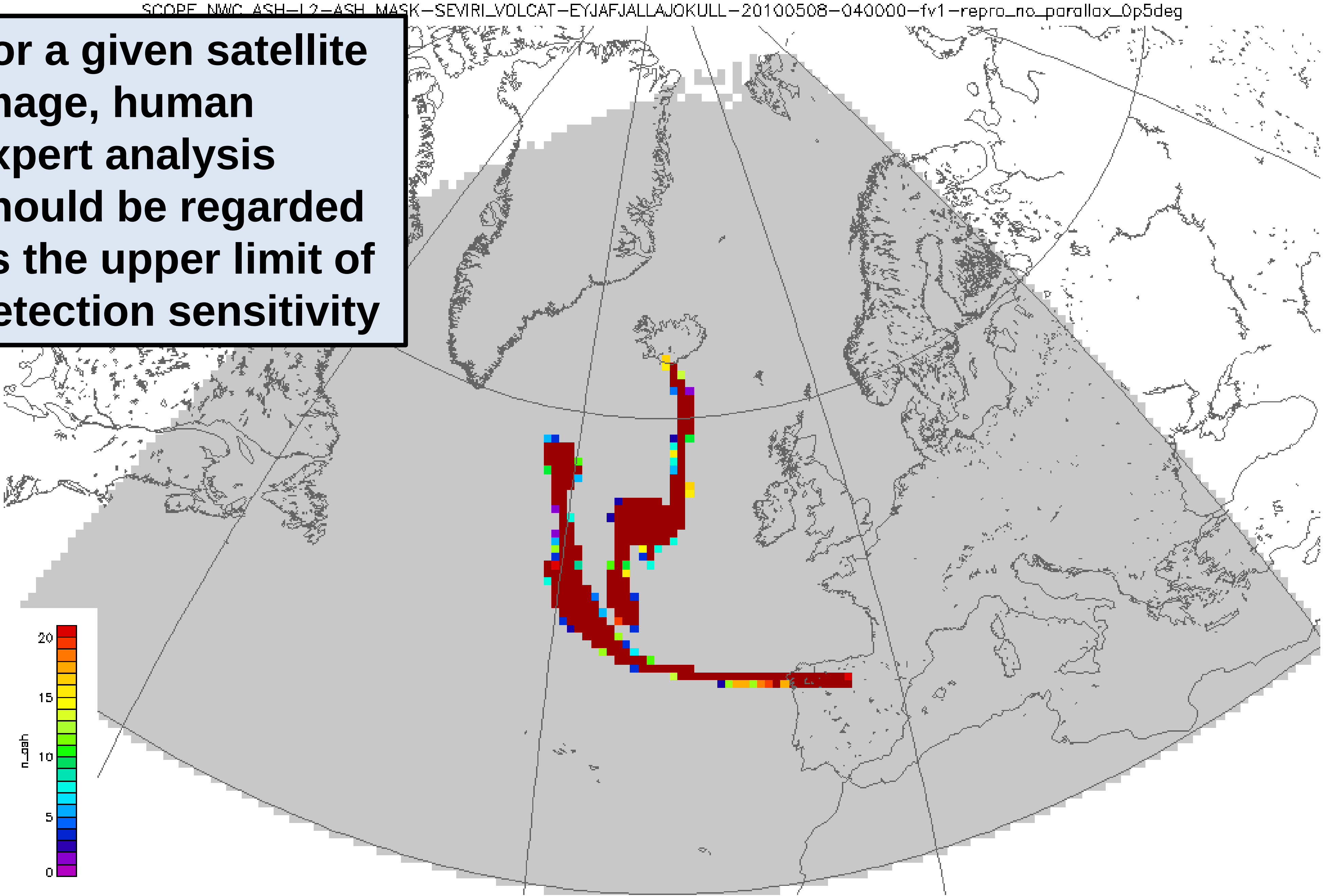
Secondary Sensitivity: Estimation of specific ash cloud properties

Major Conclusion 2: Variable Ash Detection Capabilities

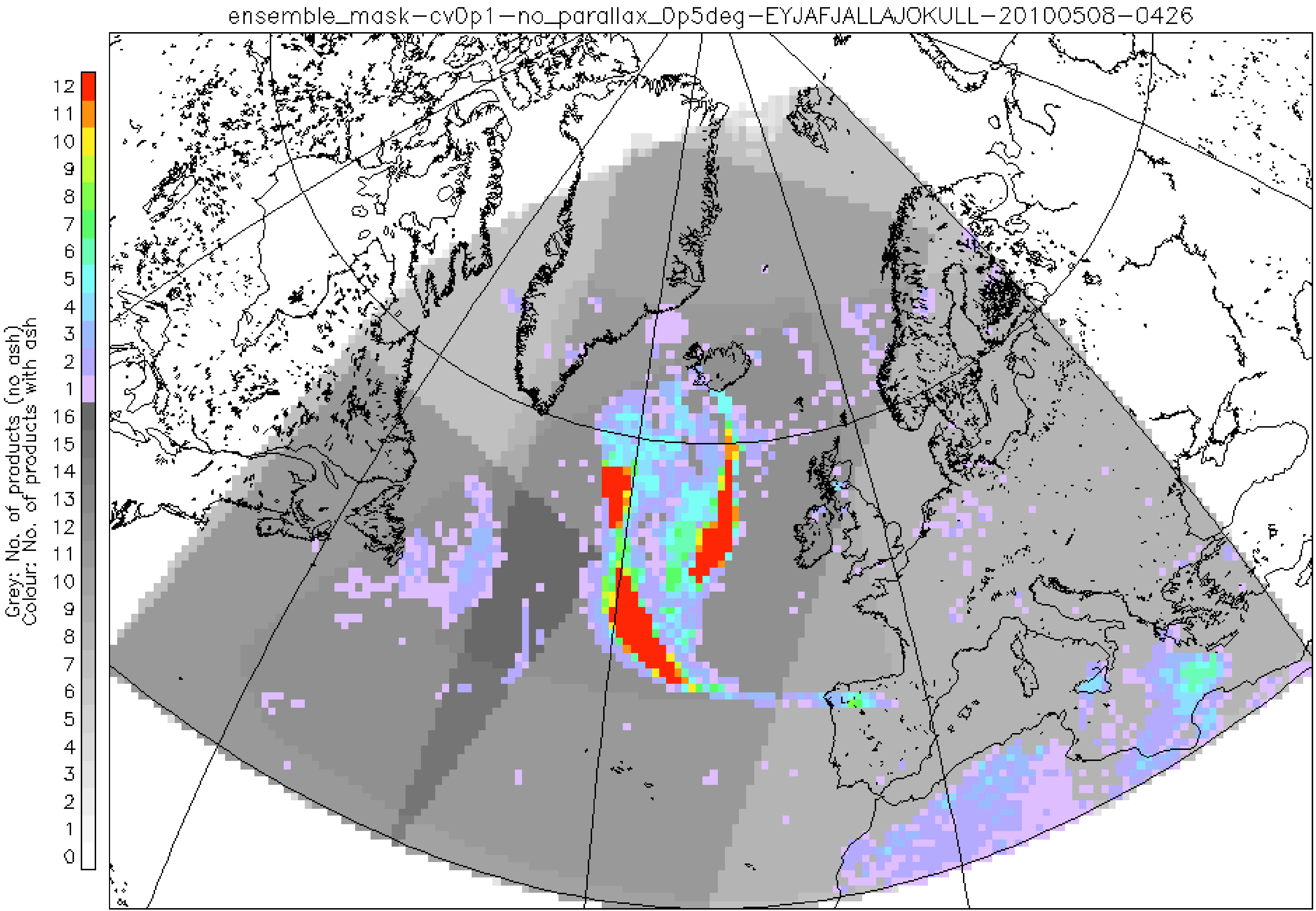


Major Conclusion 2: Variable Ash Detection Capabilities

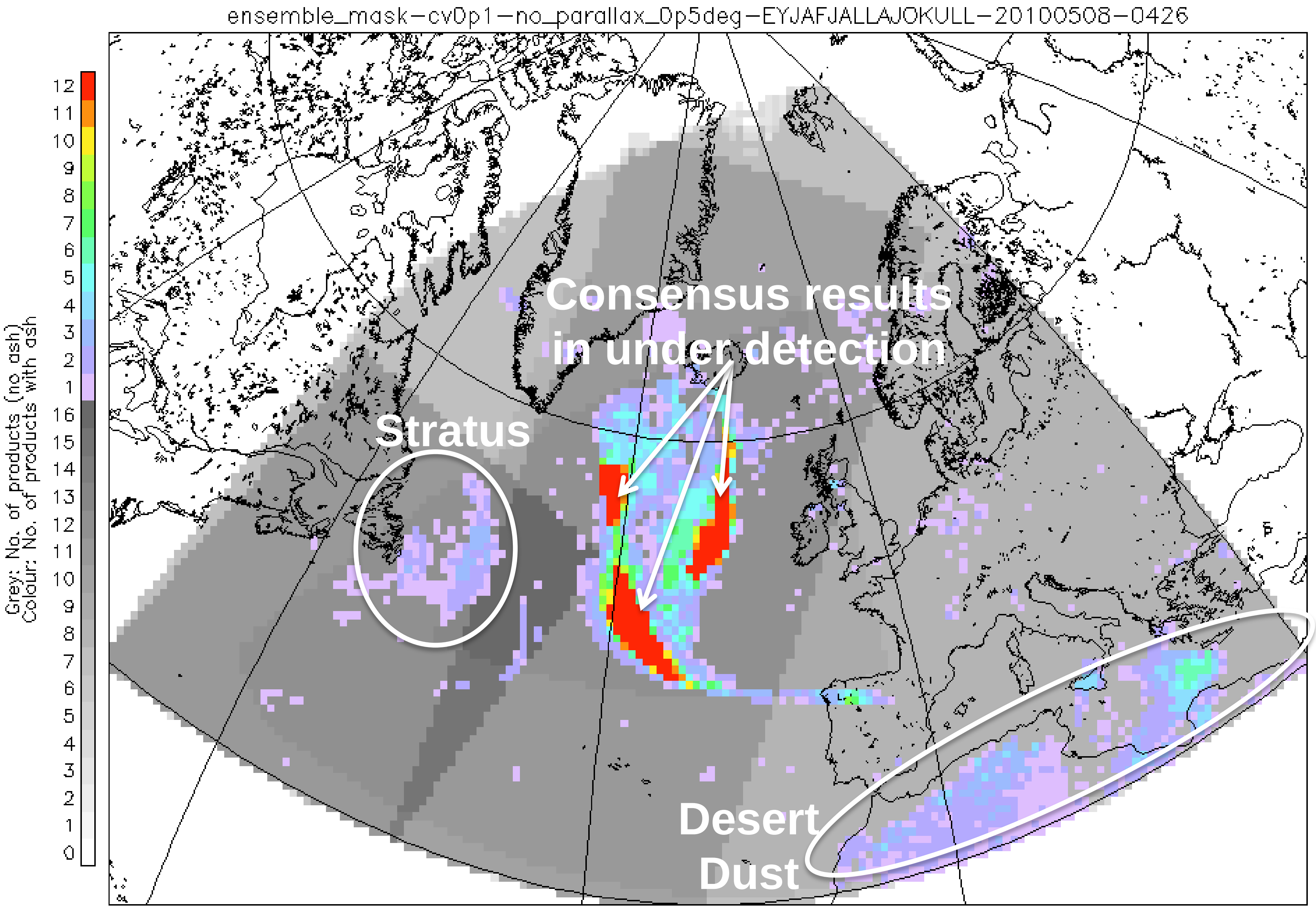
For a given satellite image, human expert analysis should be regarded as the upper limit of detection sensitivity



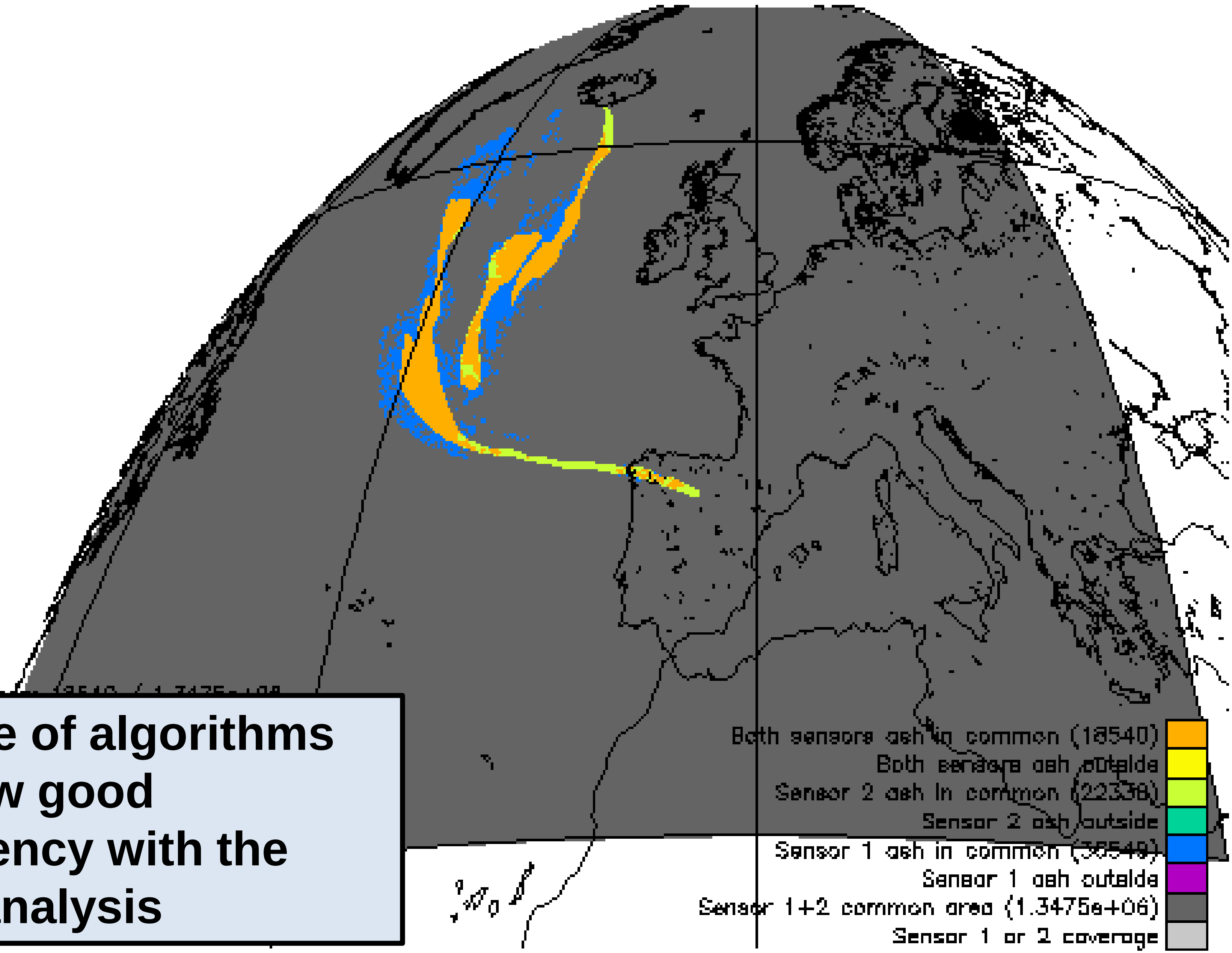
Major Conclusion 2: Variable Ash Detection Capabilities



Major Conclusion 2: Variable Ash Detection Capabilities



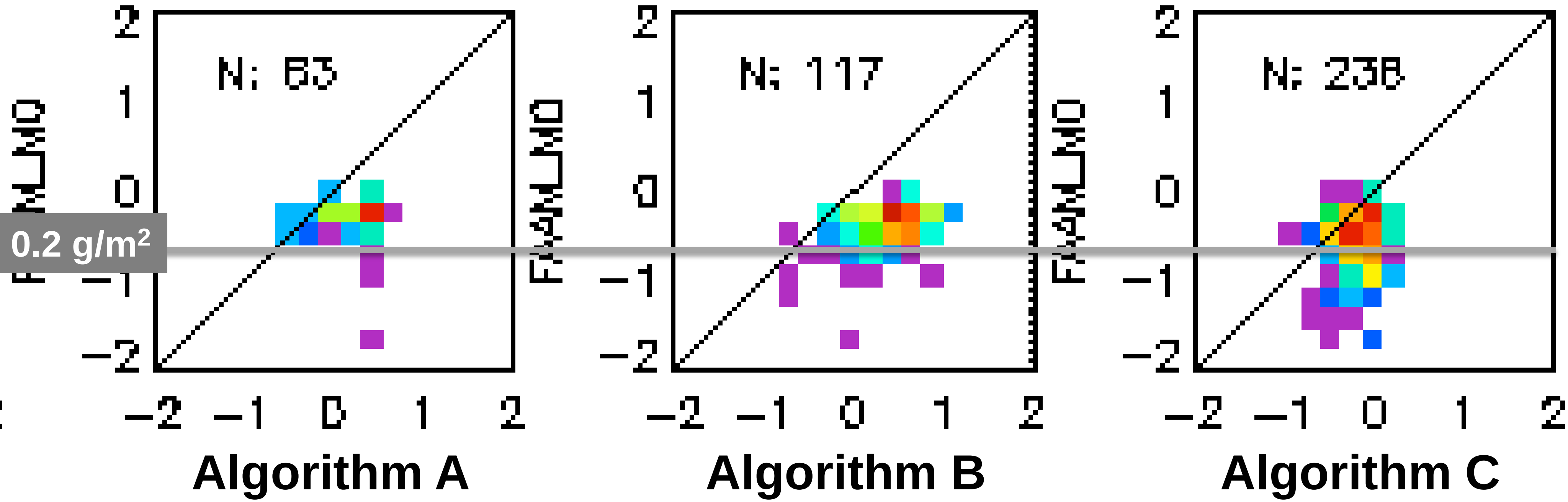
Major Conclusion 2: Variable Ash Detection Capabilities



