Marco Fulle - www.stromboli.net

Development of a System for Quantitatively Analyzing Volcanic Clouds

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2nd IUGG-WMO Workshop on Ash Dispersal Forecast and Civil Aviation

November 18 -20, 2013

Outline

- **Description of satellite-derived volcanic ash data set**
- **Summary of results from 2008 Kasatochi eruption**

Summary of Techniques

- **End products: ash probability, ash top height, mass loading, effective particle radius, volcanic cloud alerts, cloud vertical growth rate anomalies, volcanic thermal anomalies**

- **Techniques: probabilistic cloud object based ash detection, optimal estimation retrieval of ash cloud properties (ash height, mass loading, and effective radius), multi-sensor cloud tracking to improve ash detection and cloud property retrieval**

- **Ash detection does not rely on robust "split-window" signature and is designed to emulate a skilled human analyst (high probability of detection, very low false alarm rate)**

- **Value added applications: plume medial axis transformation and polygon fitting**

Making Full Use of the Space-based Observing System for Volcanic Cloud Monitoring

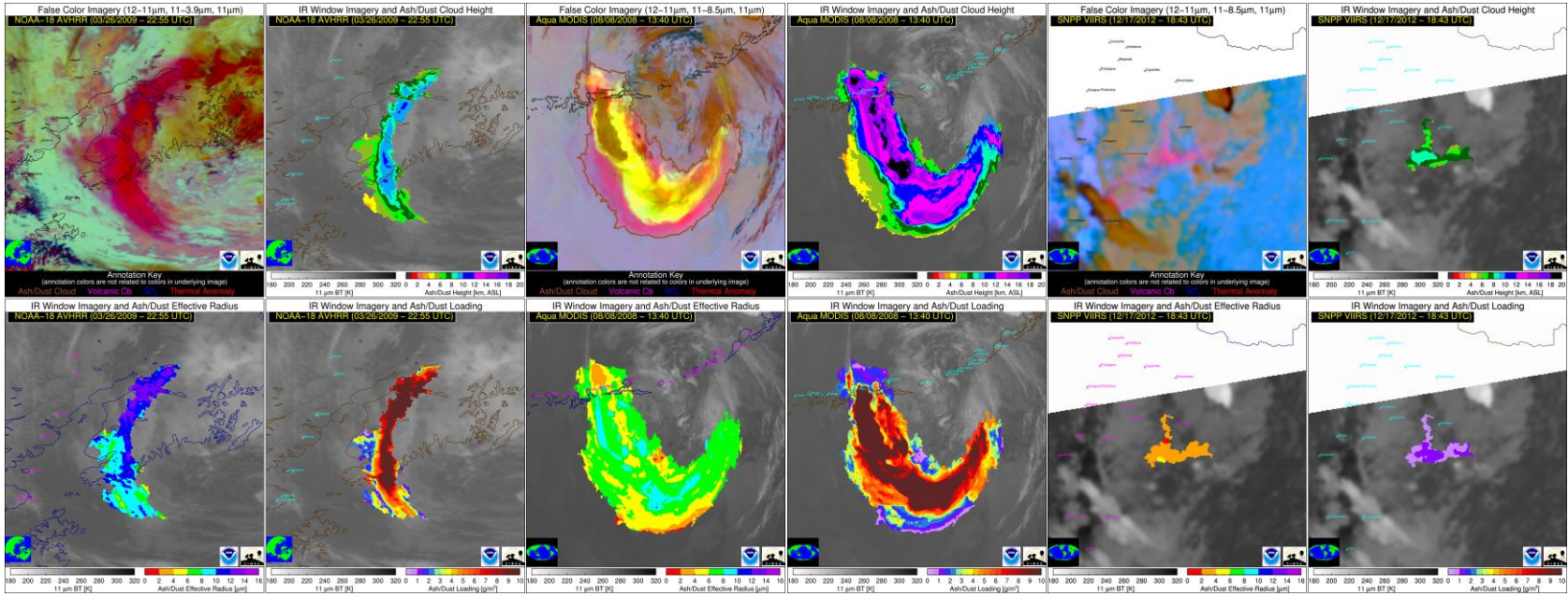
LEO

GEO

NOAA and MetOp AVHRR

Terra and Aqua MODIS

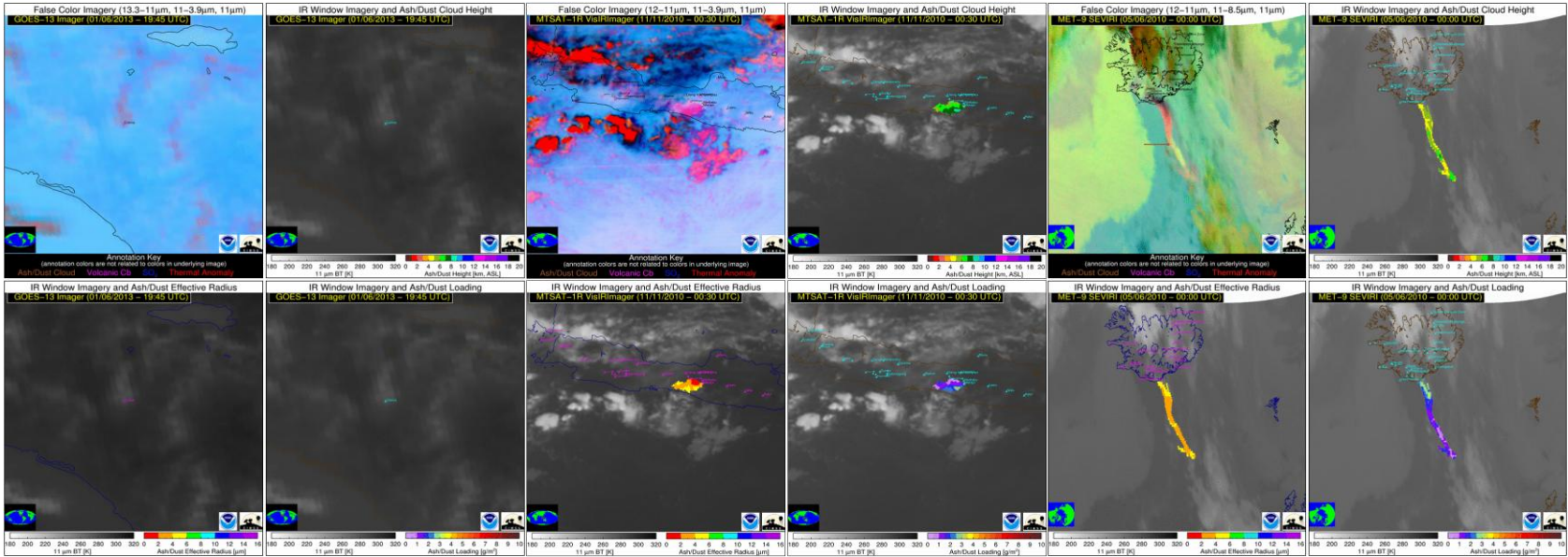
SNPP-VIIRS



GOES-13-15

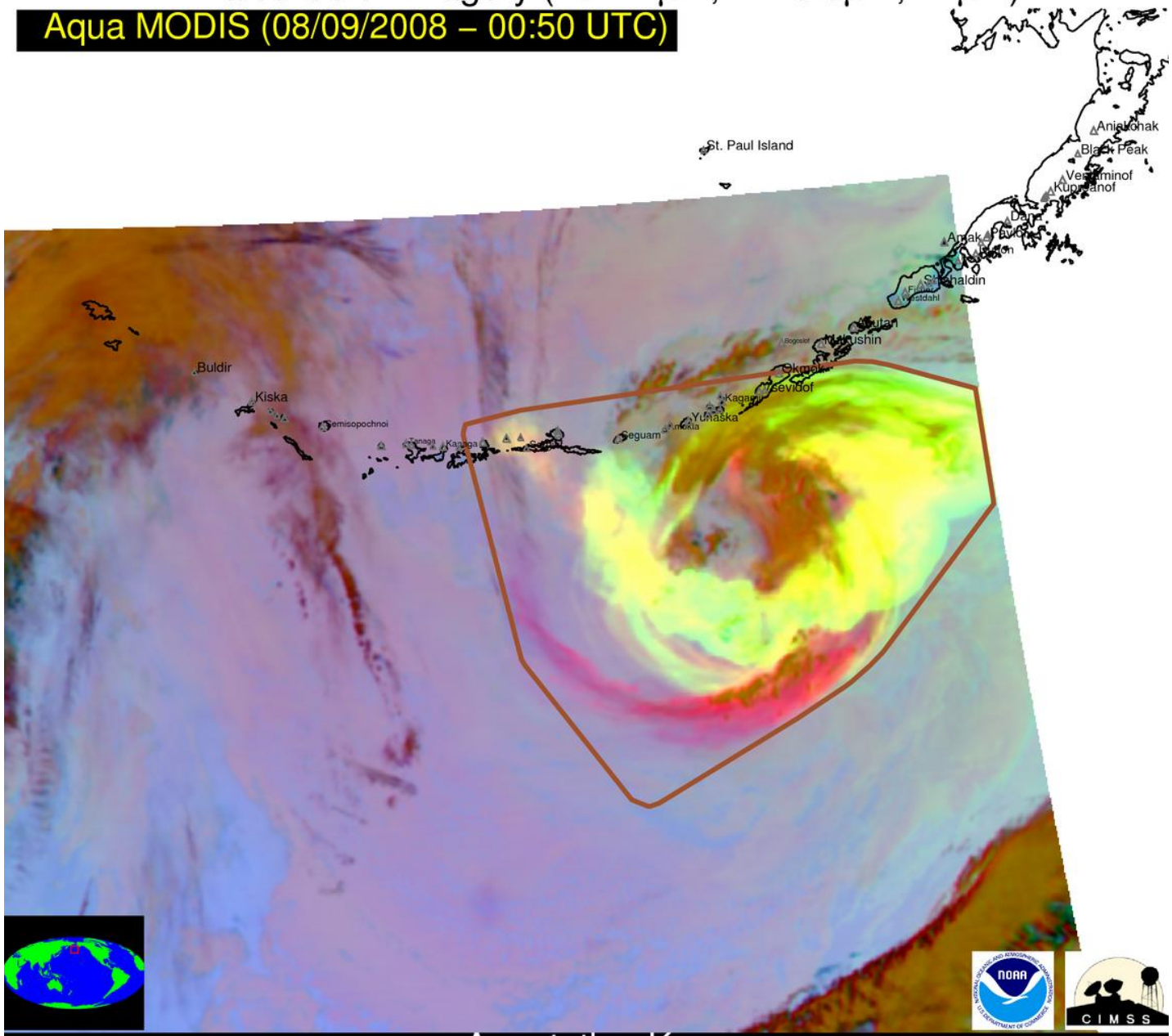
MTSAT-(1r and 2)