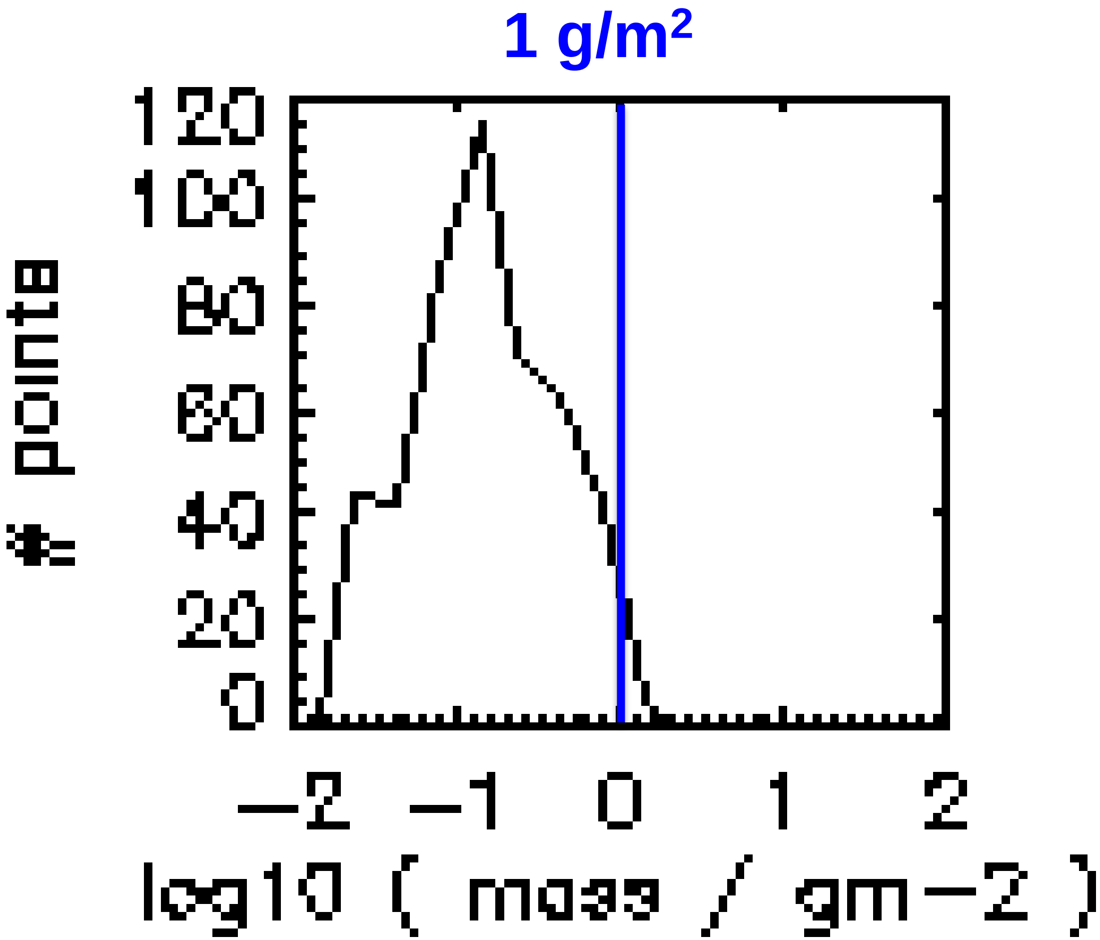
A couple of algorithms did show good consistency with the expert analysis

Major Conclusion 3: Lower Limit of Ash Detection

The lower limits of detection were found to be reasonably consistent with the 0.2 g/m^2 estimate published by Prata and Prata (2012).



Major Conclusion 4: Mass Loading Uncertainty

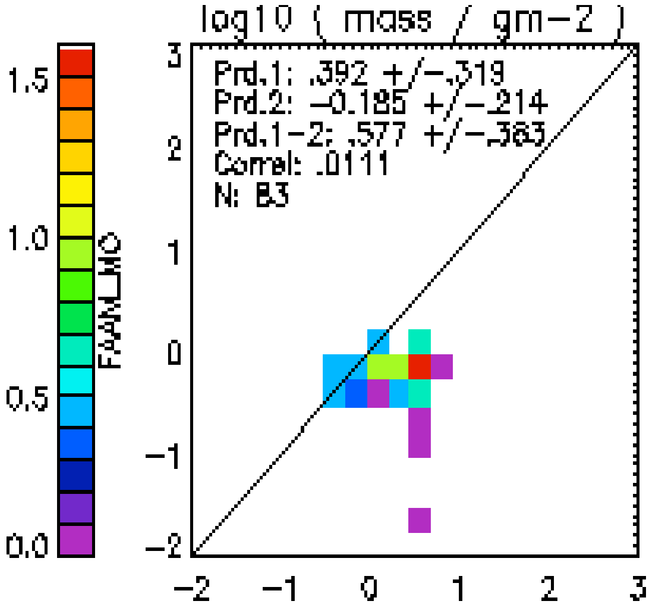


UKMO Aircraft

Uncertainty: about a factor of 2

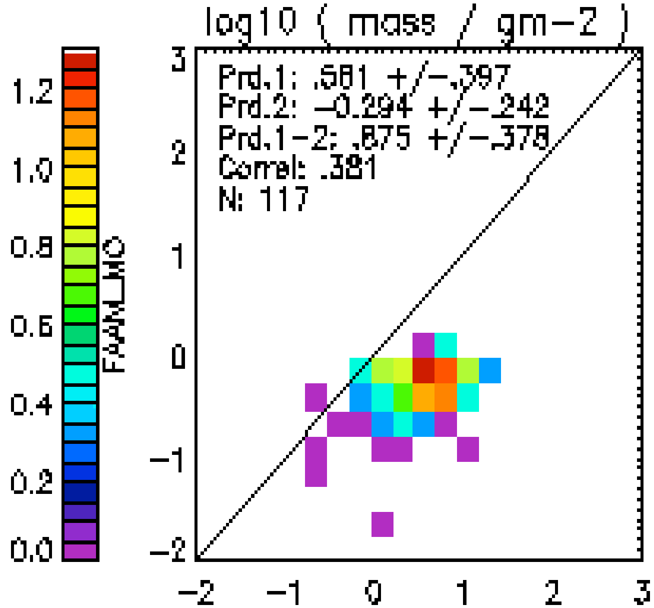
Major Conclusion 4: Mass Loading Uncertainty

Factor 5-6 > FAAM
N: 83



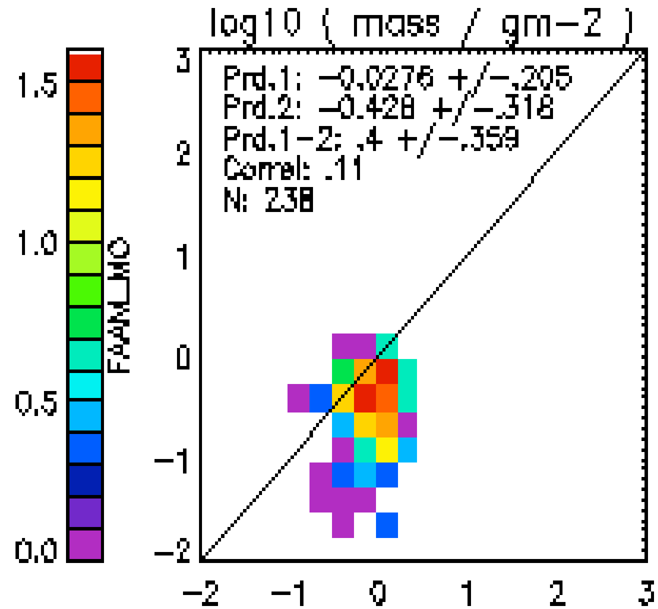
Algorithm A

Factor 8-9 > FAAM
N: 117



Algorithm B

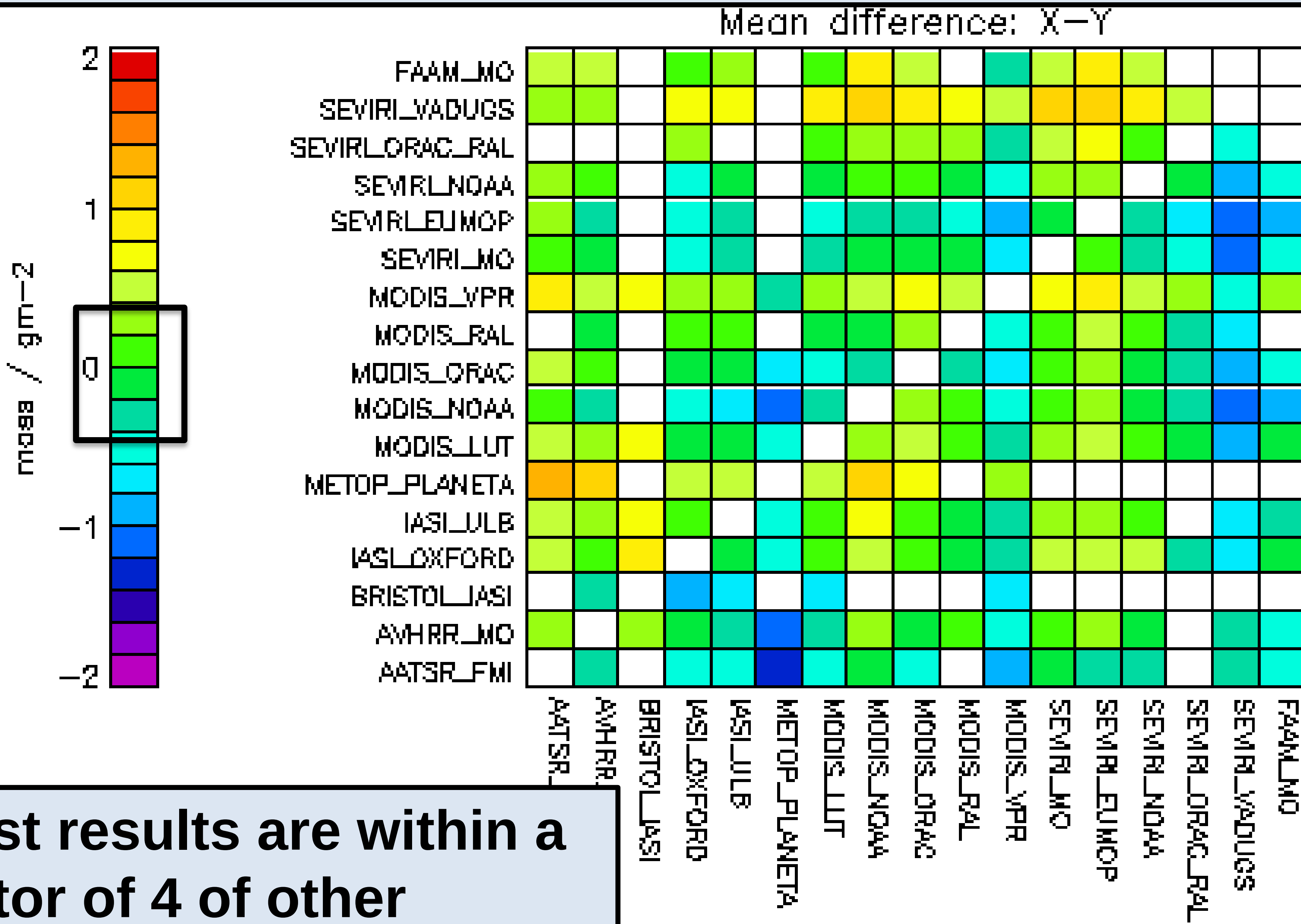
Factor 4 > FAAM
N:238



Algorithm C

Given the uncertainty in the aircraft estimates, 3 real-time relevant geostationary algorithms show reasonable agreement

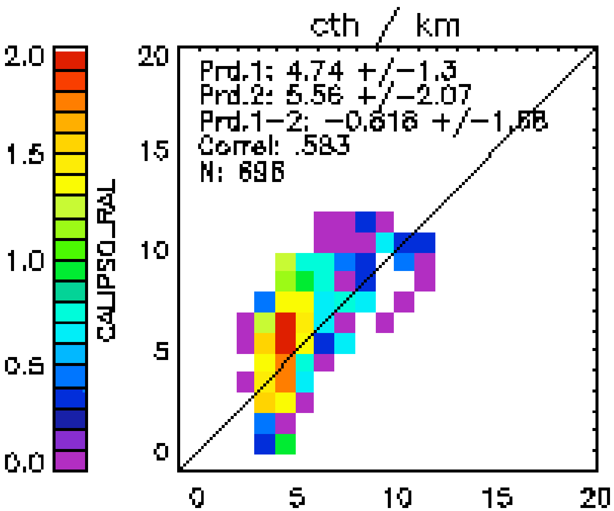
Major Conclusion 4: Mass Loading Uncertainty



Most results are within a factor of 4 of other approaches (on average)

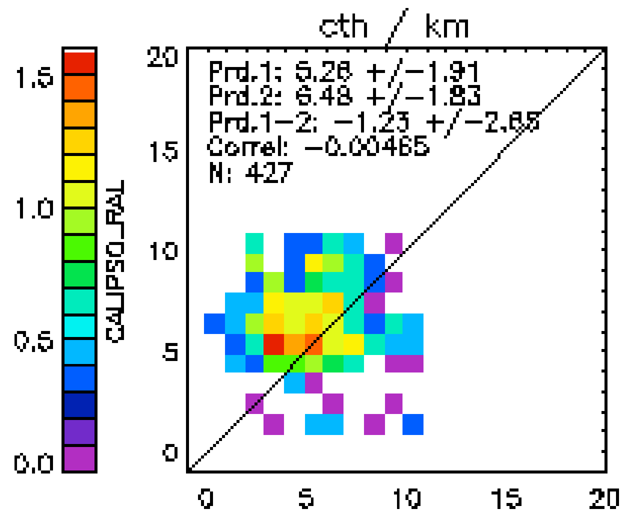
Major Conclusion 5: Issues with Complicated Scenes

0.82 km < CALIOP
Correlation: 0.58
N: 698



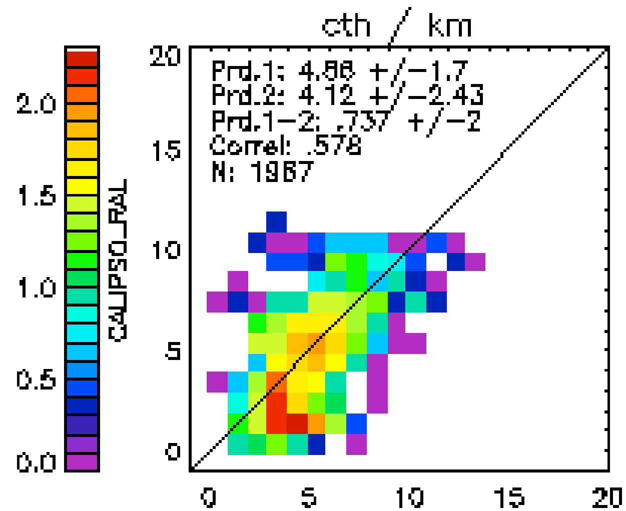
Algorithm A

1.23 km < CALIOP
Correlation: 0.00
N: 427



Algorithm B

0.74 km < CALIOP
Correlation: 0.58
N: 1987



Algorithm C

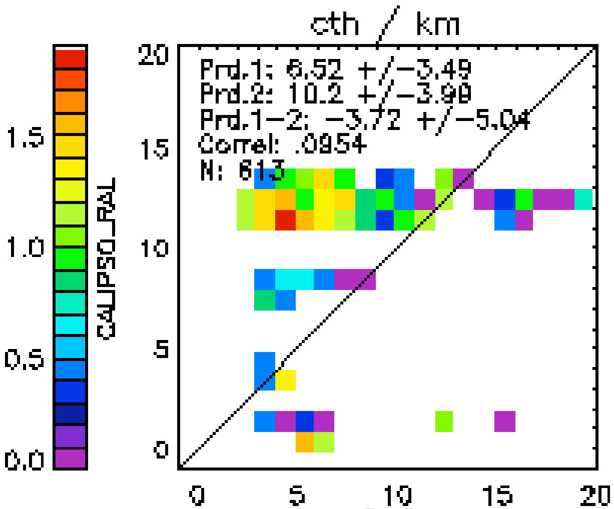
<u>Eyjafallajökull:</u> Comparison of ash cloud top height derived from three real-time relevant geostationary algorithms to spaceborne lidar (CALIOP) results in decent agreement

Major Conclusion 5: Issues with Complicated Scenes

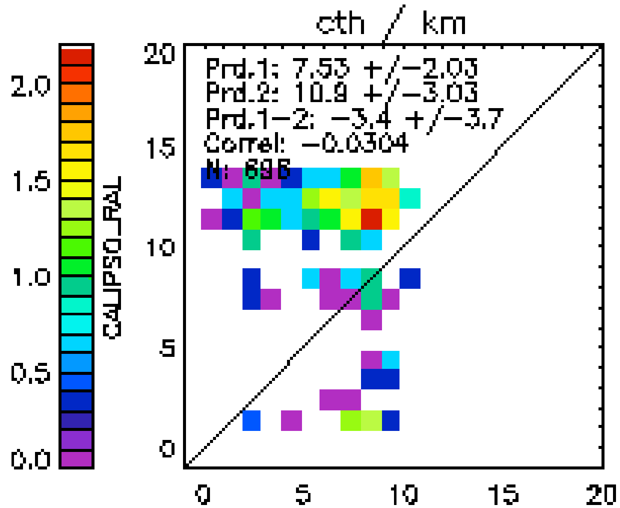
3.72 km < CALIOP
Correlation: 0.10
N: 613

3.40 km < CALIOP
Correlation: 0.03
N: 698

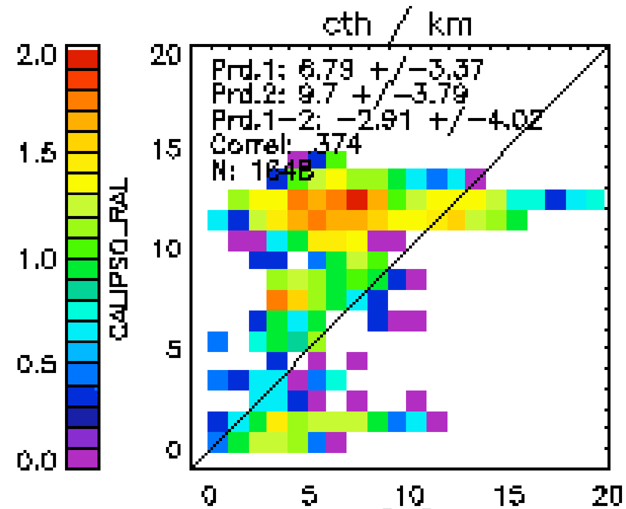
2.91 km < CALIOP
Correlation: 0.37
N: 1648



Algorithm A

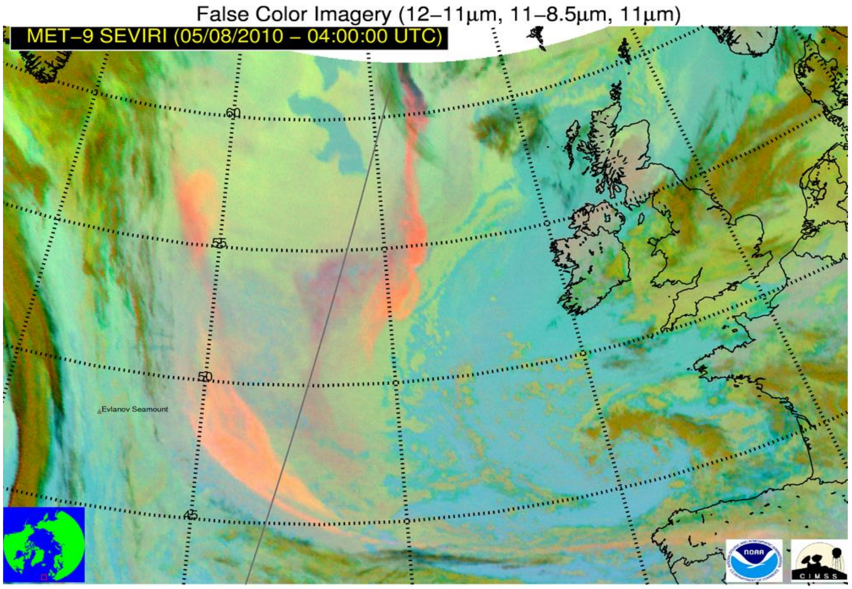


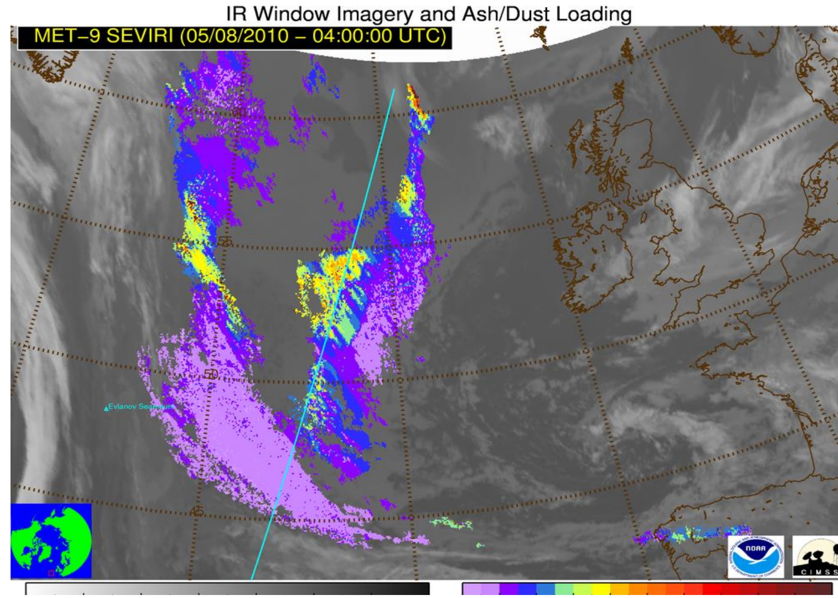
Algorithm B

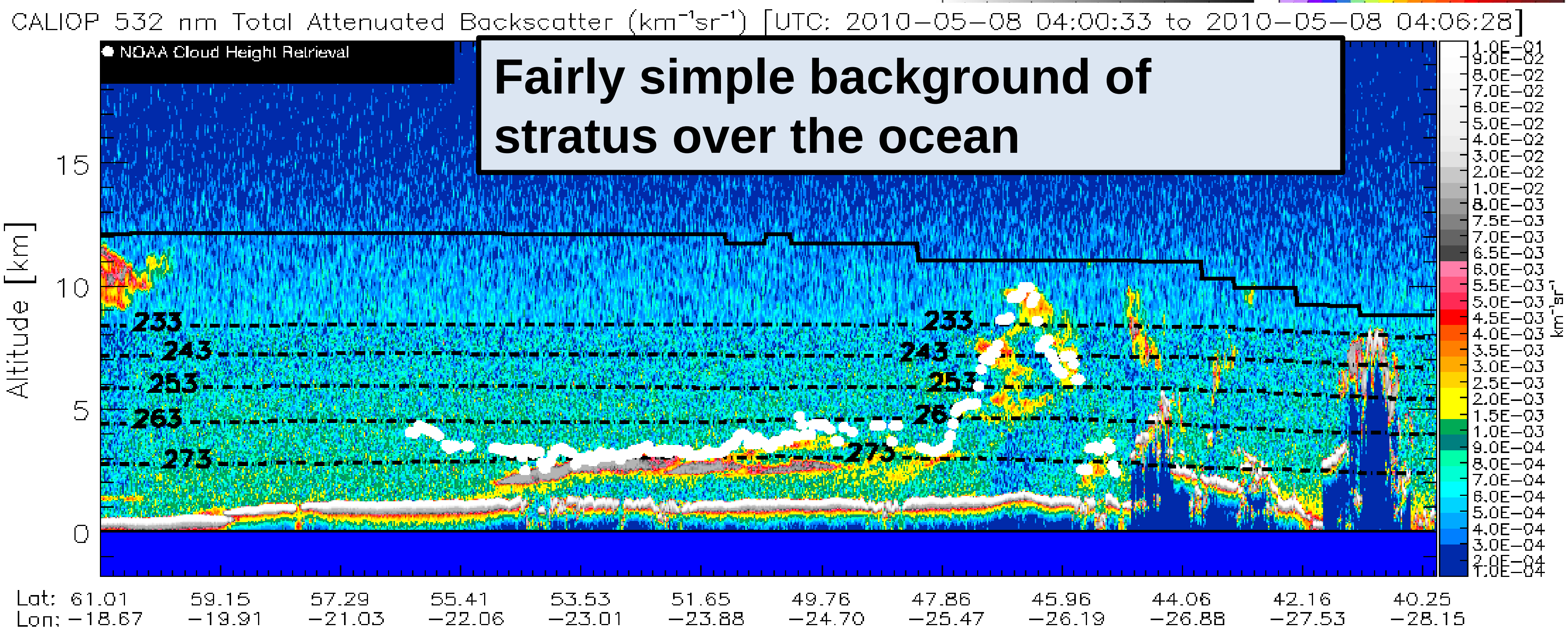


Algorithm C

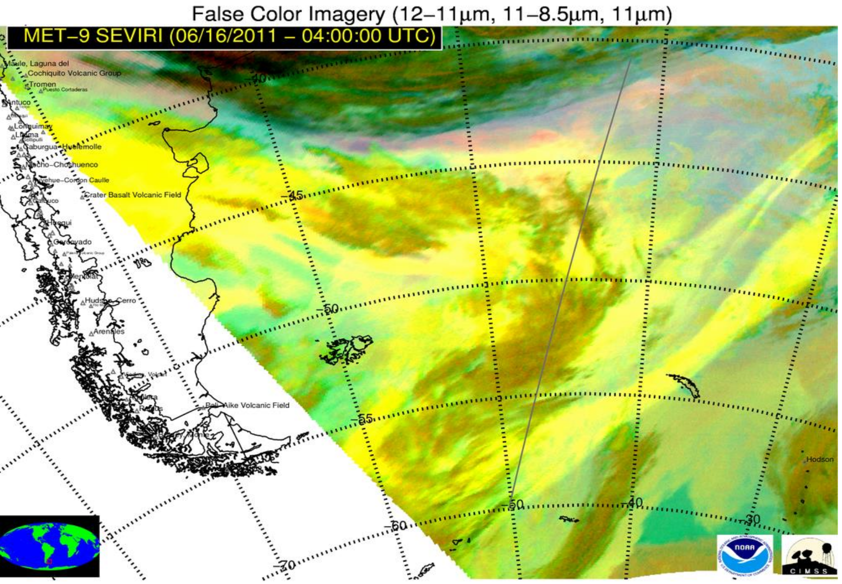
<u>Puyehue-Cordón Caulle:</u> In this case the retrieved ash cloud top height deviates more significantly from CALIOP

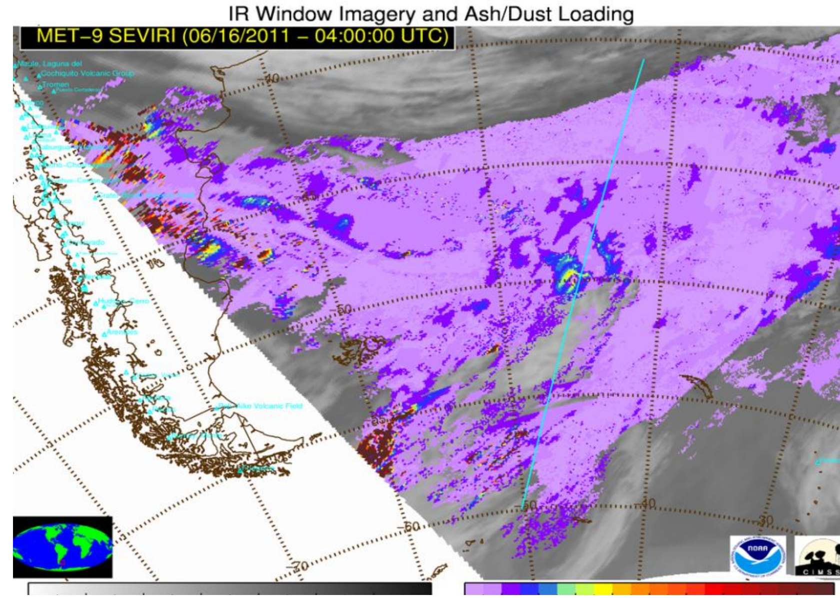


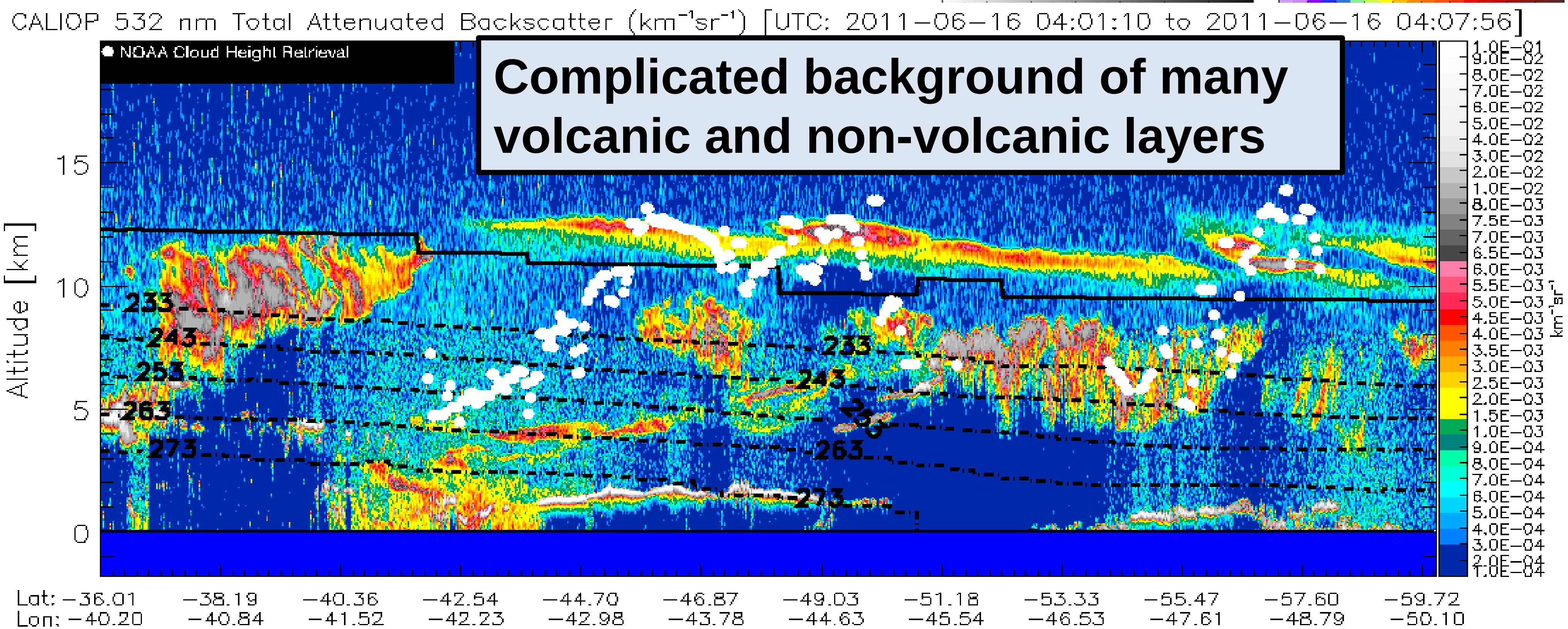


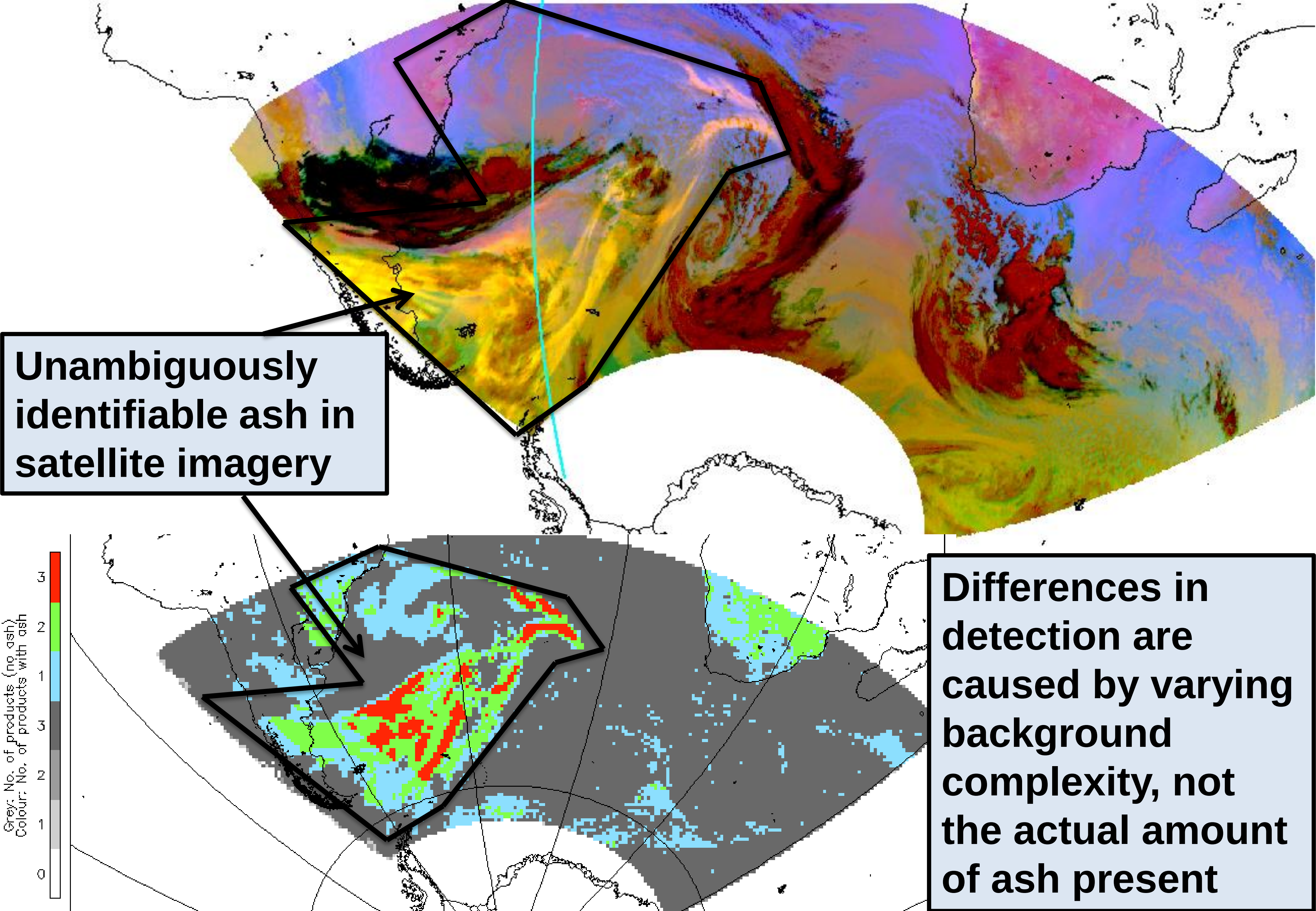


Fairly simple background of stratus over the ocean


False Color Imagery (12–11µm, 11–8.5µm, 11µm)
MET-9 SEVIRI (06/16/2011 – 04:00:00 UTC)