Met-(8,9,10) SEVIRI



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

Aqua MODIS (08/09/2008 – 00:50 UTC)

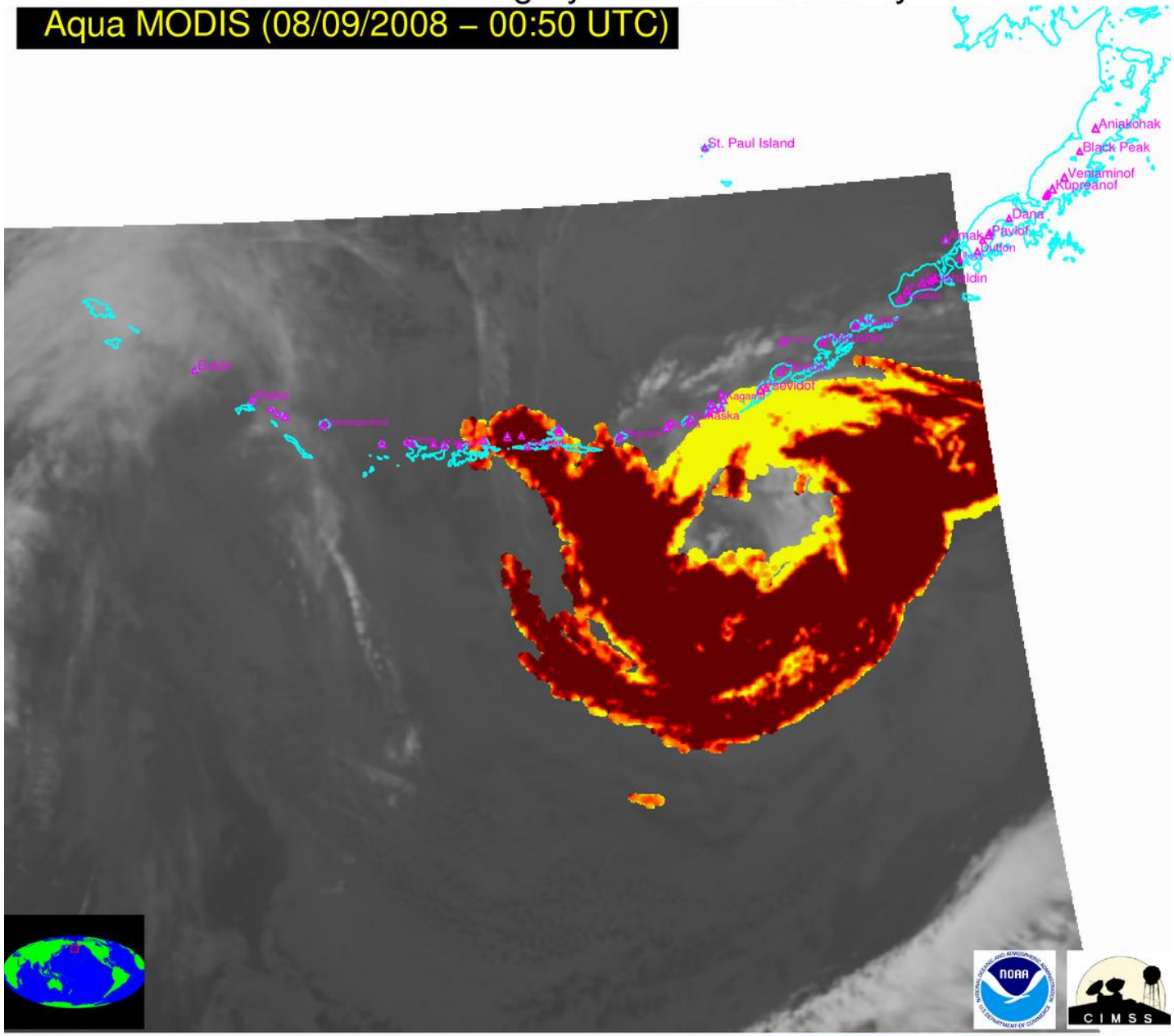


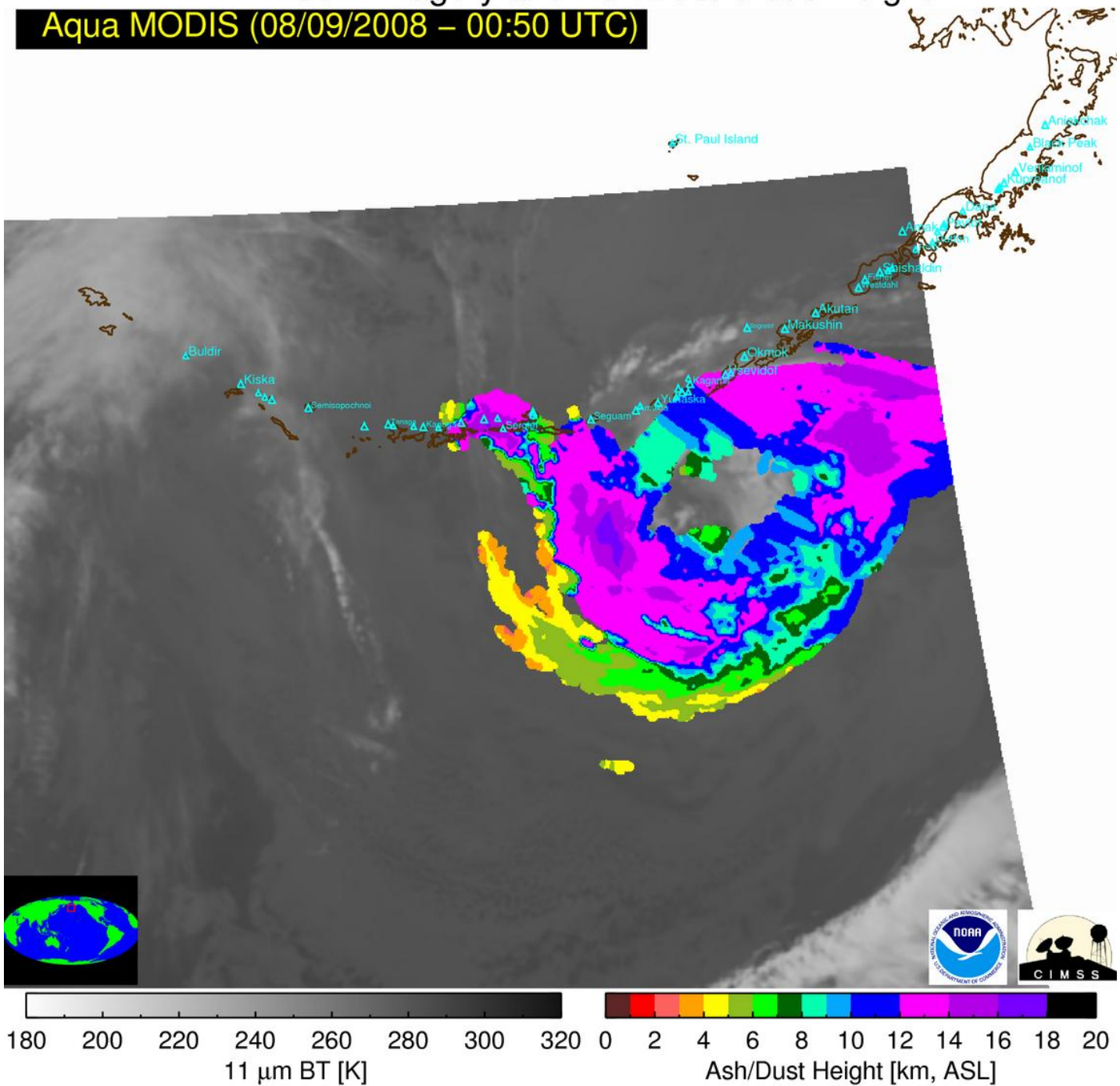
Annotation Key

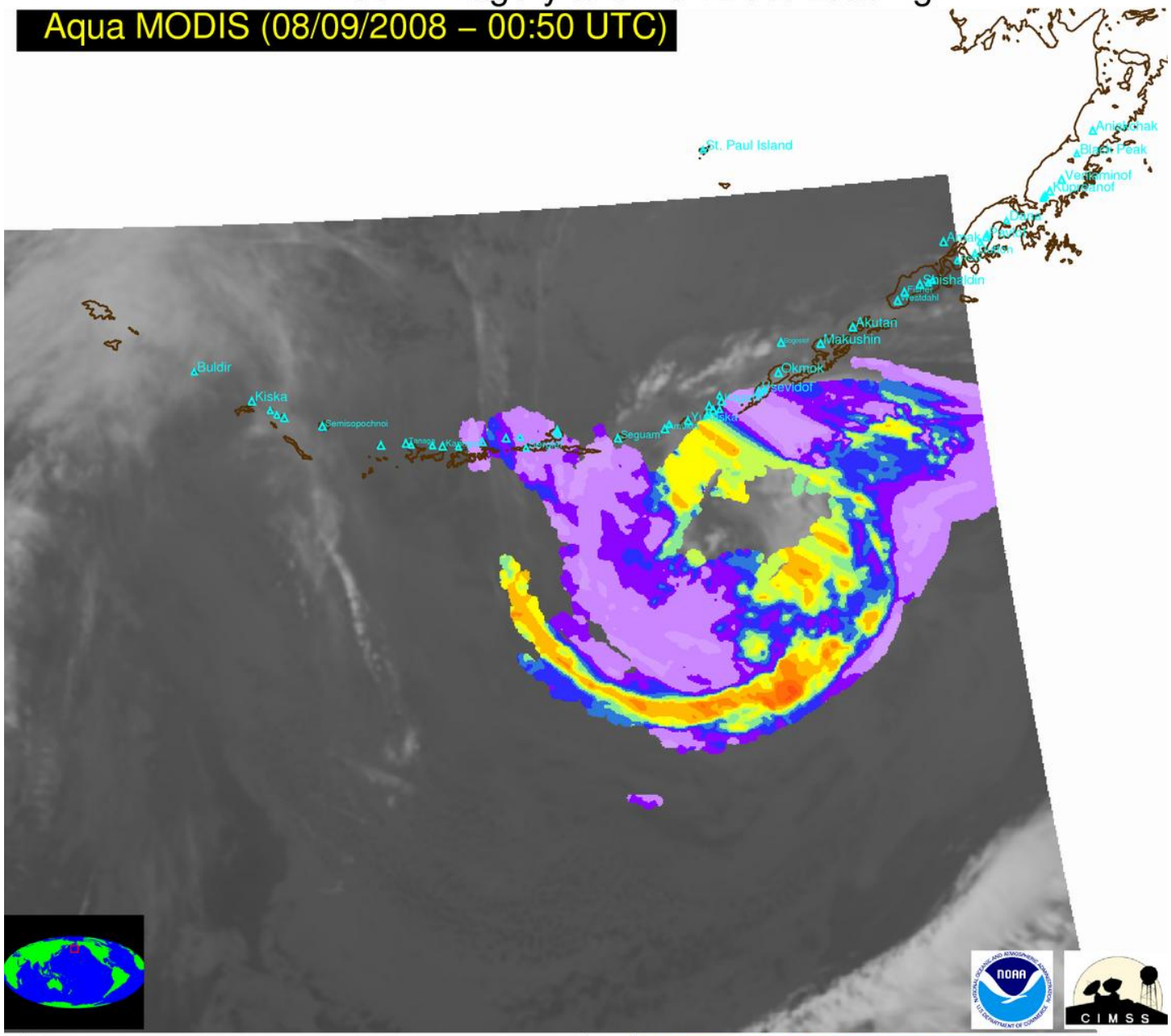
(annotation colors are not related to colors in underlying image)

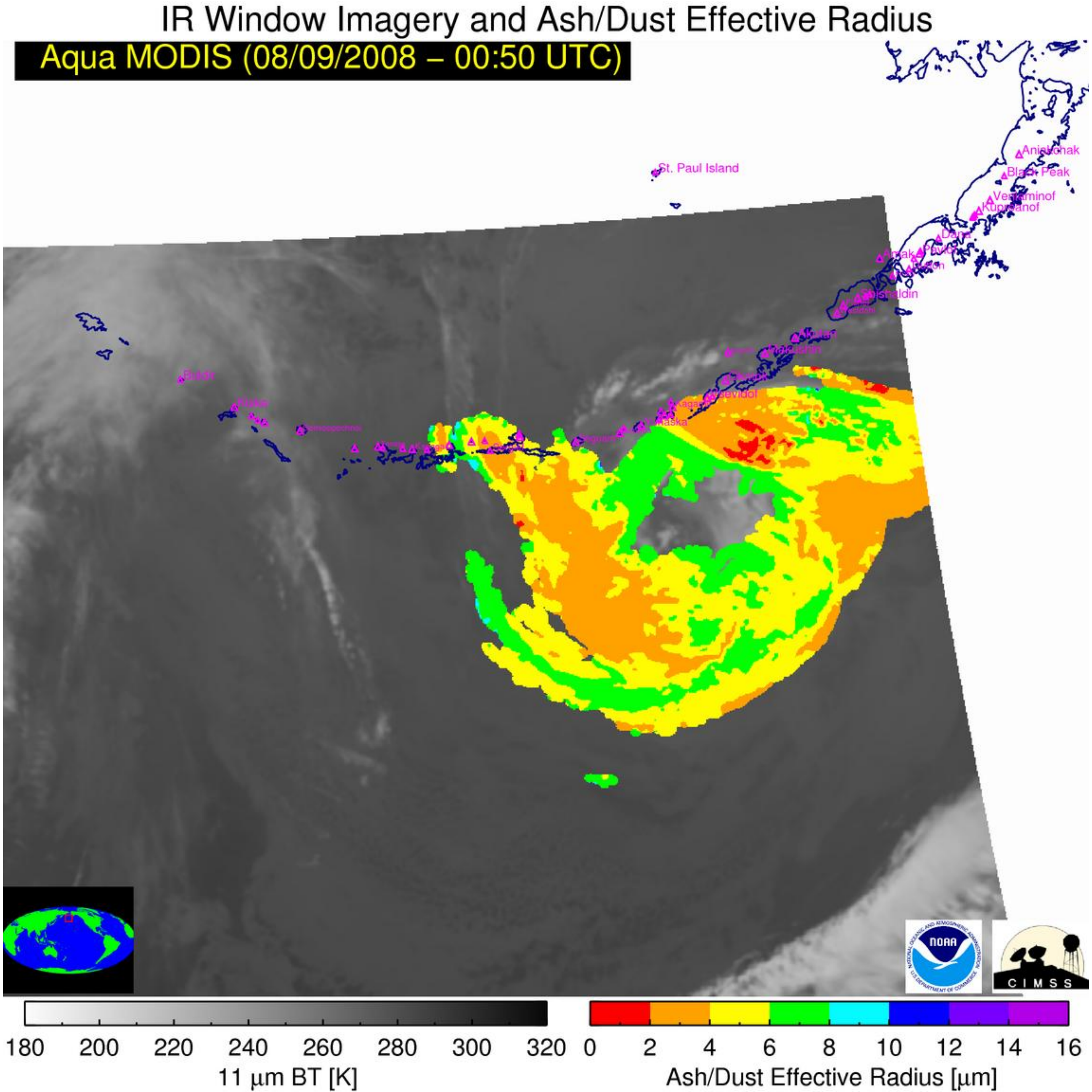
Ash/Dust Cloud Volcanic Cb SO_2 Thermal Anomaly

IR Window Imagery and Ash Probability




IR Window Imagery and Ash/Dust Cloud Height
Aqua MODIS (08/09/2008 – 00:50 UTC)
St. Paul Island
Buldir
Kiska
Semisopochnoi
Seguam
Akutan
Makushin
Okmok
Kasatochi
Shishaldin
NOAA
CIMSS
180 200 220 240 260 280 300 320
11 μm BT [K]
0 2 4 6 8 10 12 14 16 18 20
Ash/Dust Height [km, ASL]


IR Window Imagery and Ash/Dust Loading
Aqua MODIS (08/09/2008 – 00:50 UTC)
St. Paul Island
Buldir
Kiska
Semisopochnoi
Seguam
Akutan
Makushin
Okmok
Sevidof
Shishaldin
NOAA
CIMSS
180 200 220 240 260 280 300 320
11 μm BT [K]
0 1 2 3 4 5 6 7 8 9 10
Ash/Dust Loading [g/m2]



IR Window Imagery and Ash/Dust Effective Radius
Aqua MODIS (08/09/2008 – 00:50 UTC)
St. Paul Island
Aniakchak
Black Peak
Veniaminof
Kupreanof
Shishaldin
Makushin
Vsevidof
Kiska
Buldir
180 200 220 240 260 280 300 320
11 μm BT [K]
0 2 4 6 8 10 12 14 16
Ash/Dust Effective Radius [μm]
CIMSS

Volcanic cloud and volcanic thermal anomaly alerts are distributed via email and SMS. Many eruptions around the world have been detected by the NOAA system since it came online in May 2013 (some of those eruptions went undetected using current operational tools).