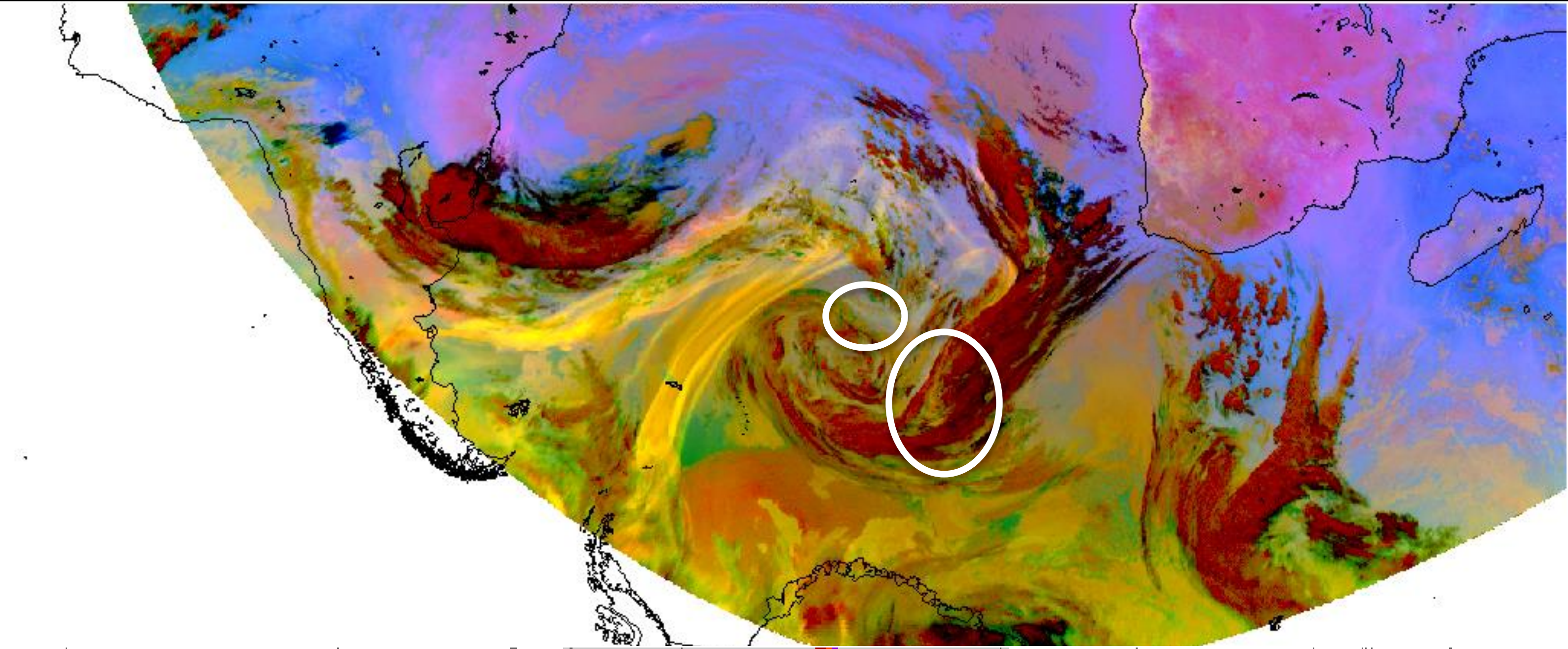

IR Window Imagery and Ash/Dust Loading
MET-9 SEVIRI (06/16/2011 – 04:00:00 UTC)

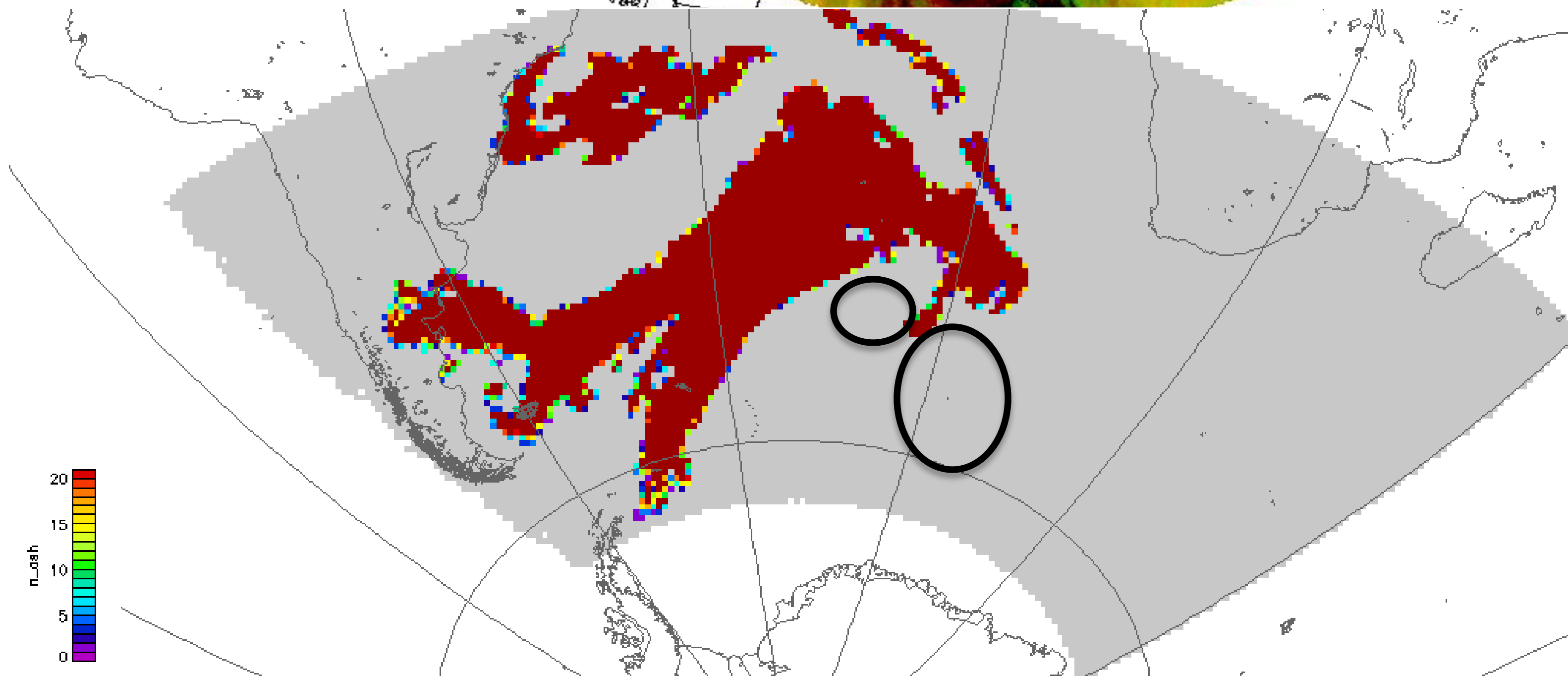

CALIOP 532 nm Total Attenuated Backscatter (km⁻¹sr⁻¹) [UTC: 2011–06–16 04:01:10 to 2011–06–16 04:07:56]
NOAA Cloud Height Retrieval
Complicated background of many volcanic and non-volcanic layers
Altitude [km]
233
243
253
263
273
Lat: –36.01 –38.19 –40.36 –42.54 –44.70 –46.87 –49.03 –51.18 –53.33 –55.47 –57.60 –59.72
Lon: –40.20 –40.84 –41.52 –42.23 –42.98 –43.78 –44.63 –45.54 –46.53 –47.61 –48.79 –50.10
km⁻¹sr⁻¹


Unambiguously identifiable ash in satellite imagery
Differences in detection are caused by varying background complexity, not the actual amount of ash present
Grey: No. of products (no ash)
Colour: No. of products with ash
3
2
1
3
2
1
0

Major Conclusion 6: Satellite Sensor Capabilities Differ

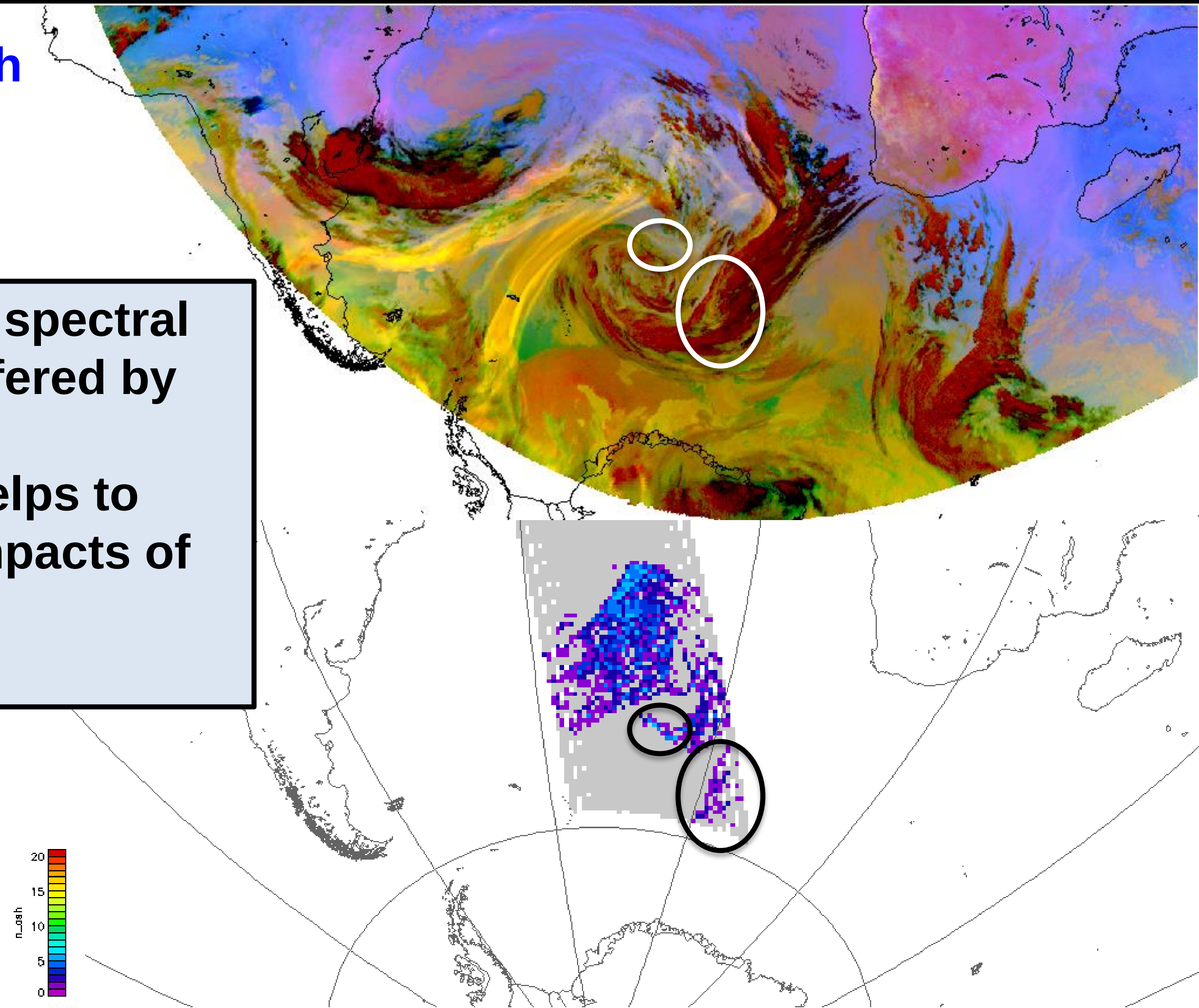
SEVIRI-based ash detection





Major Conclusion 6: Satellite Sensor Capabilities Differ

IASI-based ash detection



The additional spectral information offered by hyperspectral instruments helps to mitigate the impacts of complicated backgrounds

Satellite Inter-comparison - Primary Conclusions

1. Primary sensitivity of passive satellite measurements is to the presence or, lack there of, of detectable volcanic ash
2. Only a couple of automated ash detection methods were able to approach the skill of a human analyst
3. The lower detection limit of the most sensitive algorithm/sensor combinations was between 0.01-0.1 g/m^2
4. Given the uncertainty of aircraft based estimates of mass loading, the uncertainty in satellite based assessments is greater than a factor of 2 and most satellite derived mass loadings differed from aircraft assessments by a factor of 4 or more. The uncertainty in concentration will be greater.
5. Complicated backgrounds are common and further increase uncertainty in all satellite derived products
6. High spectral resolution measurements, while currently spatially and temporally limited, help to mitigate some issues with complicated scenes

The Last 5 Years

Good progress on research applications and some, but significantly less, overall progress on operational applications

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Good progress on research applications and some, but significantly less, overall progress on operational applications

Why?

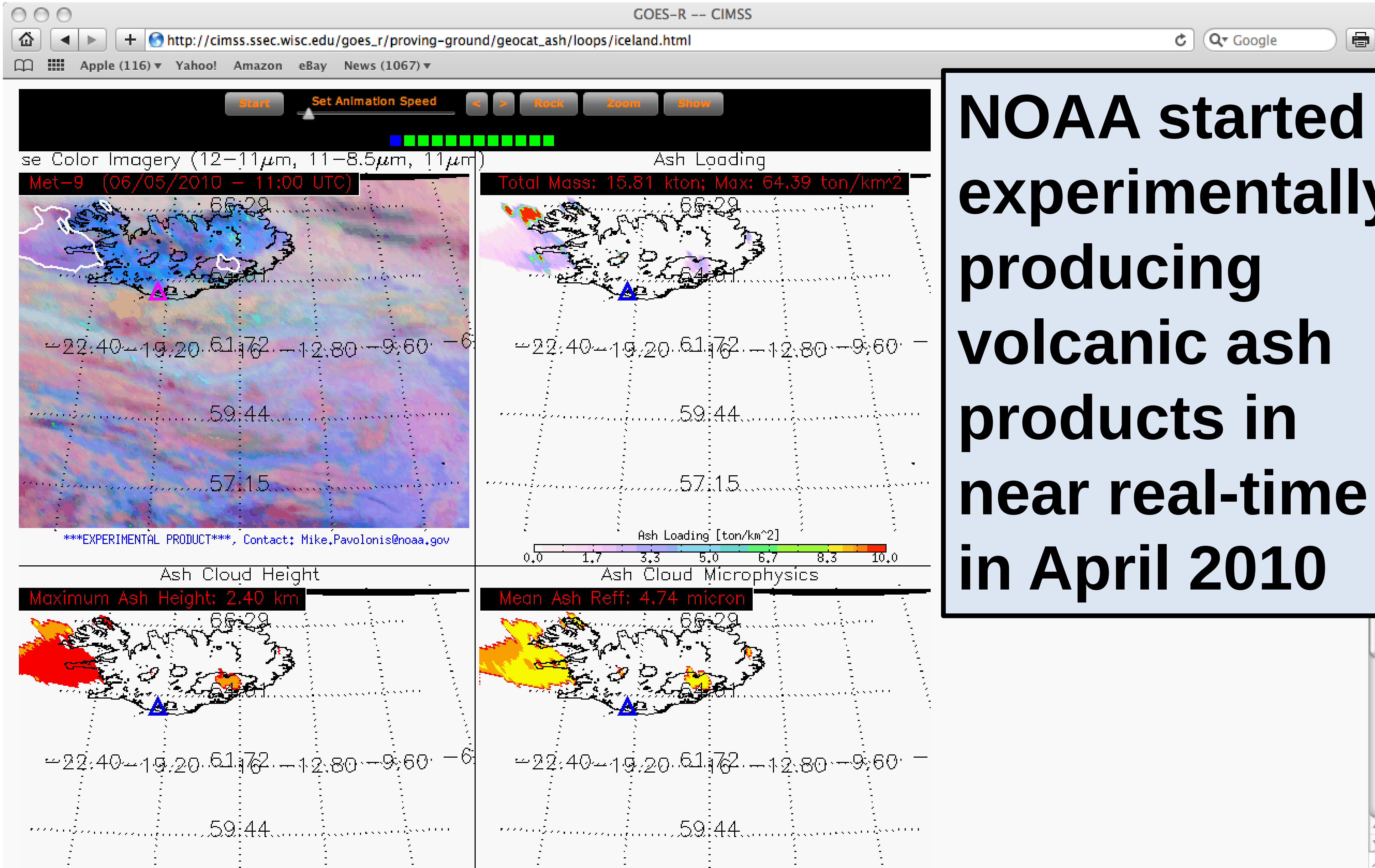
The Last 5 Years

Good progress on research applications and some, but significantly less, overall progress on operational applications

Why?

The challenges of automated near real-time product generation are numerous and there is generally little motivation for non-operational groups to address these challenges

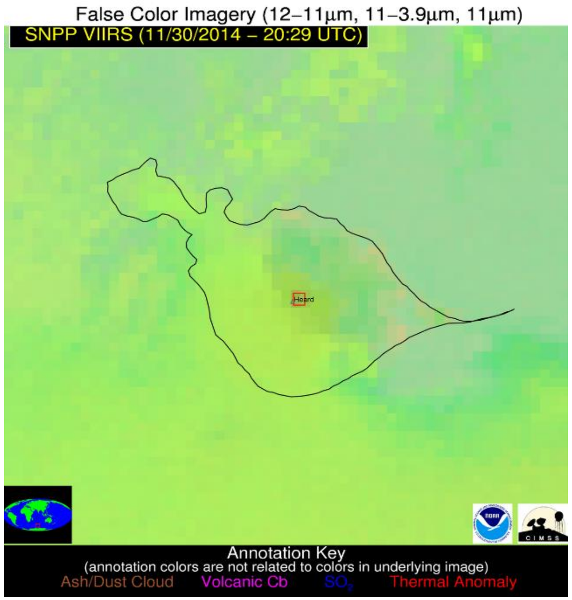
The NOAA Experience



NOAA started experimentally producing volcanic ash products in near real-time in April 2010

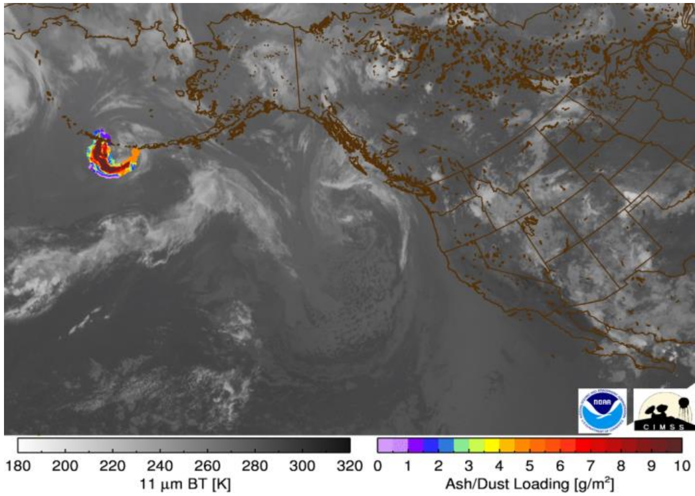
Development of a Multi-sensor System (VOLCAT)