Volcanic Cloud Monitoring -- NOAA/CIMSS (BETA)

http://volcano.ssec.wisc.edu/alert/report/3017

Apple (13) Yahoo! eBay Amazon News (1,466)

CIMSS » Volcanic Cloud Monitoring » Event Alerts » 2013-05-16

Volcanic Cloud Monitoring — NOAA/CIMSS

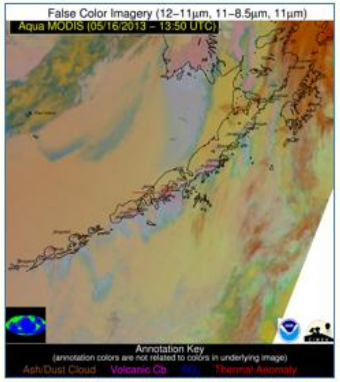
Home | Sector Imagery | Alerts | Admin | Logout (mpav@ssec.wisc.edu)

Volcanic Cloud Alert Report

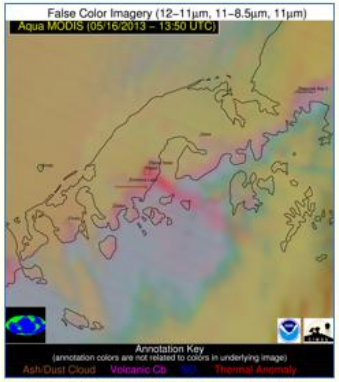
Date:	2013-05-16
Time:	13:49:59
Primary Instrument:	Aqua MODIS

More details ▼

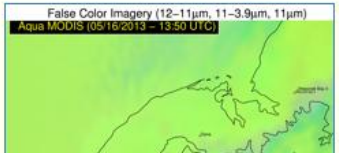
Possible Volcanic Ash Cloud — View event imagery »



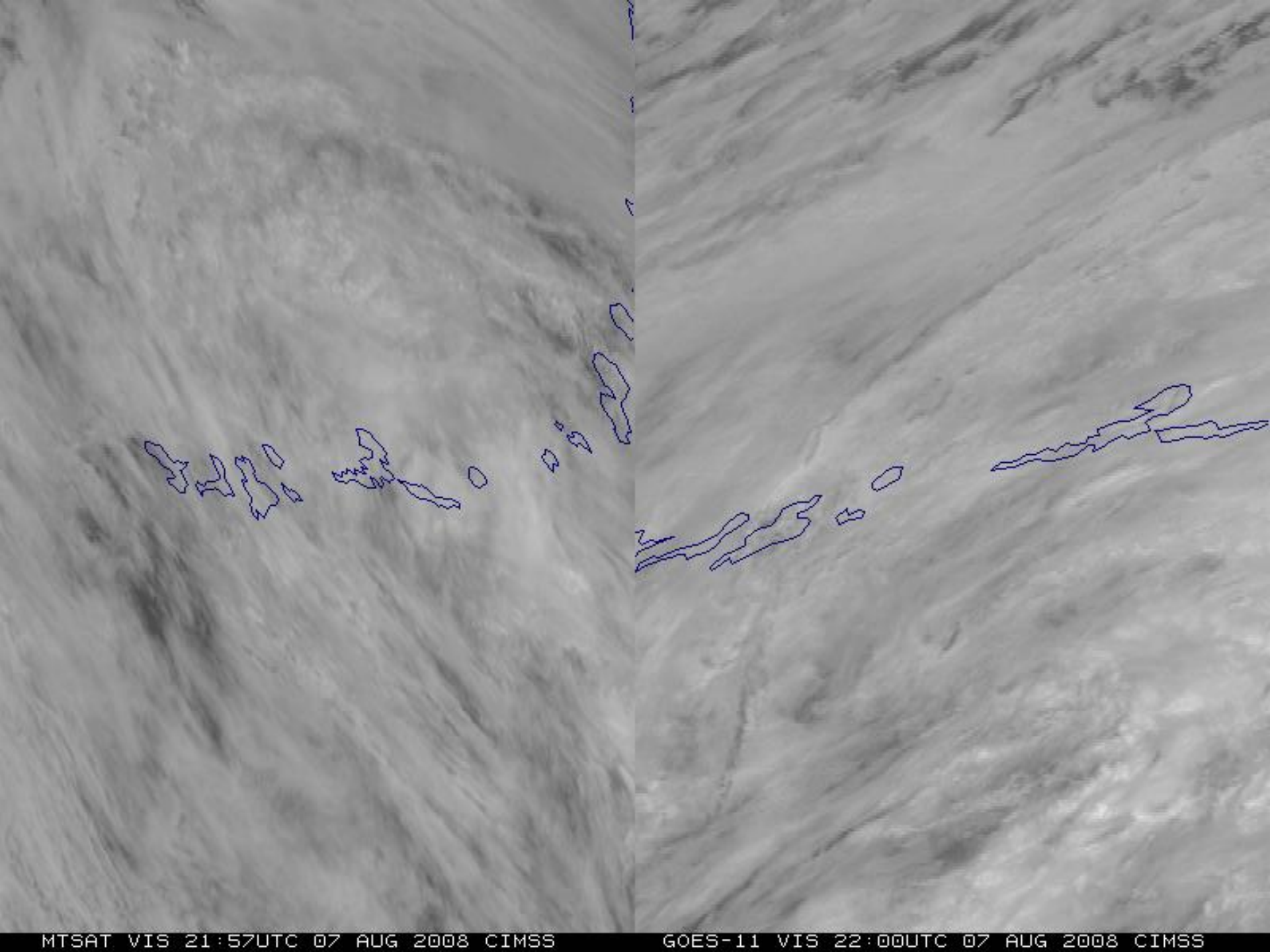
False Color Image (12-11, 11-8.5, 11)

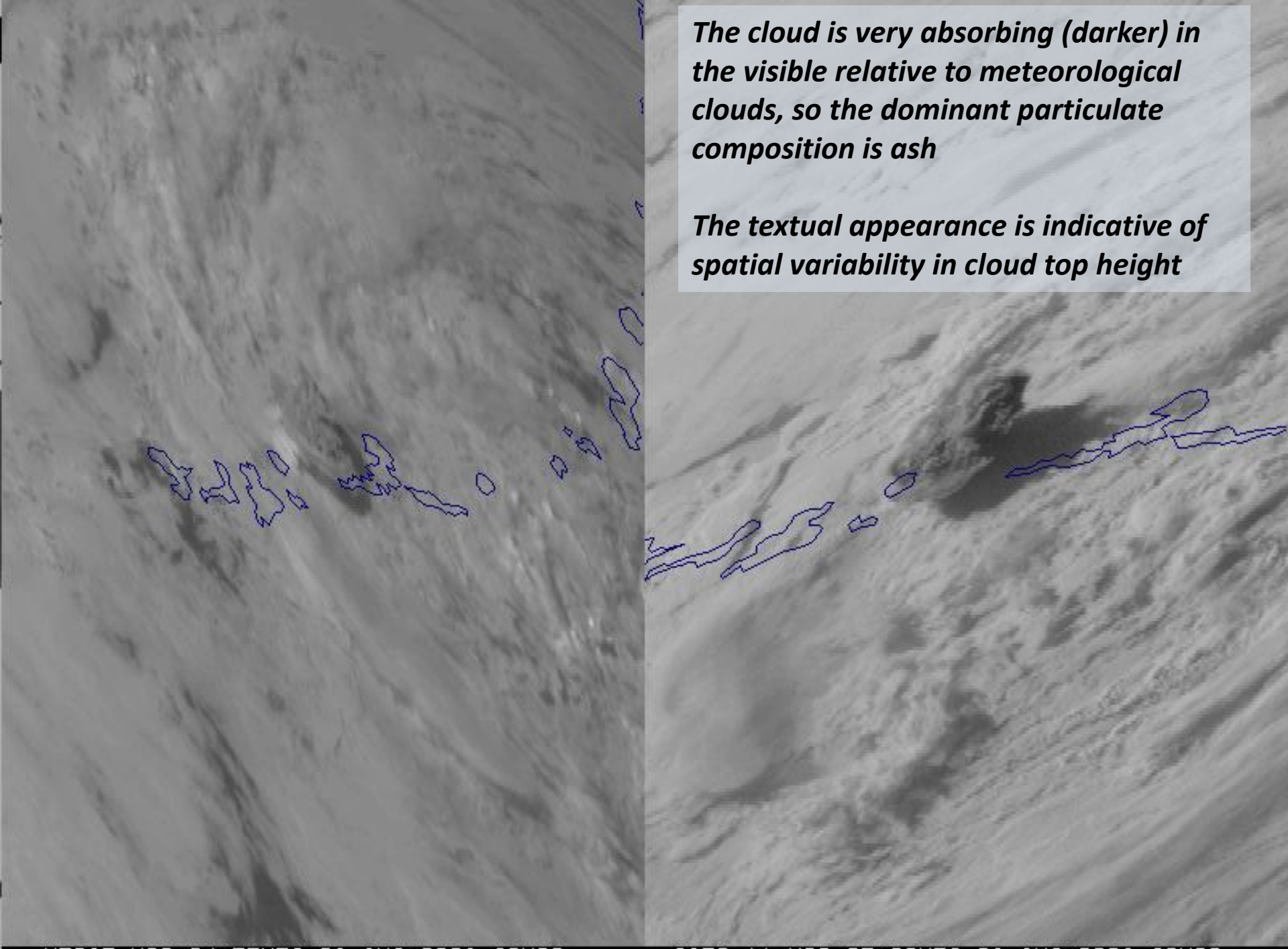


False Color Image (12-11, 11-8.5, 11) [zoomed-in]



Alert Status	Newly detected feature
Radiative Center (Lat, Lon):	55.367 °, -161.736 °
Mean Viewing Angle	46.50 °
Mean Solar Zenith Angle	95.30 °
Nearby Volcanoes (meeting alert criteria):	Dutton (40.52 km) Pavlof (11.07 km) [Thermal Anomaly Present] Pavlof Sister (11.73 km) [Thermal Anomaly Present] Emmons Lake (21.86 km) Dana (44.93 km)
Cloud Object Probability	99.99996 %
Median Probability Of Object Pixels	98.71912 %
Percent Unambiguous Pixels	16.16000 %
Maximum Height [amsl]	5.80 km
90th Percentile Height [amsl]	4.60 km
Mean Tropopause Height [amsl]	8.80 km


MTSAT VIS 21:57UTC 07 AUG 2008 CIMSS
GOES-11 VIS 22:00UTC 07 AUG 2008 CIMSS



The cloud is very absorbing (darker) in the visible relative to meteorological clouds, so the dominant particulate composition is ash

The textual appearance is indicative of spatial variability in cloud top height

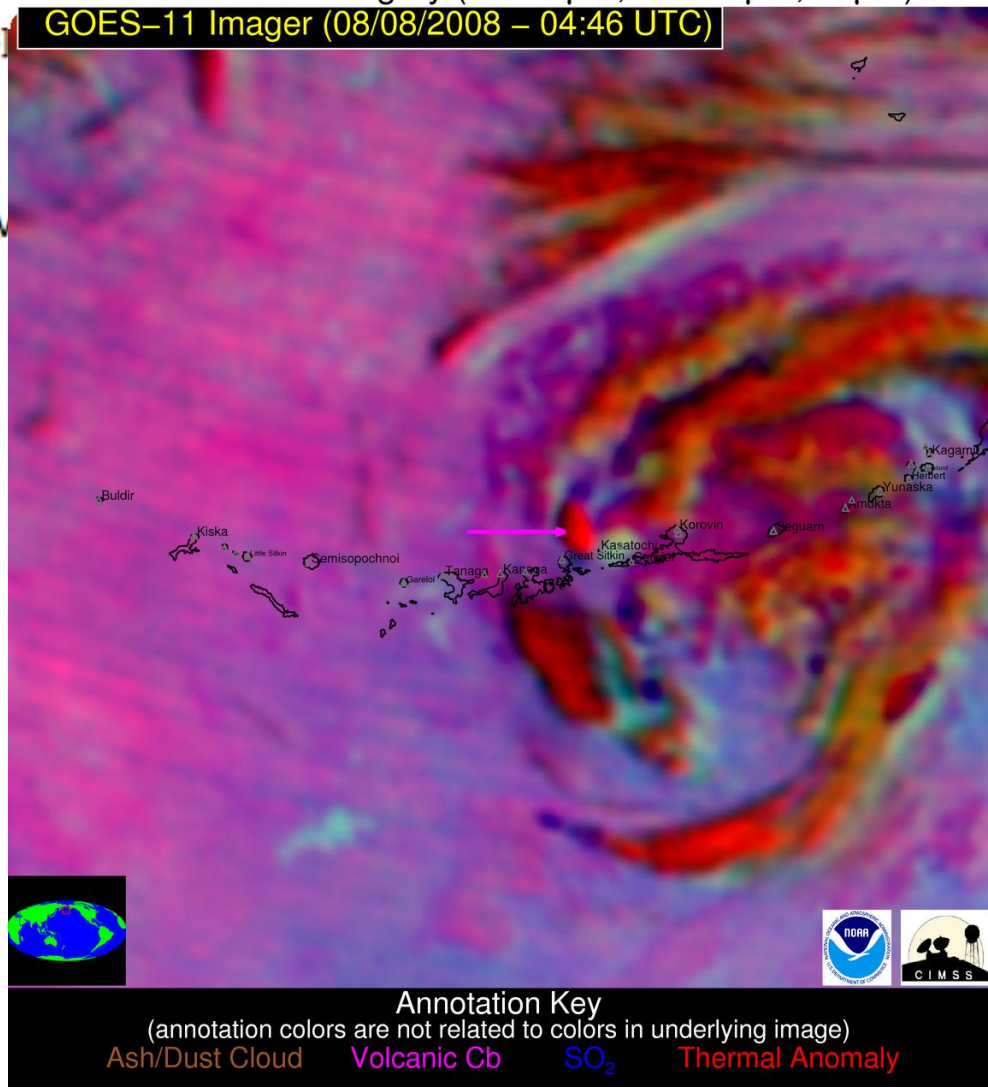
@**********VOLCANIC ALERTS**********
STARTING DATE/TIME OF IMAGE: 2008-08-08 04:45:59 [UTC]
PRIMARY INSTRUMENT: GOES-11 Imager
WMO SPACECRAFT ID: 255
LOCATION/ORBIT: GEO
L1 FILE: goes11_1_2008_221_0446.area.gz
VOLCANO DATABASE: /data/common/VOLCAT_DATA/alerts/V
NUMBER OF ASH CLOUD ALERTS: 0
NUMBER OF VOLCANIC Cb ALERTS: 1
NUMBER OF VOLCANIC THERMAL ANOMALY ALERTS: 0
NUMBER OF SO2 CLOUD ALERTS: 0

REPORT WITH IMAGES:
http://volcano.ssec.wisc.edu/alert/report/10614

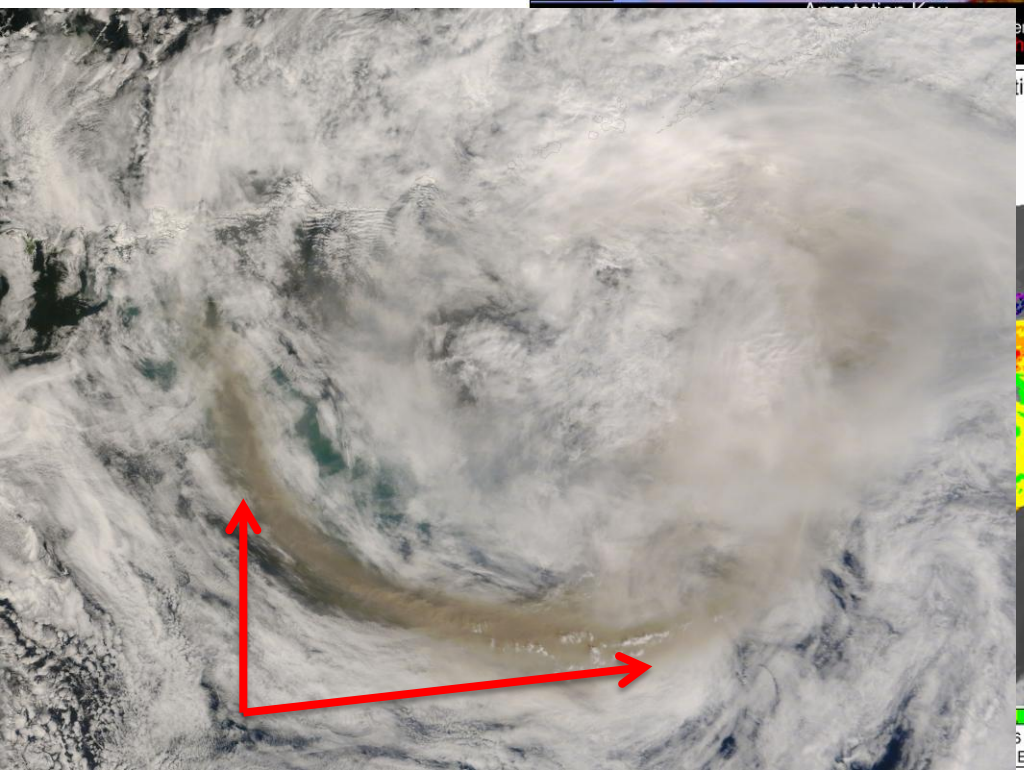
POSSIBLE VOLCANIC ERUPTION DETECTED
Alert Status: New Alert Object
Latitude of Radiative Center: 52.161 [degrees]
Longitude of Radiative Center: -175.397 [degrees]
Mean Viewing Angle: 71.30 [degrees]
Mean Solar Zenith Angle: 67.53 [degrees]
Nearby Volcanoes (meeting alert criteria):
Kasatochi(7.84 km)
Koniuji(19.03 km)
Maximum Height [AMSL]: 13.7 [km] (45112.91 [ft])
90th Percentile Height [AMSL]: 13.2 [km] (43433.68 [ft])
Mean Tropopause Height [AMSL]: 10.6 [km] (34680.12 [ft])
Trend in IR Brightness Temperature: -44.67 [K]
Vertical Growth Rate Time Interval: 16 [minutes]
Vertical Growth Rate Anomaly: 13.99 [number of stddev above mean]
Total Area: 1045.84 [km^2]