1). Unrest Alerts

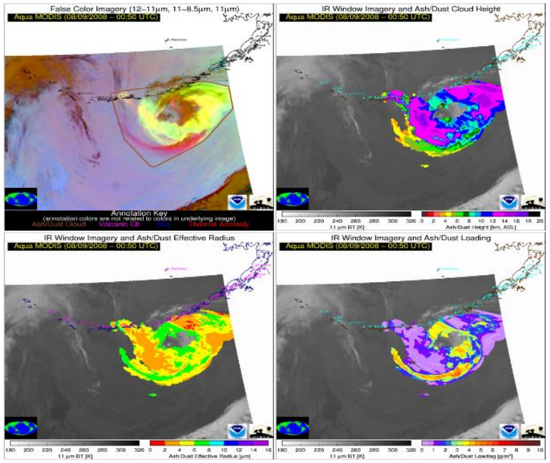


2). Eruption Alerts

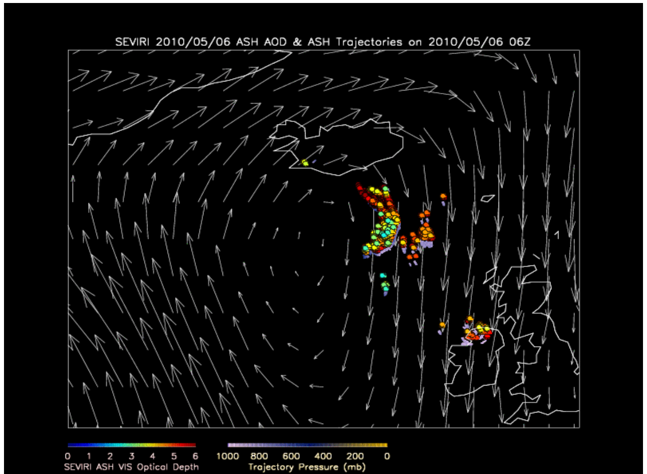
3). Volcanic Cloud Tracking



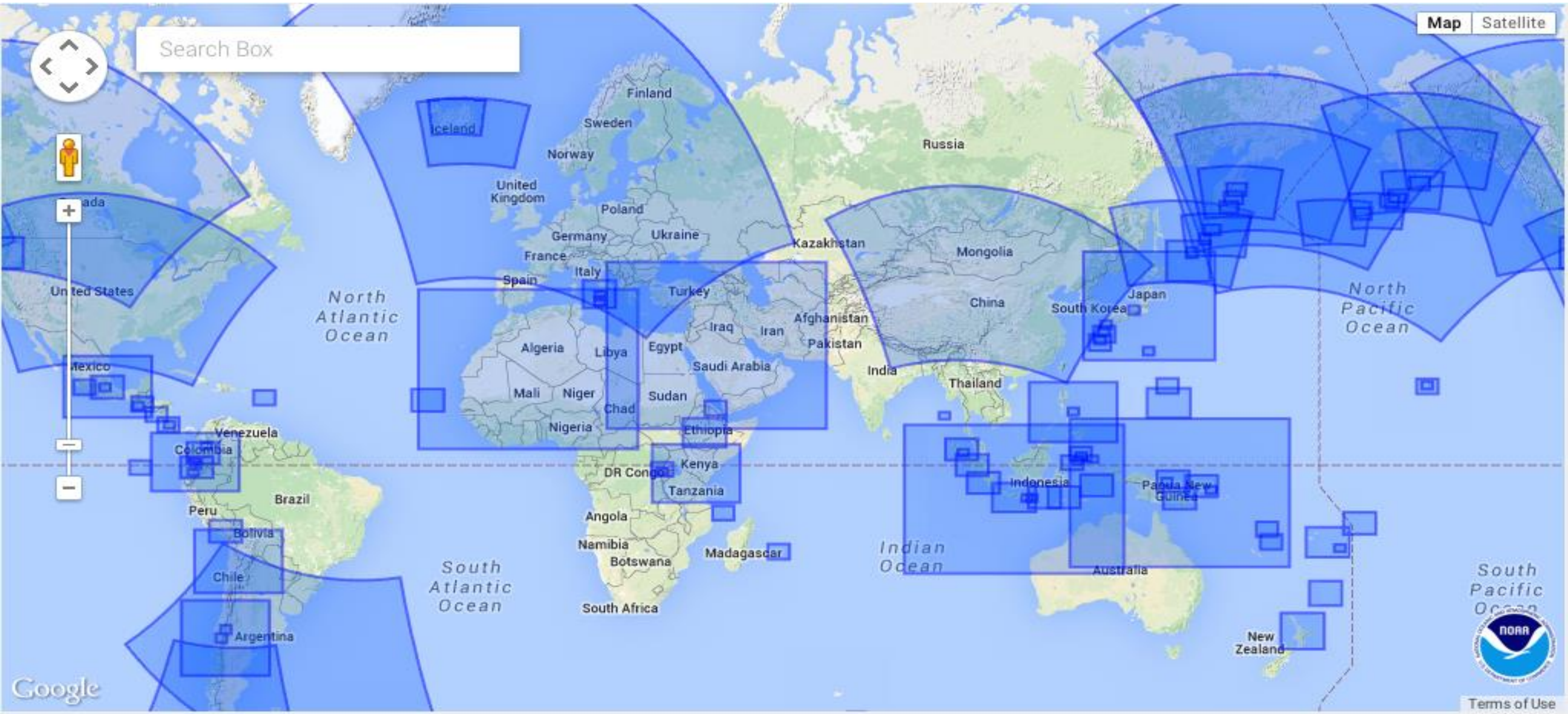
4). Volcanic Cloud Characterization



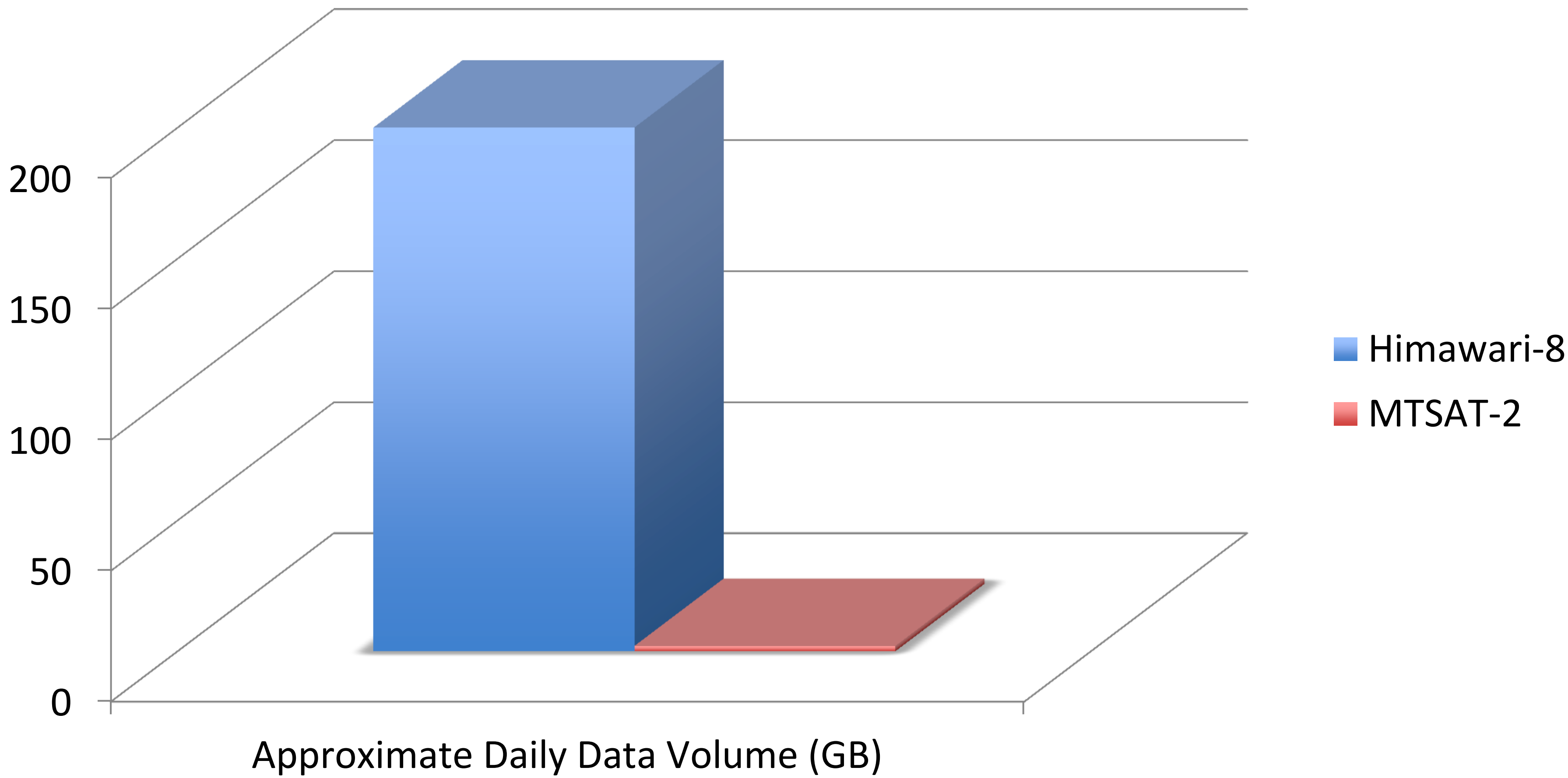
5). Dispersion Forecasting



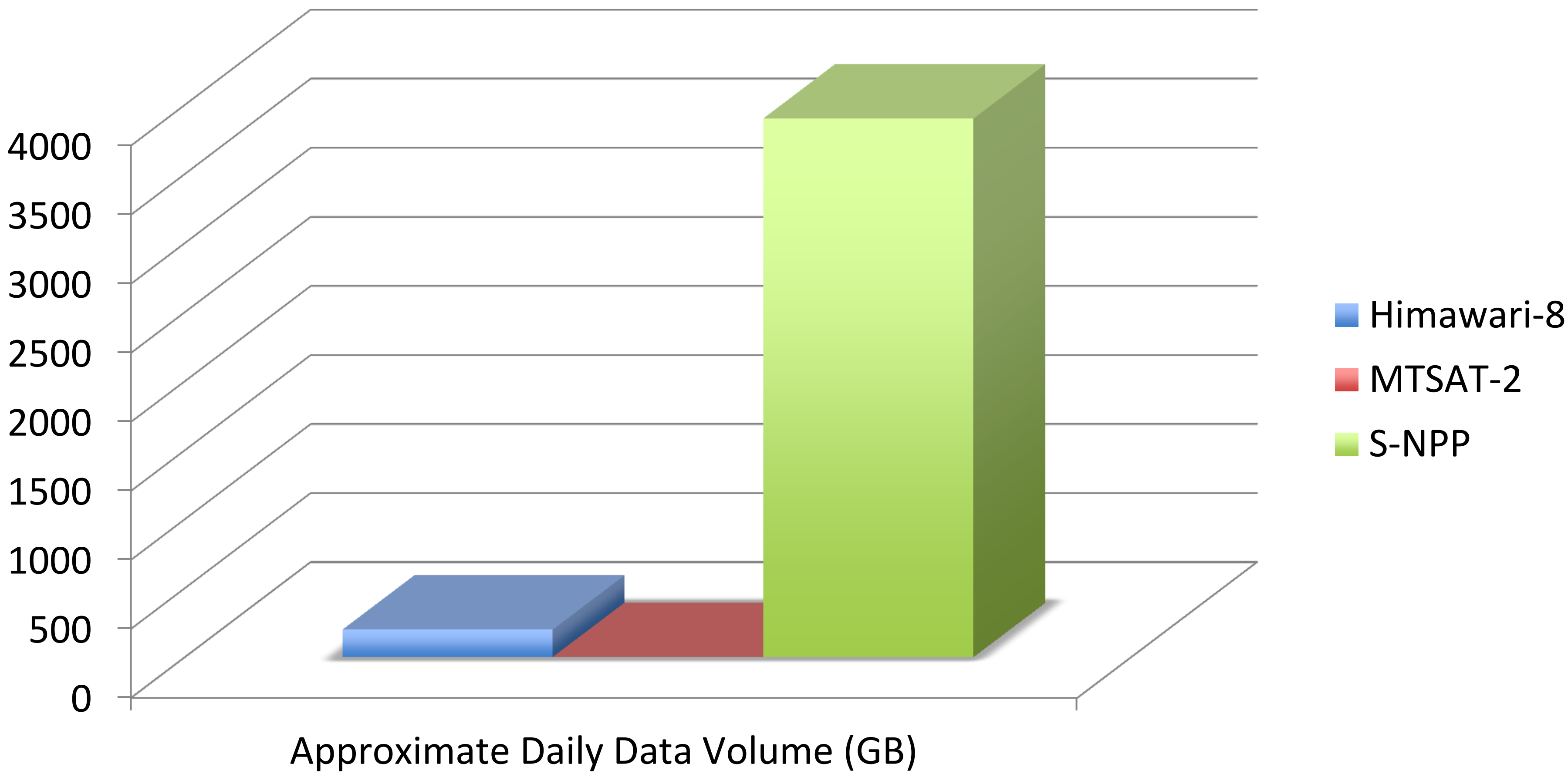
http://volcano.ssec.wisc.edu



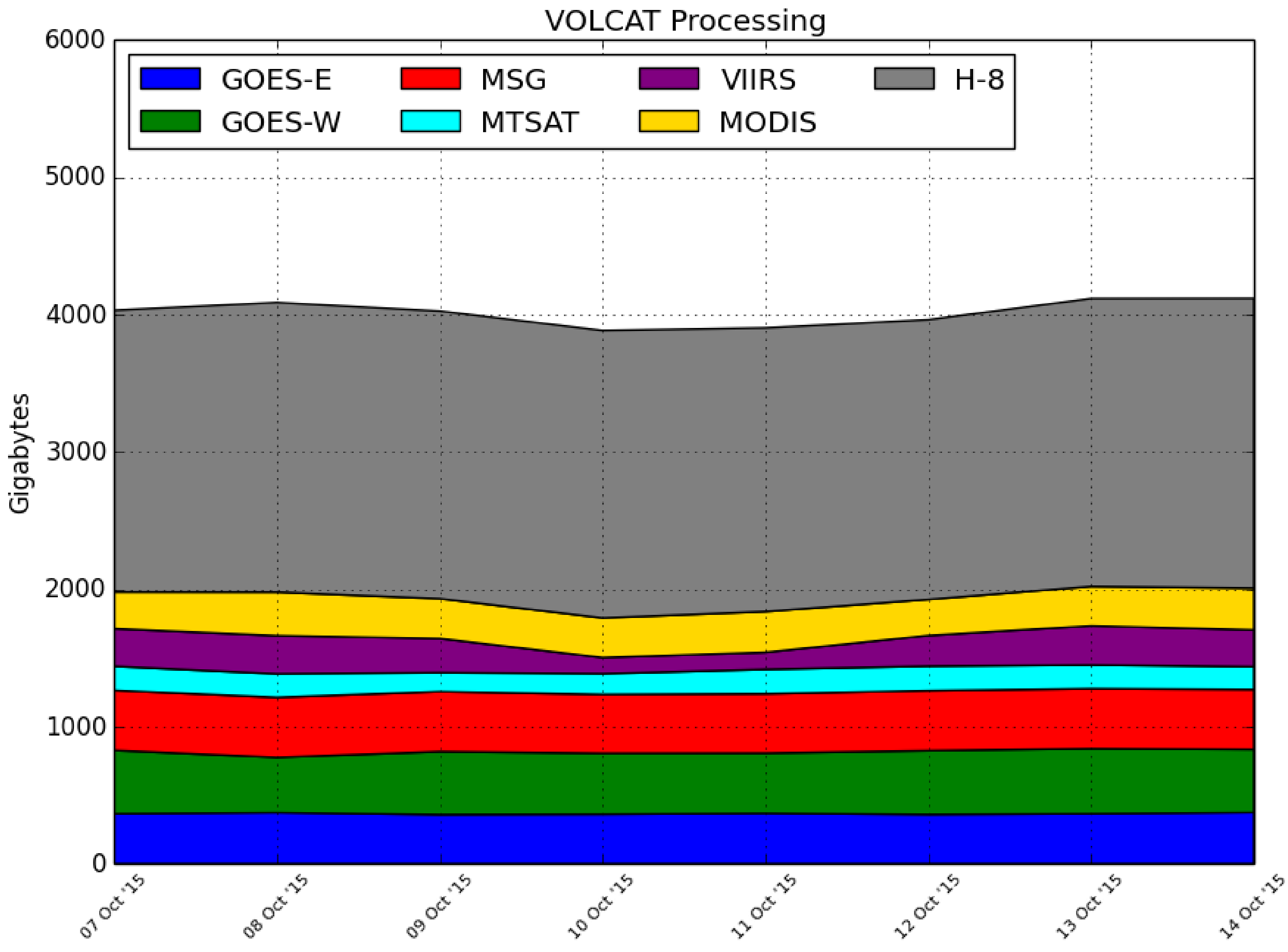
Challenge 1: “Big Data”



Challenge 1: “Big Data”

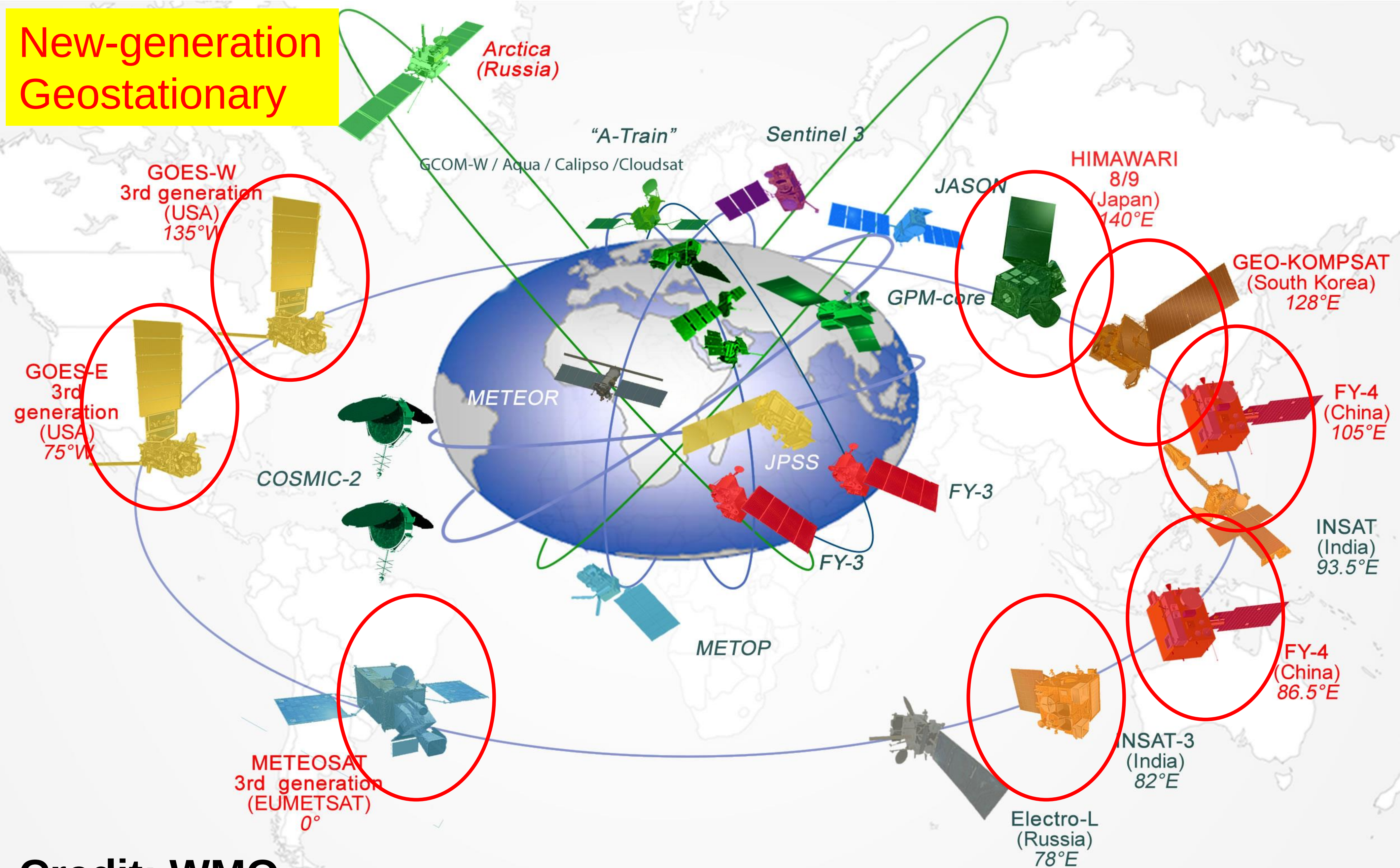


Challenge 1: “Big Data”