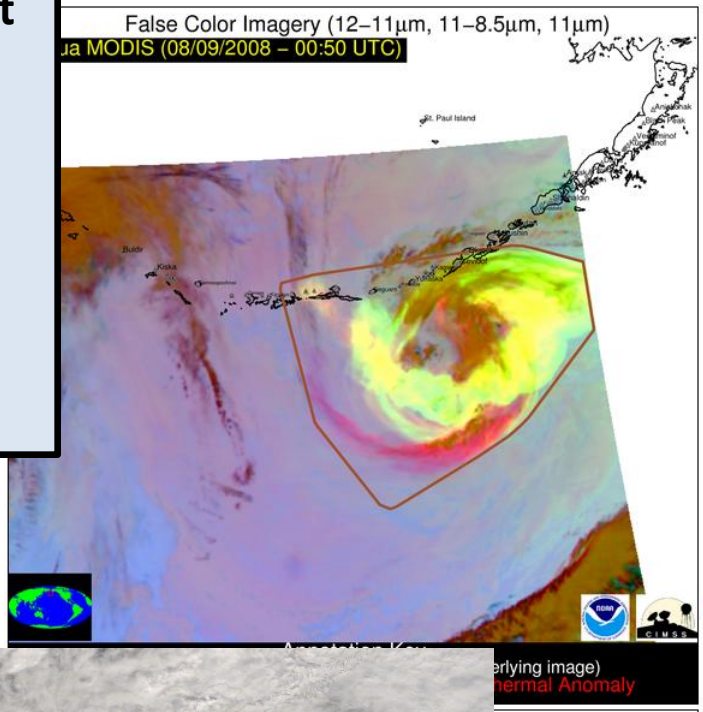
Geographic Regions of Nearby Volcanoes: Aleutian Is
VAAC Regions of Nearby Volcanoes: Anchorage
FIR Regions of Nearby Volcanoes: Unknown

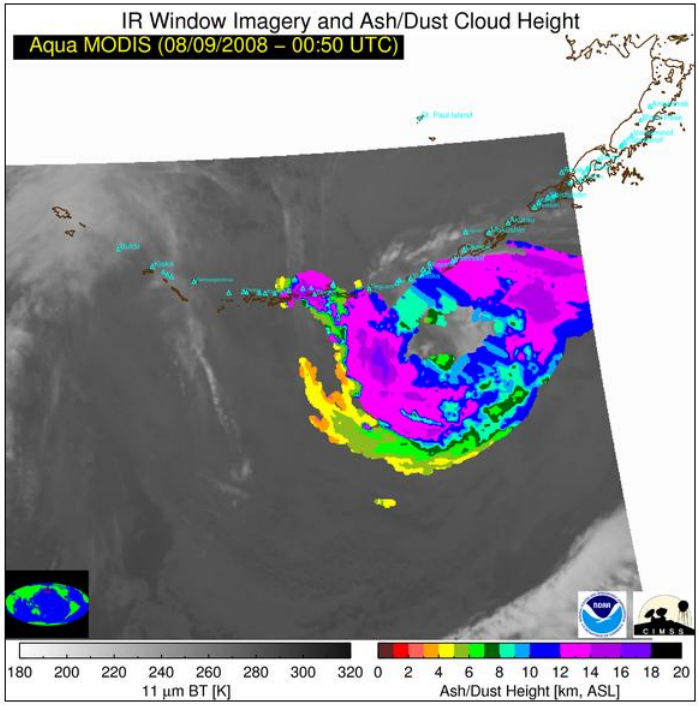
False Color Imagery (12–11μm, 11–3.9μm, 11μm)

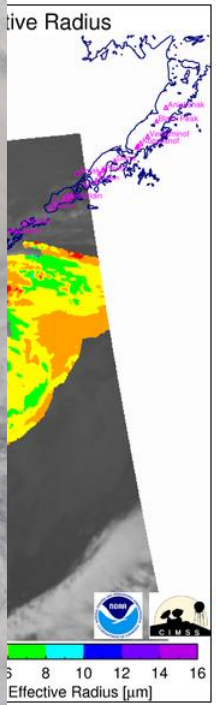


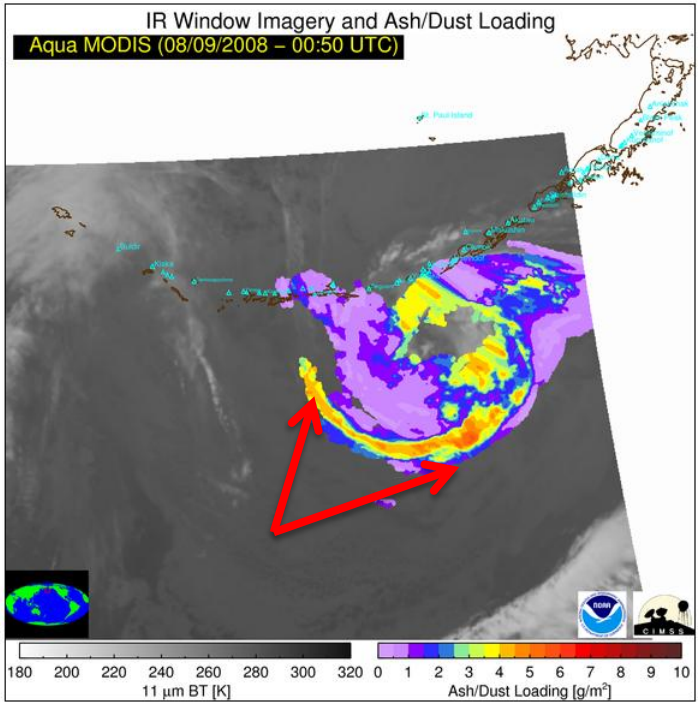
The location of the largest mass loadings are consistent with the corresponding true color image (darker brown colors are indicative of larger visible ash optical depths)

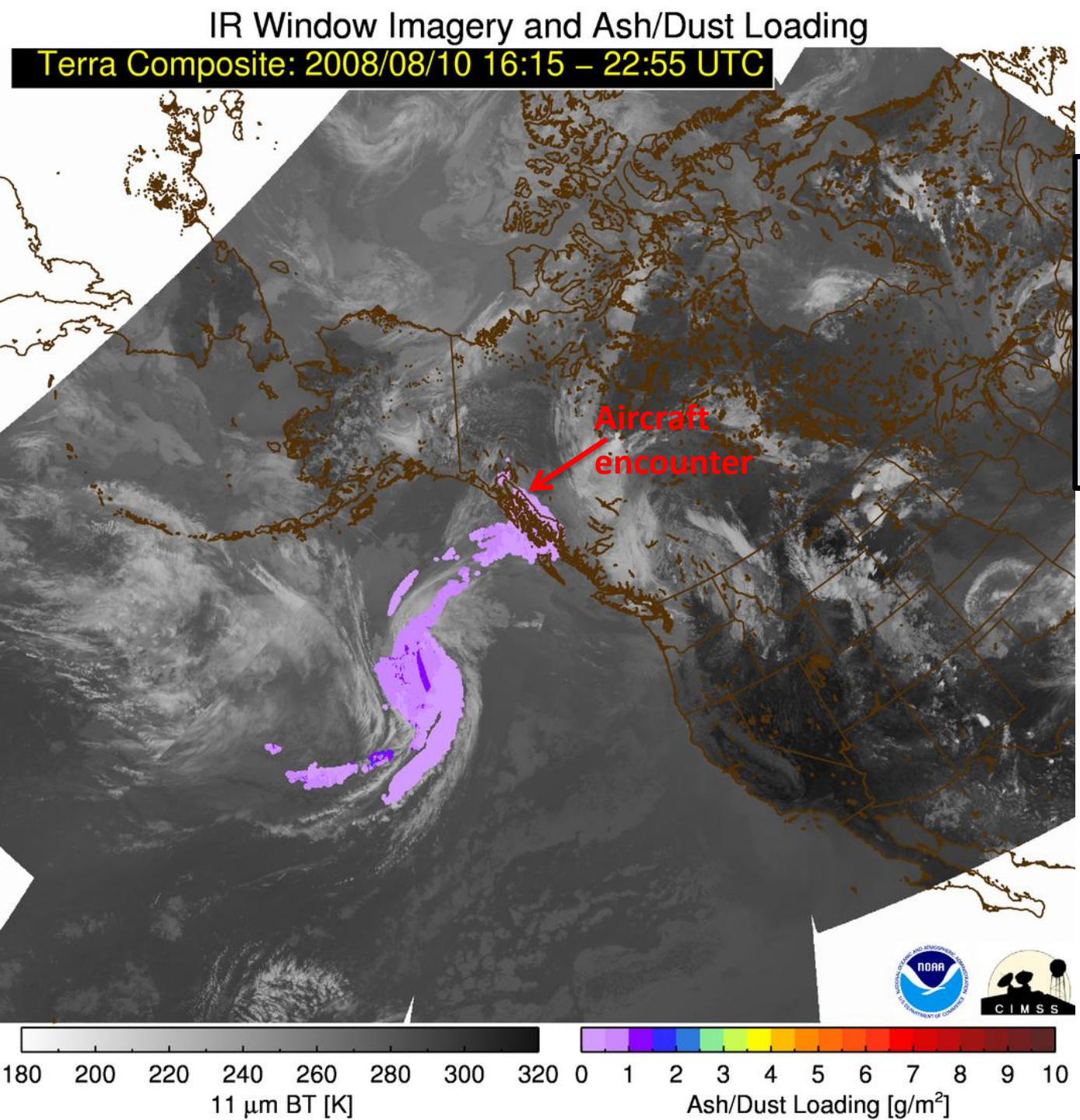




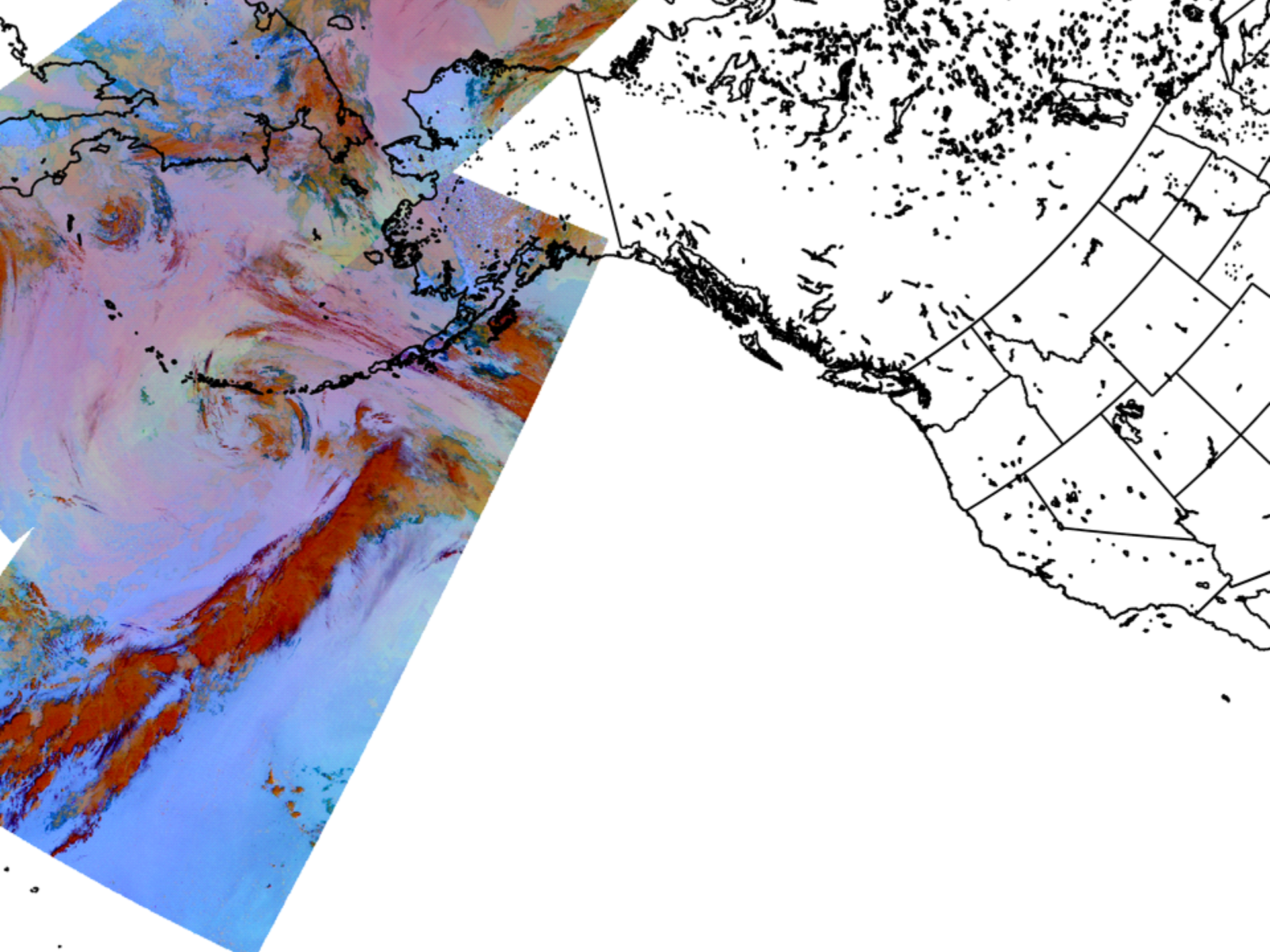


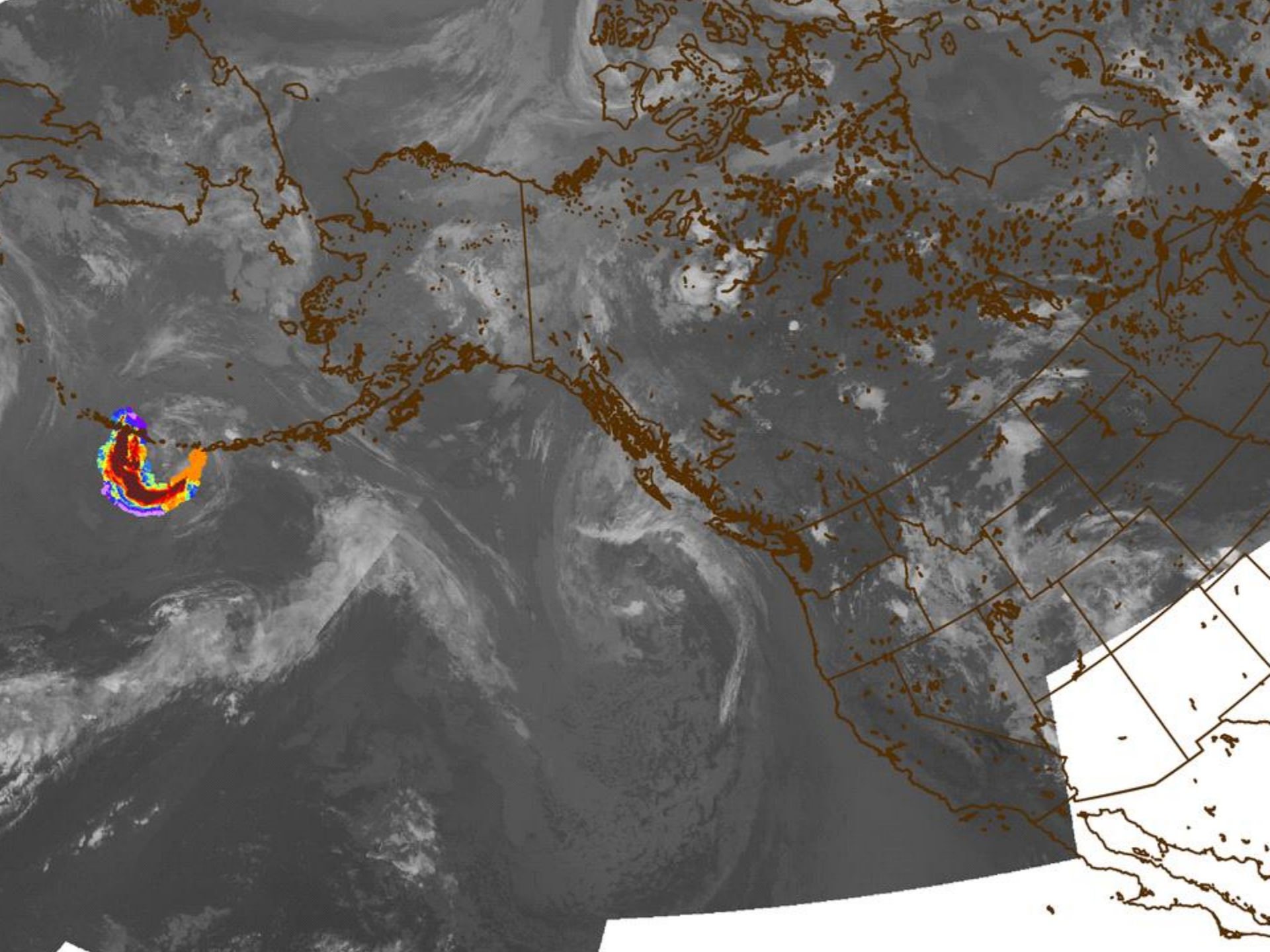






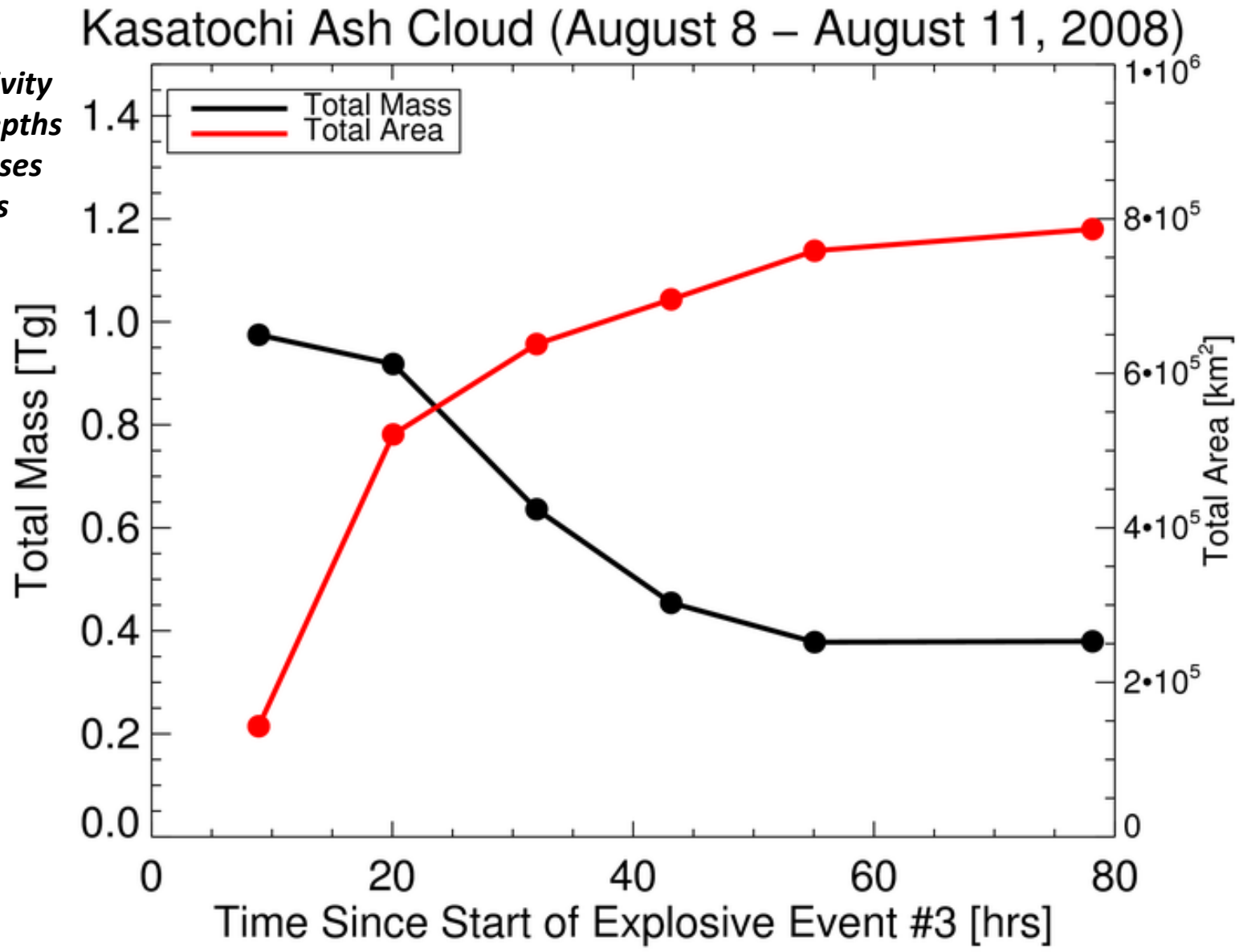