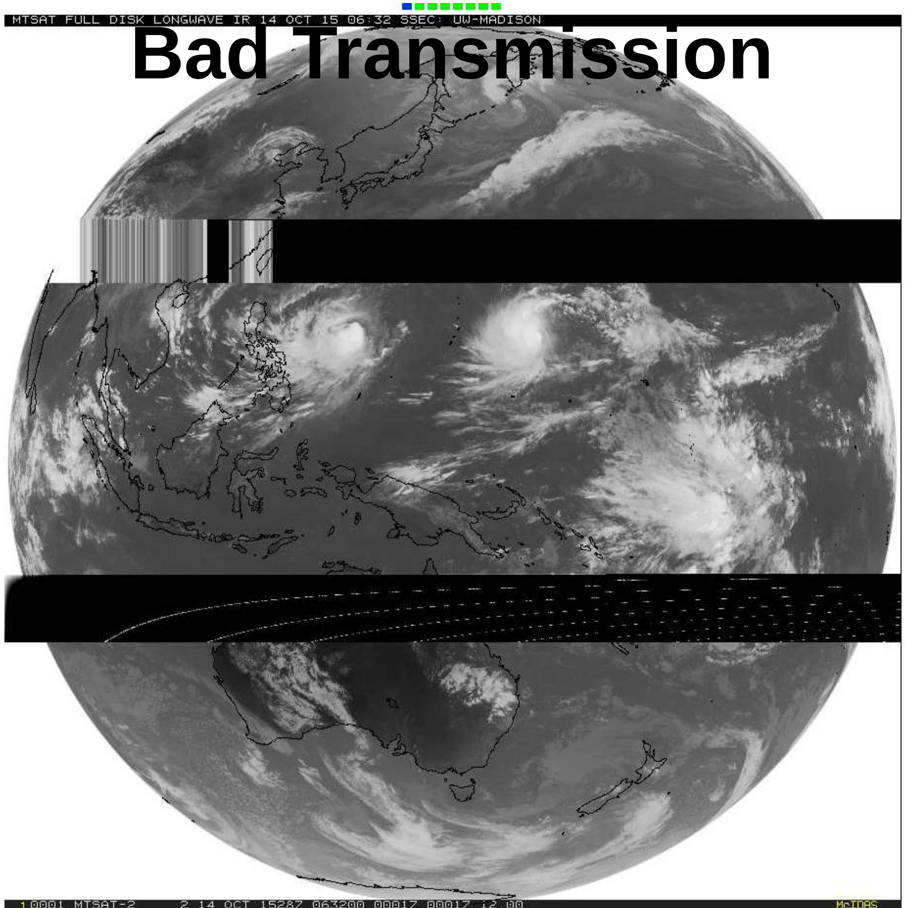
2015 - 2020

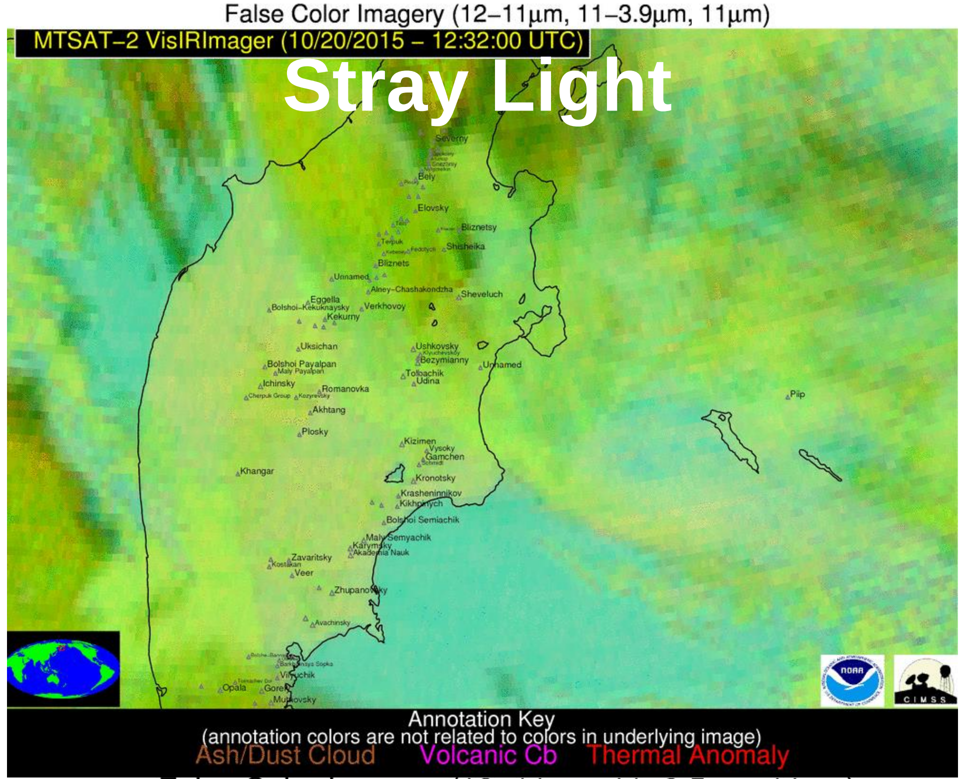
New-generation Geostationary

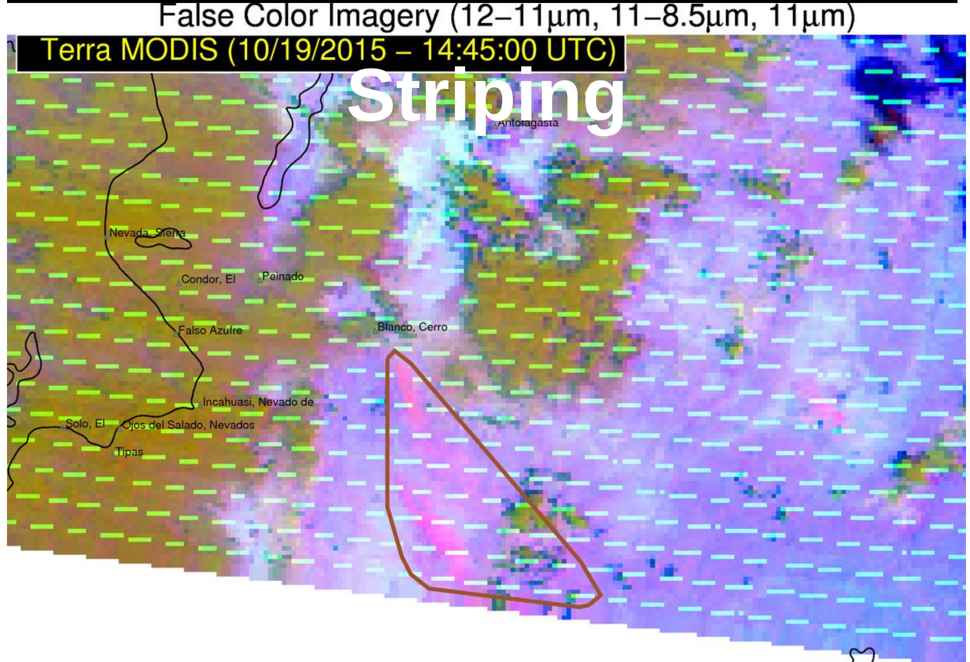


Credit: WMO

Challenge 2: Uncertainty/Artifacts in Raw Satellite Data





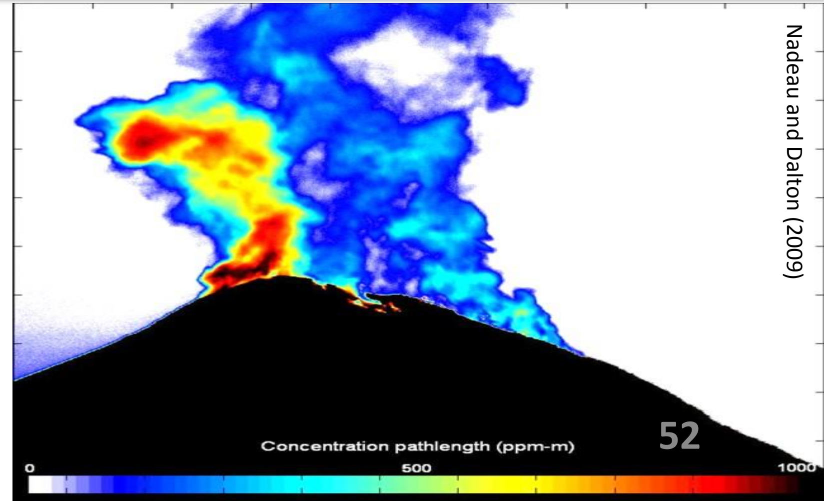


Challenge 3: The Science is Complicated

1). Ash dominated volcanic plumes – **Semi-transparent clouds dominated by volcanic ash. Lightning is usually not present in these clouds.**

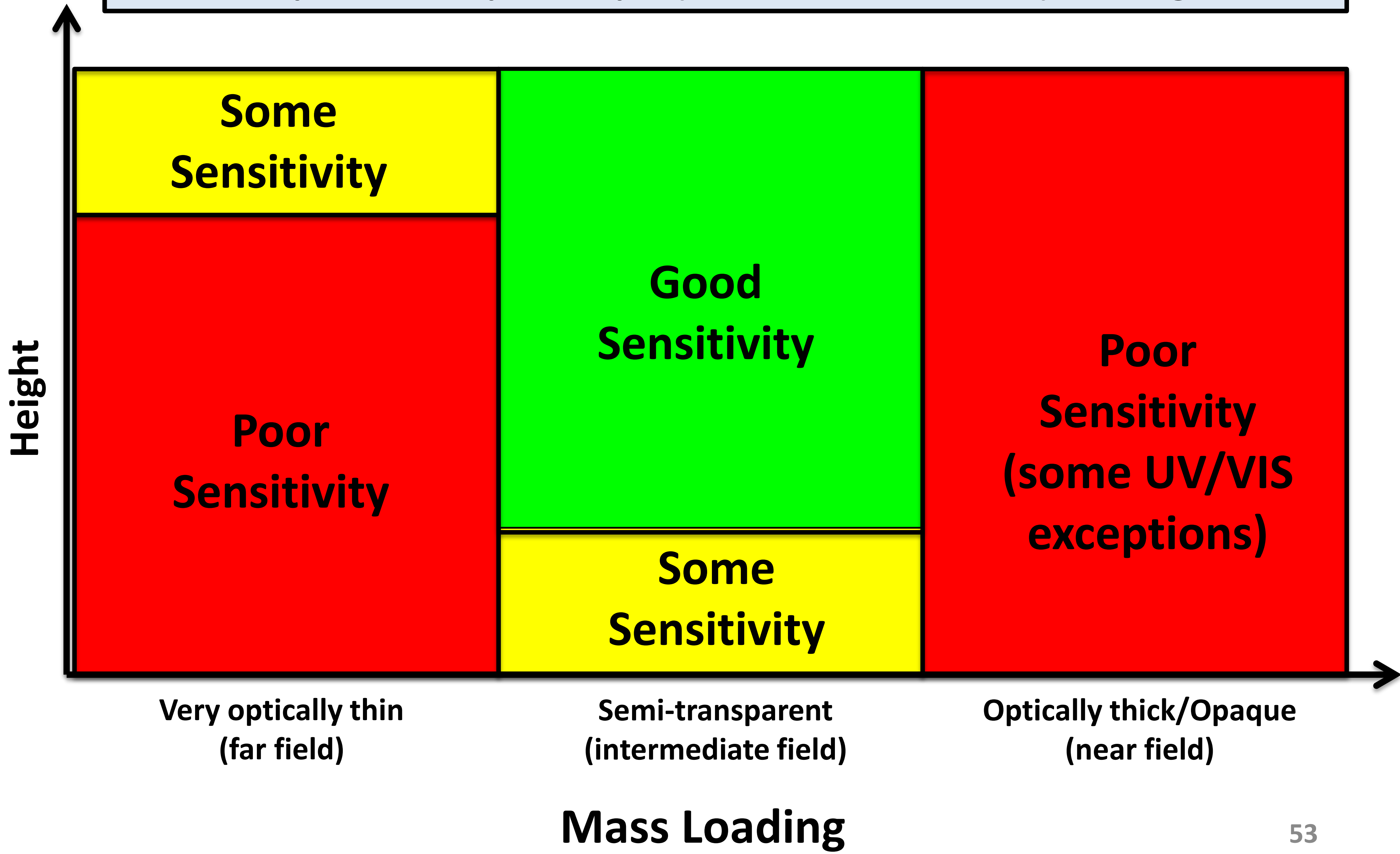
2). Ice topped umbrella clouds – **These cloud are mostly observed during a major eruption. A spectral based volcanic ash signal is usually initially absent because the ash is encased in ice and/or the cloud is opaque. Lightning is often present in these clouds.**

3). SO_2 clouds – **Sulfur dioxide clouds (SO_2 gas is invisible to the eye) that may or may not contain volcanic ash. Some eruptions produce large amounts of SO_2 and very little ash and vice-versa.**

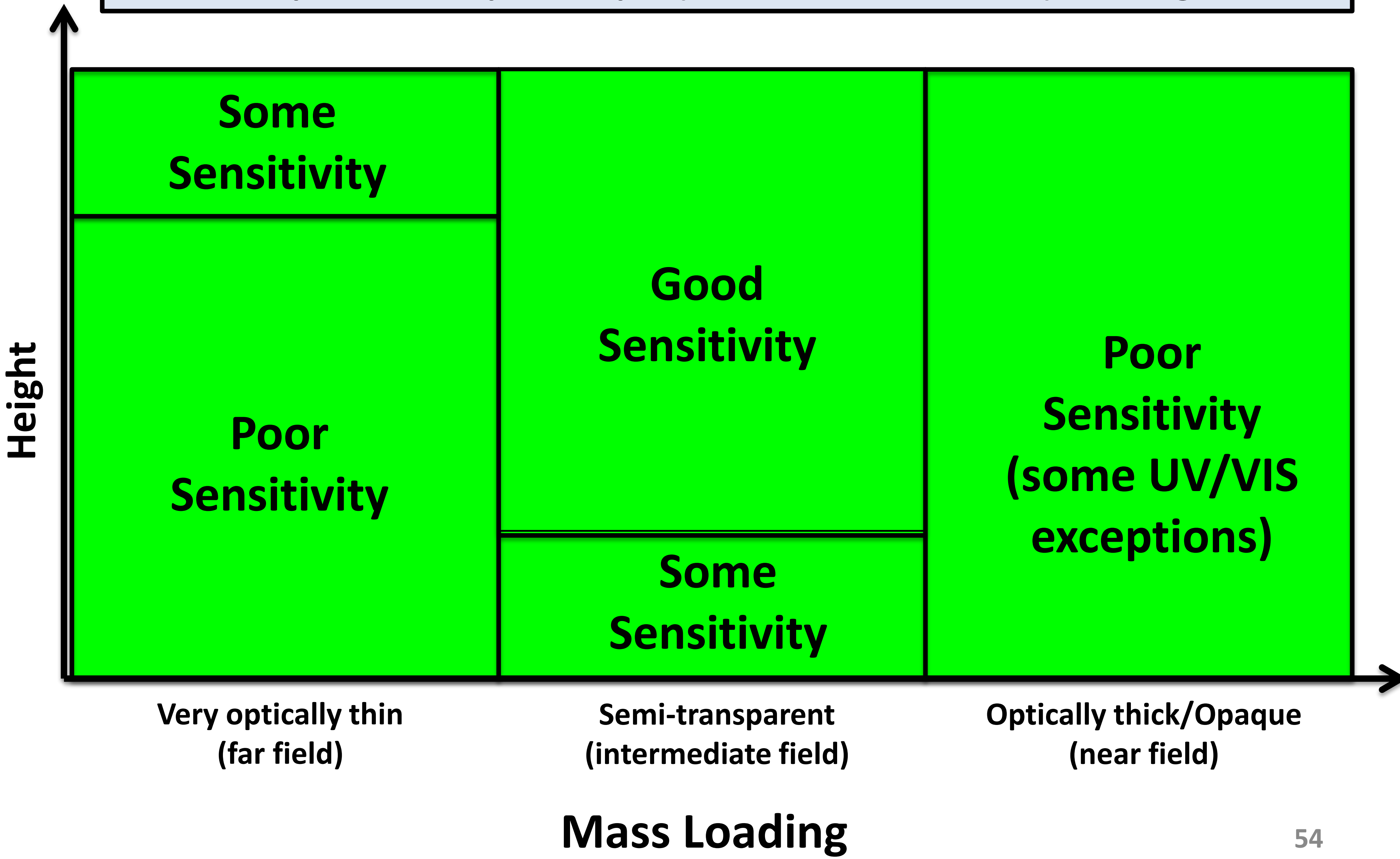


Nadeau and Dalton (2009)

More consistent ash detection and characterization capabilities are needed across the spectrum of optical depth (down to detection limit) and height



More consistent ash detection and characterization capabilities are needed across the spectrum of optical depth (down to detection limit) and height



Early Detection of Explosive Volcanic Eruptions by Quantifying the Evolution of the Cloud in Time

July 31, 2015
Manam Volcano, PNG

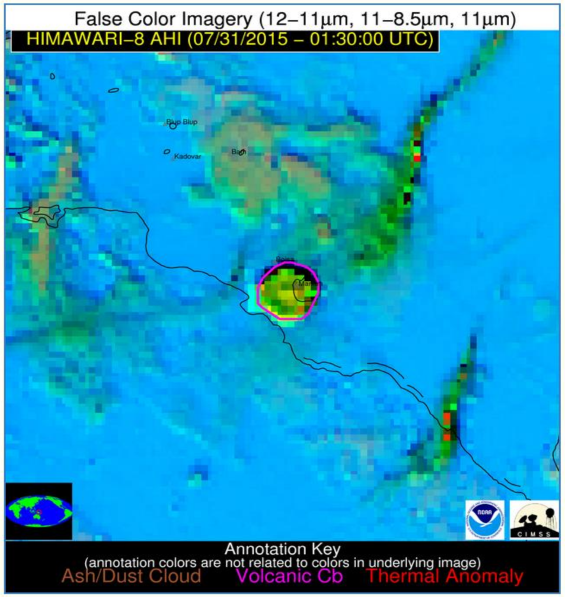
Actual near real-time results

Volcanic Cloud Alert Report

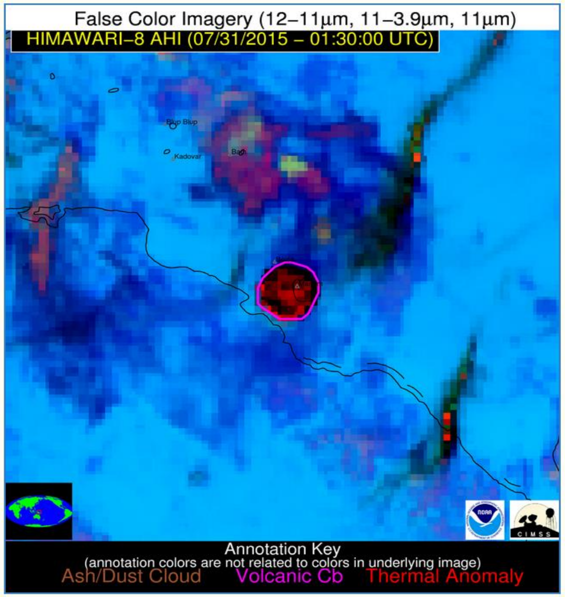
DATE:	2015-07-31
TIME:	01:30:00
Production Date and Time:	2015-07-31 02:01:32 UTC
PRIMARY INSTRUMENT:	Himawari-8 AHI

More details ▼

Possible Volcanic Cb



False Color Image (12-11, 11-8.5, 11) [zoomed-in]



False Color Image (12-11, 11-3.9, 11) [zoomed-in]

Basic Information

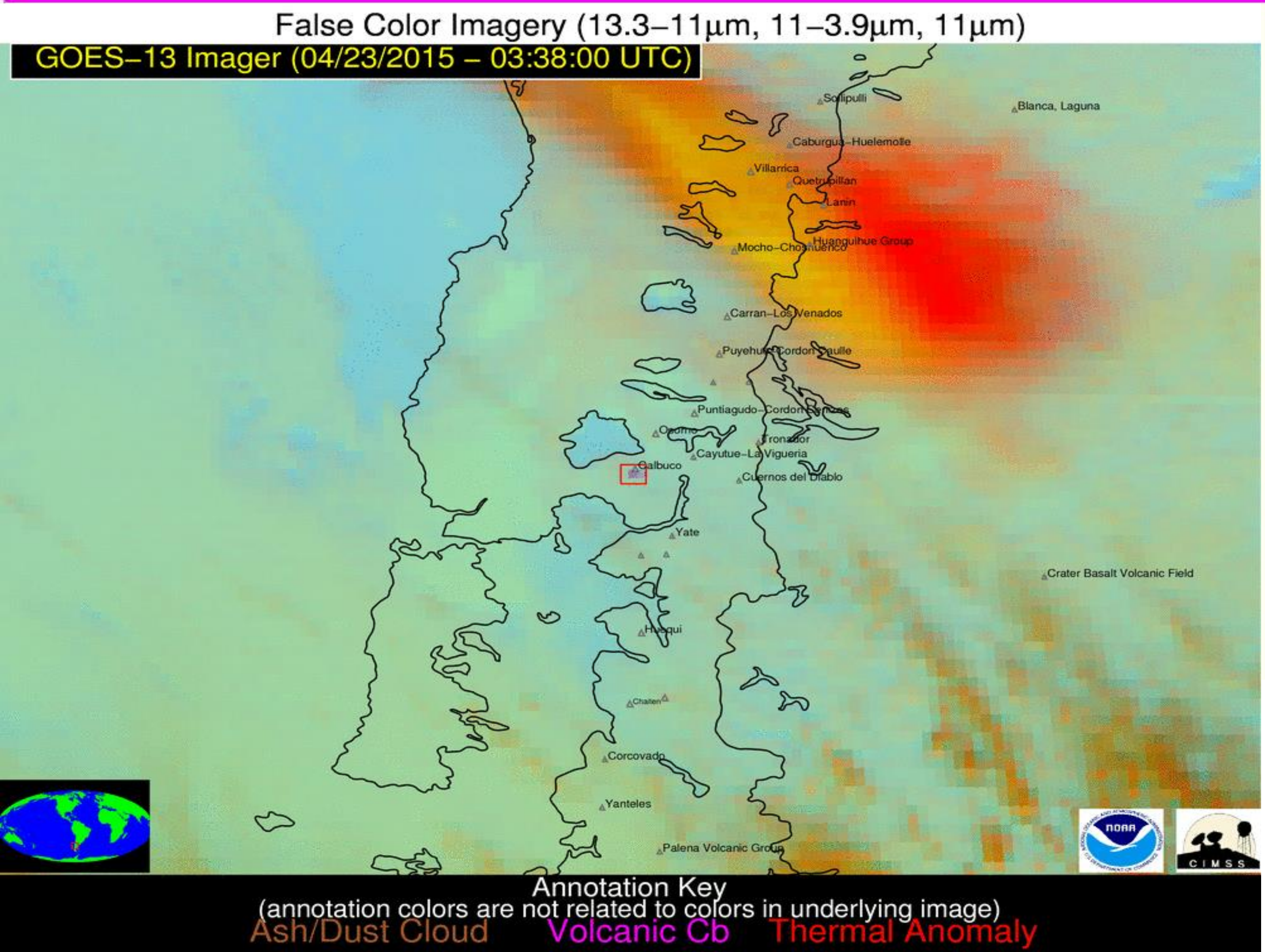
Volcanic Region(s)	Melanesia and Australia
Country/Countries	Papua New Guinea
Volcanic Subregion(s)	Northeast of New Guinea
VAAC Region(s) of Nearby Volcanoes	Darwin
Mean Object Date/Time	2015-07-31 01:35:14UTC
Radiative Center (Lat, Lon):	-4.080 °, 145.020 °
Nearby Volcanoes (meeting alert criteria):	Manam (0.60 km) Boisa (0.90 km)
Trend in IR Brightness Temperature	-62.10 °C
Vertical Growth Rate Time Interval	10 minutes
Vertical Growth Rate Anomaly	11.60 number of stddev above mean
Maximum Height [AMSL]	22.30 km; 73163 ft
90th Percentile Height [AMSL]	18.80 km; 61680 ft
Mean Tropopause Height [AMSL]	16.40 km; 53806 ft

Show More ▲ View all event imagery »

Explosive eruptions can be detected (day and night) by quantifying the time evolution of the cloud

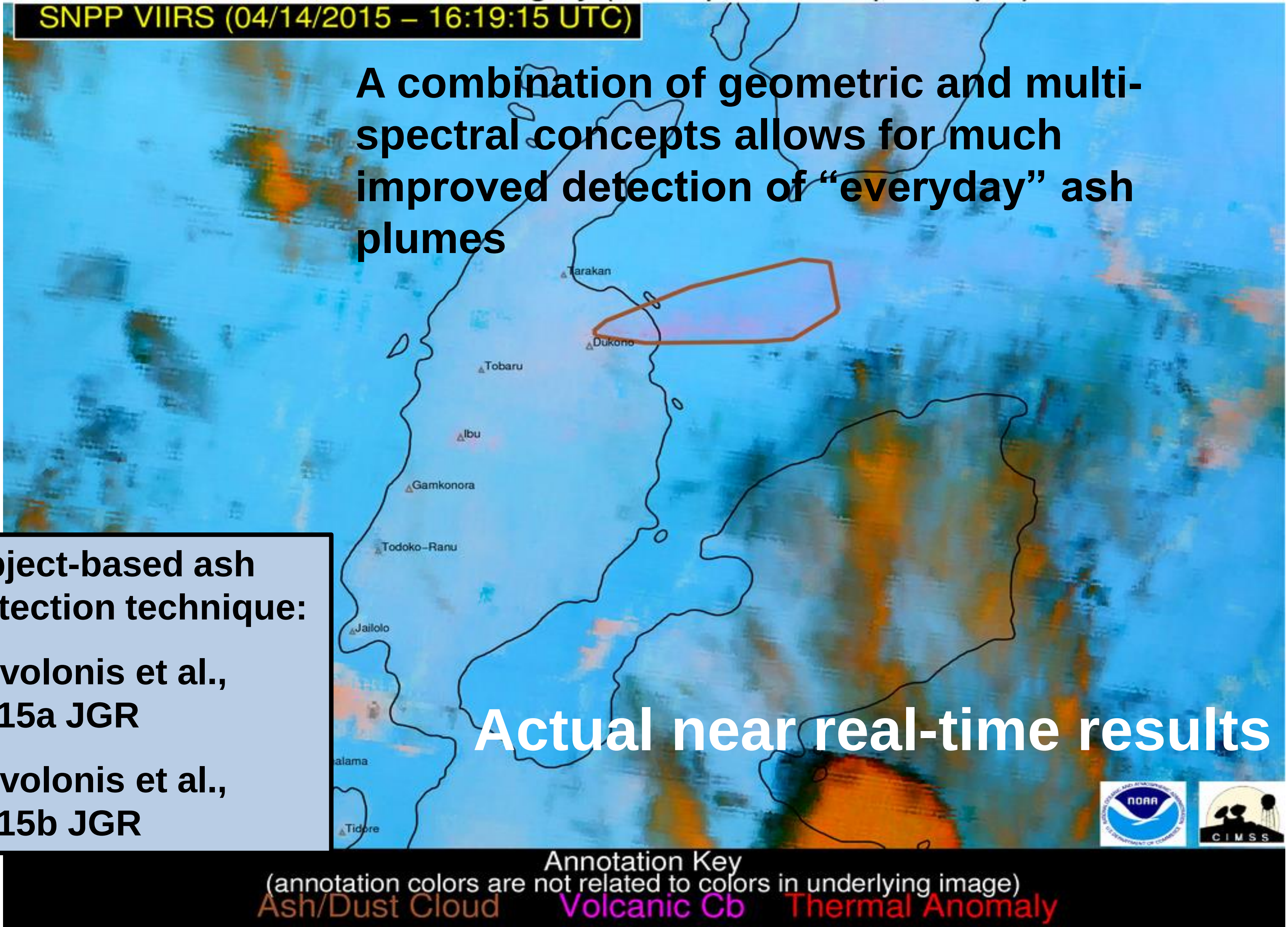
Actual near real-time results

Possible Volcanic Cb



Basic Information	
VAAC Regions of Nearby Volcanoes	Buenos Aires
Mean Object Date/Time	2015-04-23 04:11:48UTC
Radiative Center (Lat, Lon):	-41.310 °, -72.570 °
Nearby Volcanoes (meeting alert criteria):	Calbuco (3.20 km)
Trend in IR Brightness Temperature	-59.50 °C
Vertical Growth Rate Time Interval	30 minutes
Vertical Growth Rate Anomaly	11.50 number of stddev above mean
Total Area	515.00 km^2
Additional Information	
Alert Status	New Alert Object
Mean Viewing Angle	48.10 °
Mean Solar Zenith Angle	149.50 °
Maximum Height [AMSL]	11.70 km; 38386 ft
90th Percentile Height [AMSL]	11.10 km; 36417 ft
Mean Tropopause Height [AMSL]	12.10 km; 39698 ft
Geographic Regions of Nearby Volcanoes	Chile-S

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



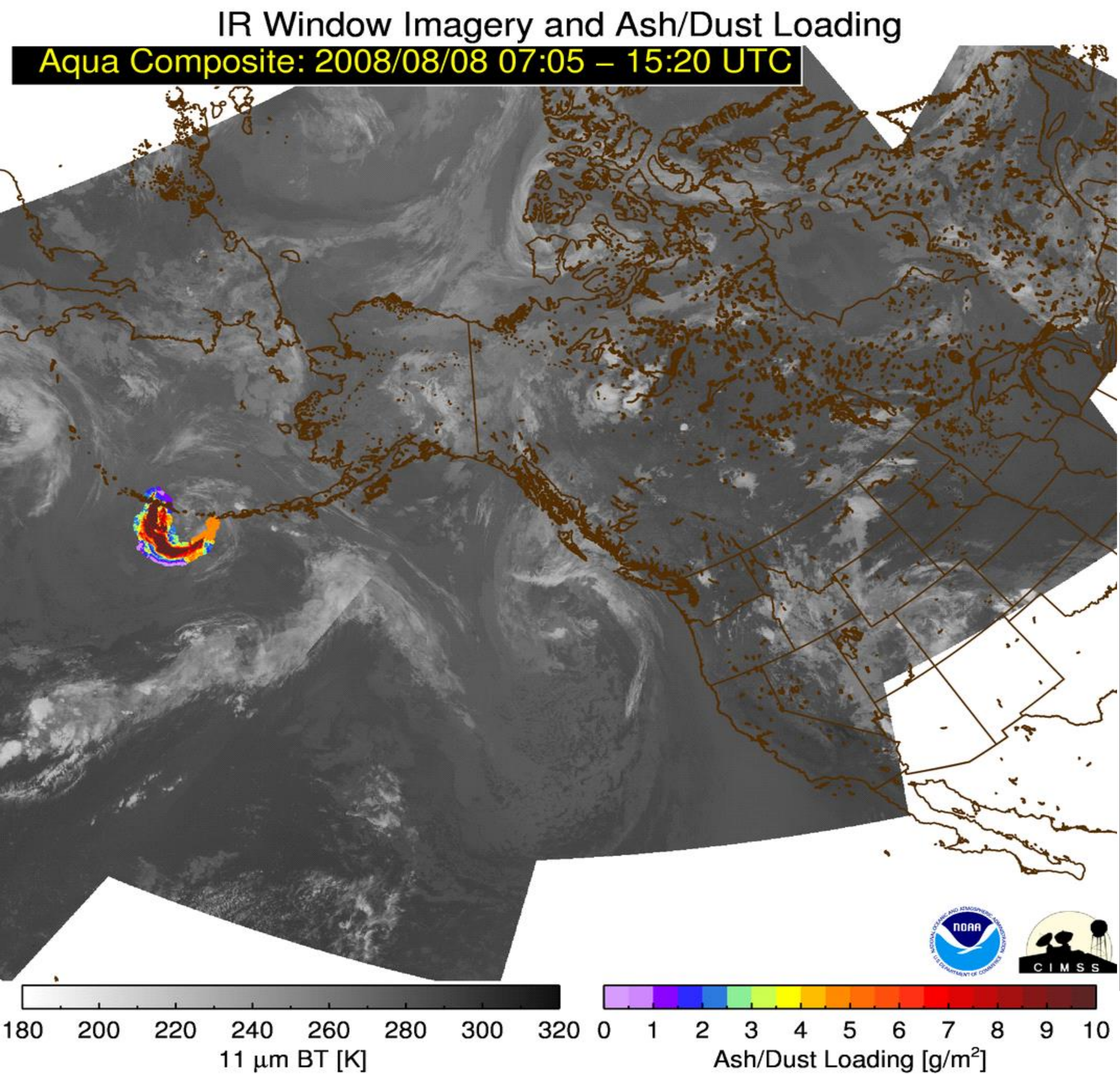
A combination of geometric and multi-spectral concepts allows for much improved detection of "everyday" ash plumes

Actual near real-time results

Object-based ash detection technique:

Pavolonis et al., 2015a JGR

Pavolonis et al., 2015b JGR



Putting it all together

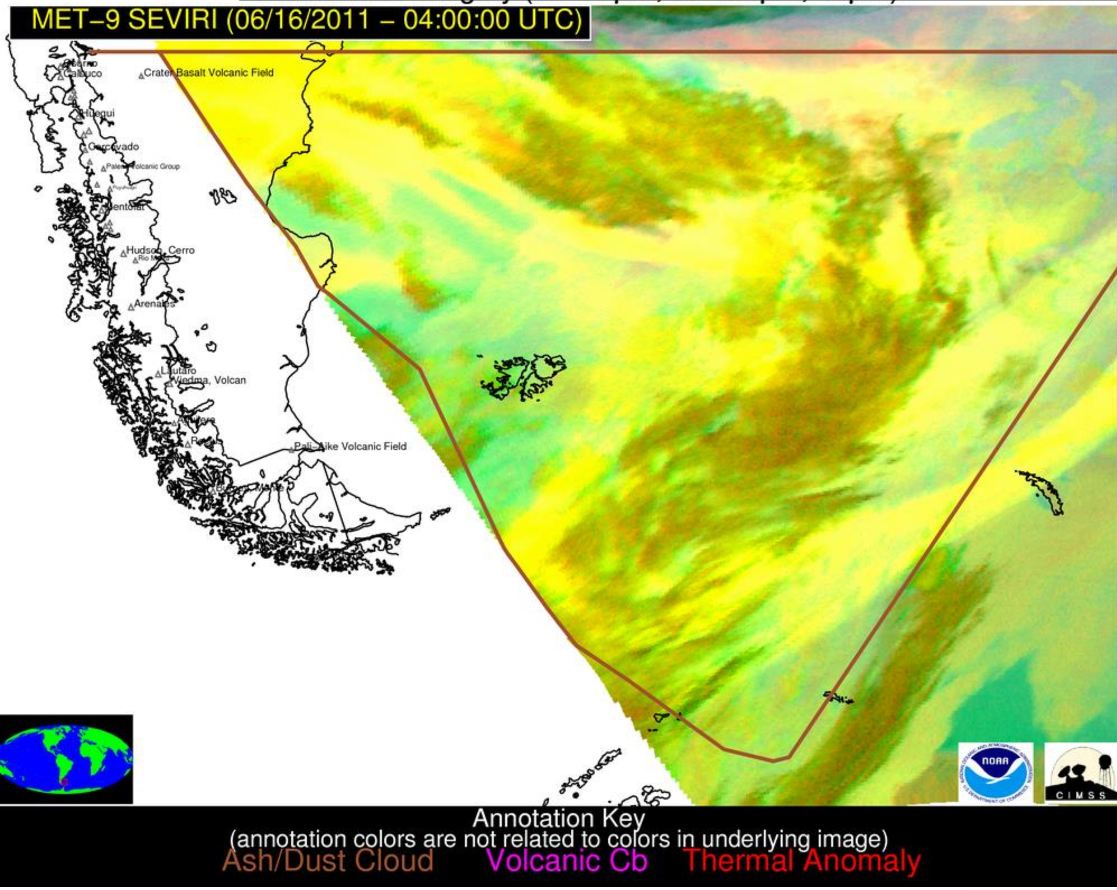
Object-based ash detection technique:

Pavolonis et al., 2015a JGR

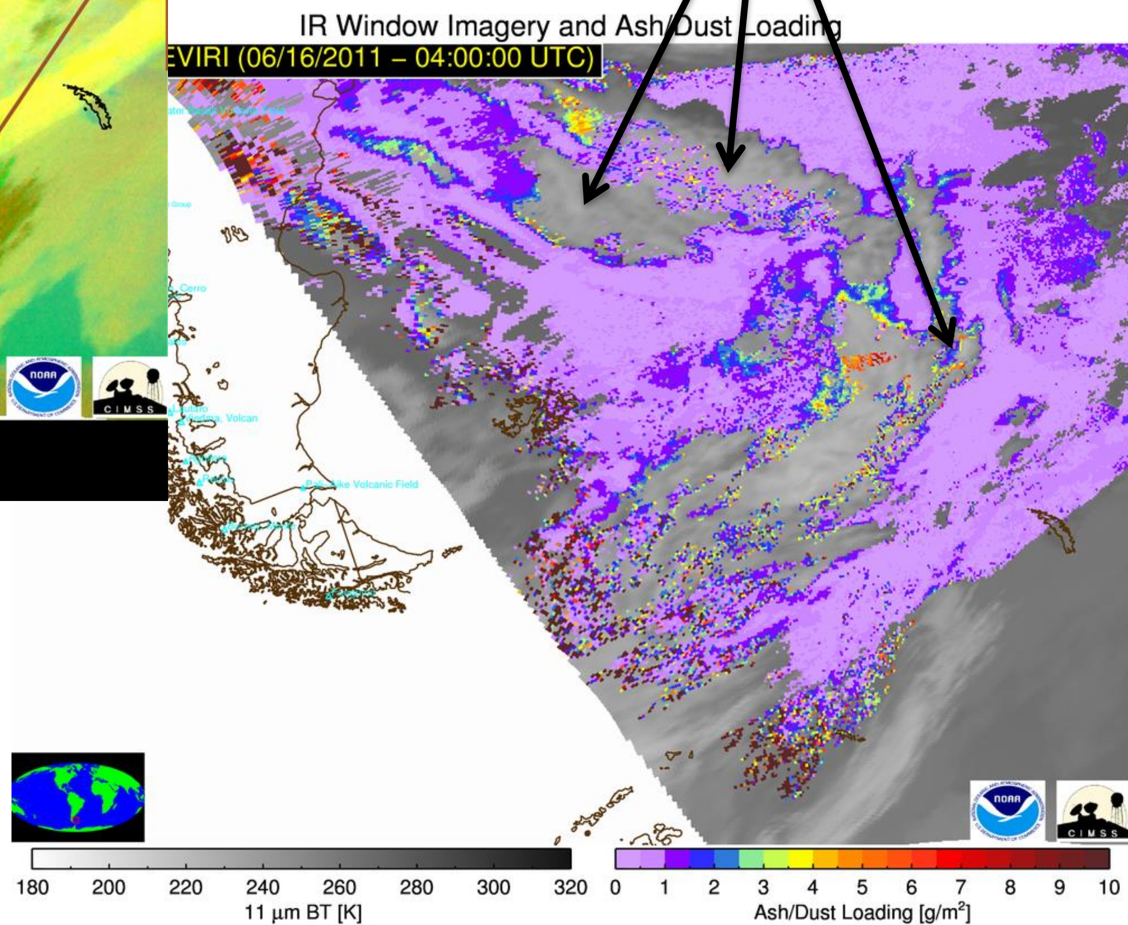
Pavolonis et al., 2015b JGR

Challenge 4: The End User Connection

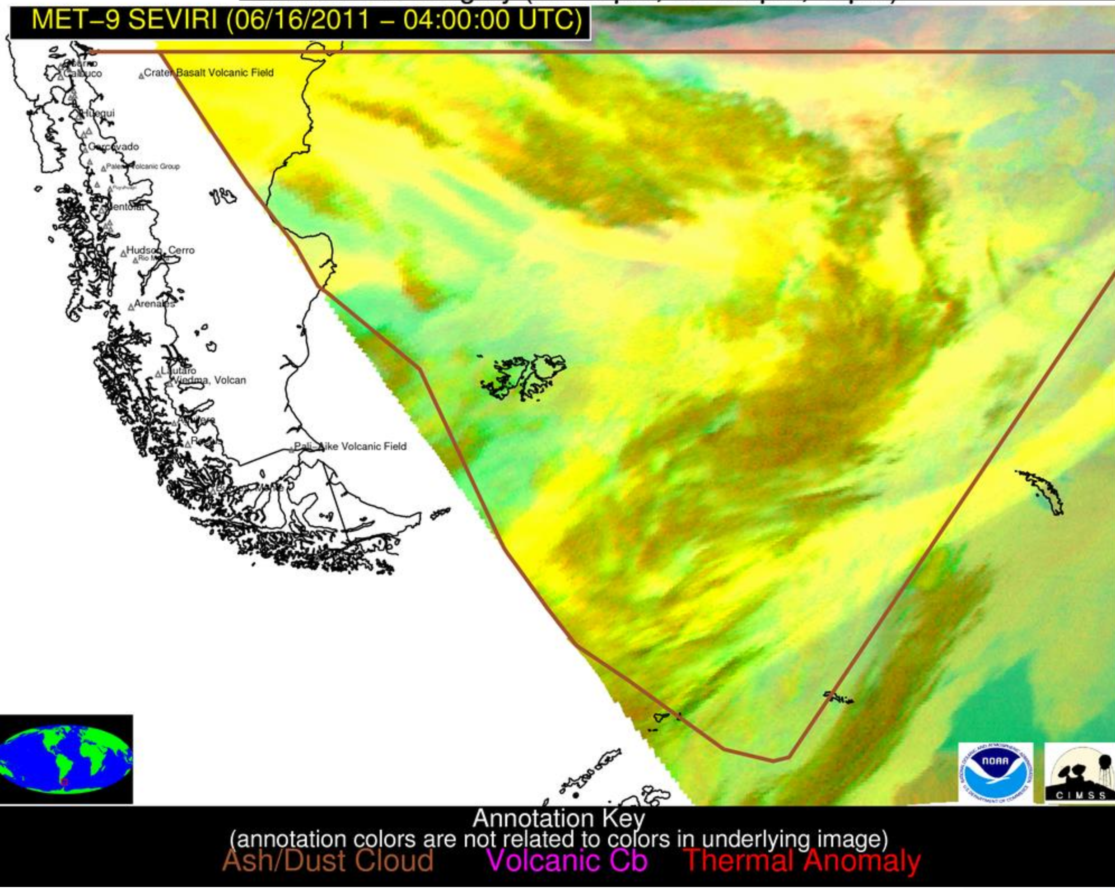
Minimize Product Limitations/Caveats



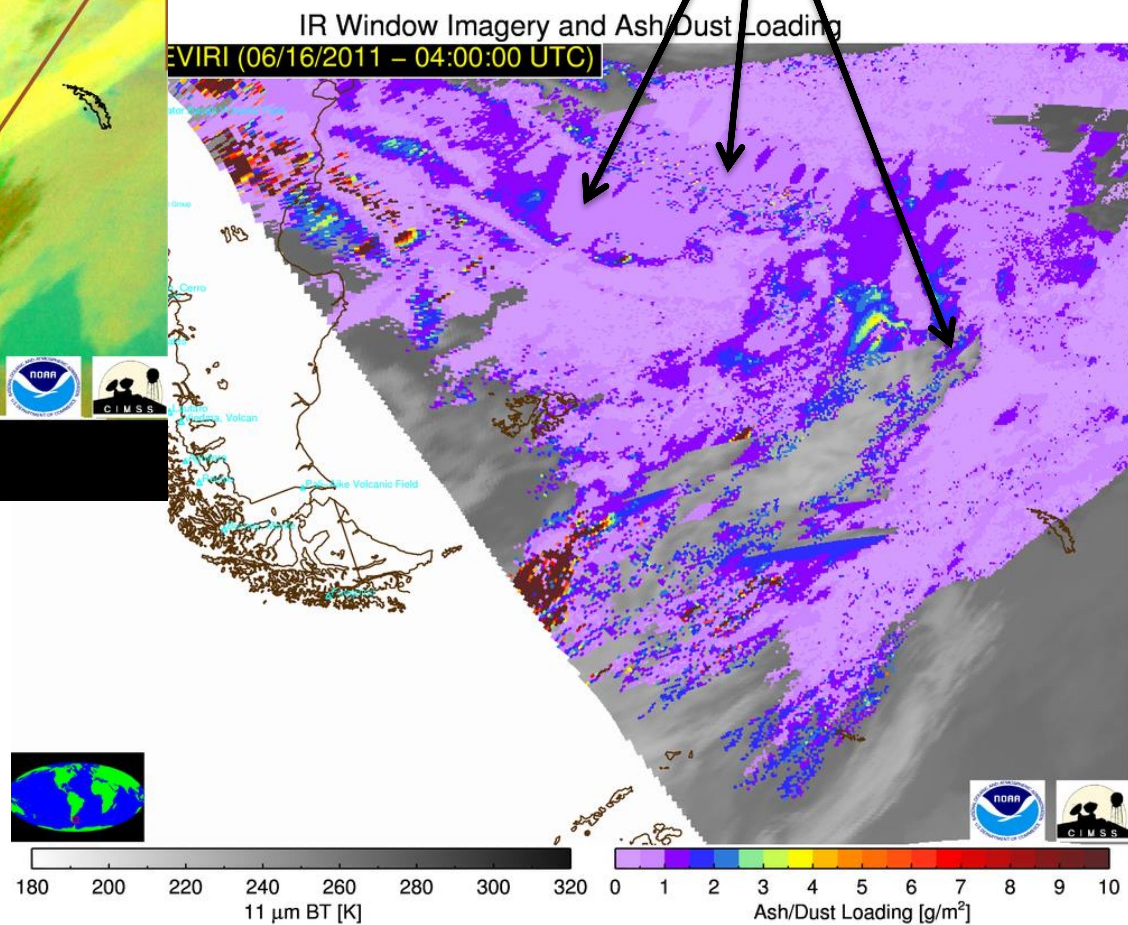
Holes and spurious values



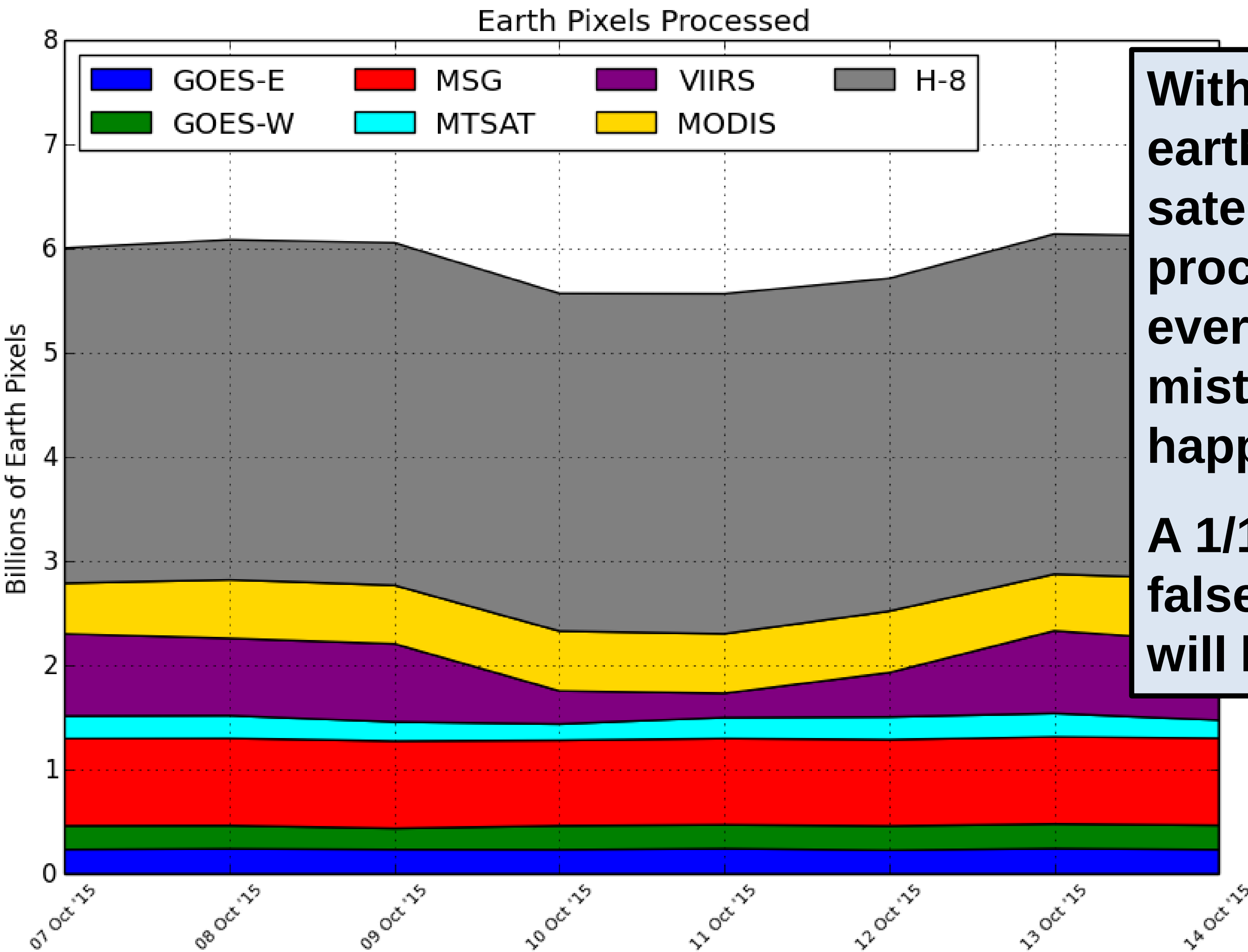
Minimize Product Limitations/Caveats



After quality control procedure



Managing Expectations



With billions of earth located satellite pixels processed everyday, mistakes will happen!

A 1/10,000th % false alarm rate will have impacts

Continuous Training

Volcanic Cloud Monitoring Blog

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Raung Volcano July 7, 2015

NOAA/CIMSS Volcano Monitoring Blog

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Justin Sieglaff on Raung Volcano July 7, 2015

ARCHIVES

July 2015

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false-color imagery

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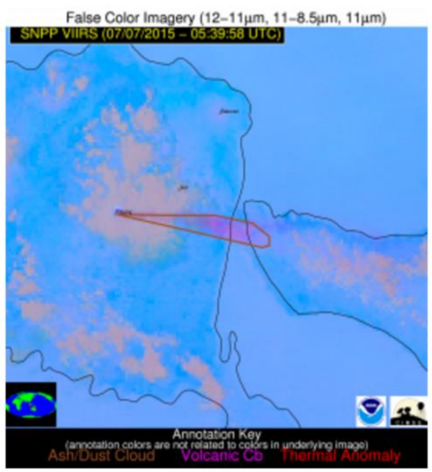
RAUNG VOLCANO JULY 7, 2015

JULY 10, 2015 · 1 COMMENT

A volcanic ash cloud from Raung volcano in Indonesia was observed by SNPP-VIIRS at 0540 UTC 07 July 2015. Two commonly created false-color images using the SNPP-VIIRS data are shown below for this volcanic ash cloud.



The image on the left here is the false-color image (learn more about false-color imagery on the Tutorials page) created with the 8.5 micron channel, which is not sensitive to reflected solar radiation. In general, ash appears the same in this type of false-color image day or night. The ash is the pink/purple region extending to the east of the volcano. The brown polygon represents the NOAA/CIMSS data processing automated ash detection results.

Another false-color image using the 3.9 micron channel instead of the 8.5 micron channel is

Summary

- The WMO inter-comparison analysis showed that:
  - More groups than ever are working on satellite retrievals of volcanic ash cloud properties
  - Reasonable agreement with independent data sets is achievable
  - Additional work is required to understand the underlying cause of the observed differences
  - Good progress have been made, but more work is needed to provide satellite retrievals with all of the attributes (accuracy, reliability, latency, refresh, etc.) needed for operational applications. **Ready by 2020?**

- WMO inter-comparison report:

http://www.wmo.int/pages/prog/sat/documents/SCOPE-NWC-PP2_VAIntercompWSReport2015.pdf

Summary of recommendations

Meeting reported generated 22 recommendations to improve satellite-based volcanic ash detection and quantification in the future, including:

- VAACs, VOs, and the remote sensing community encouraged to work together
  - Acceptable false alarms rates need to be determined
  - Confidence levels to detection products needed (e.g., ‘low, medium, high’, or probabilities)
  - Satellite retrievals efficiently used when available in VAAC’s operational analysis platform.
  - Quantitative products should be presented with imagery (for human interpretation).
- Useful to flag where ash is possible due to spatio-temporal context but cannot be directly detected
- More / better validation data needed to assess satellite products
  - Systematic analysis of CALIOP reference data required
  - Better access to ground-based lidar data, and better network coverage
  - Provision of airborne ash measurements during future eruptions, plus resources for associated analysis
  - More in-situ and remotely-sensed particle size distribution (PSD) measurements are required

Summary of recommendations

- More measurements of ash optical properties are needed
- The volcano ash community is encouraged to formulate requirements (parameters, data formats, latency, possibly sites) to the WMO GAW Lidar Observation Network.
- A follow-up inter-comparison is recommended to better understand the differences between algorithms – to build on approach and tools developed for this first exercise.

General Conclusion: Different algorithms and/or sensors provide a range of solutions