Kasatochi ash was found in the engine of a 757 that encountered a volcanic cloud in Northern British Columbia, Canada (Guffanti et al., 2010)

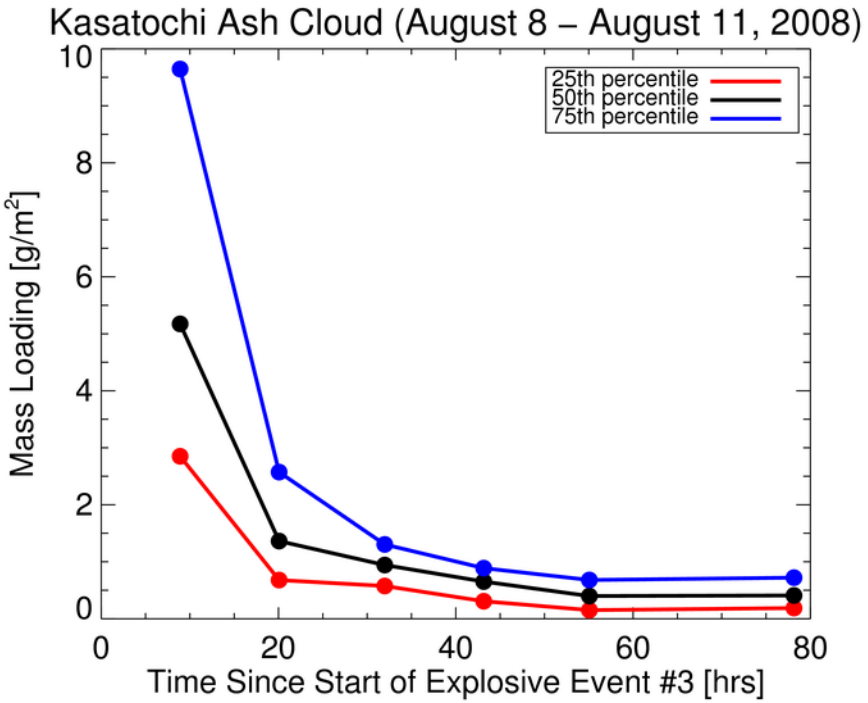


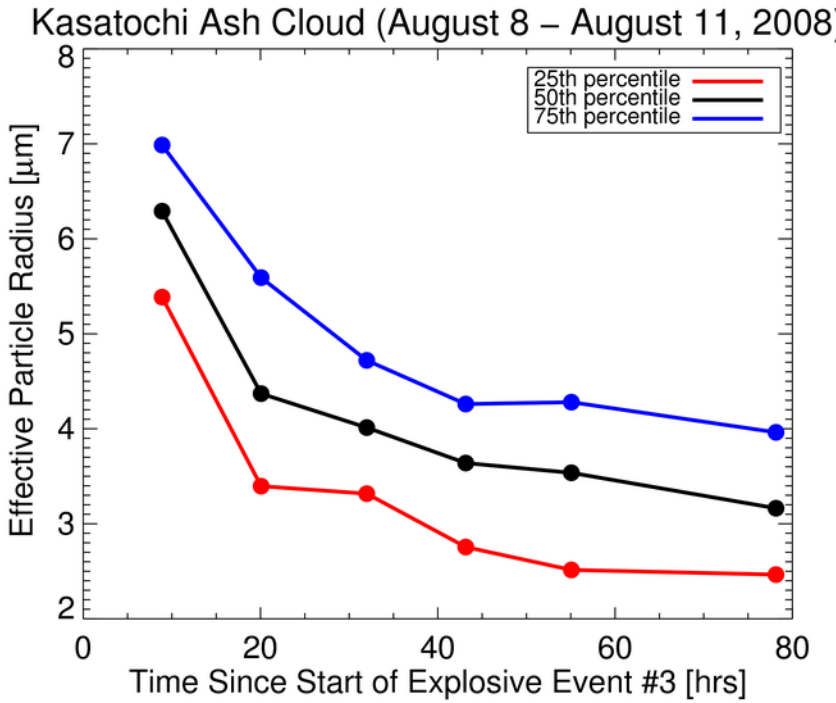


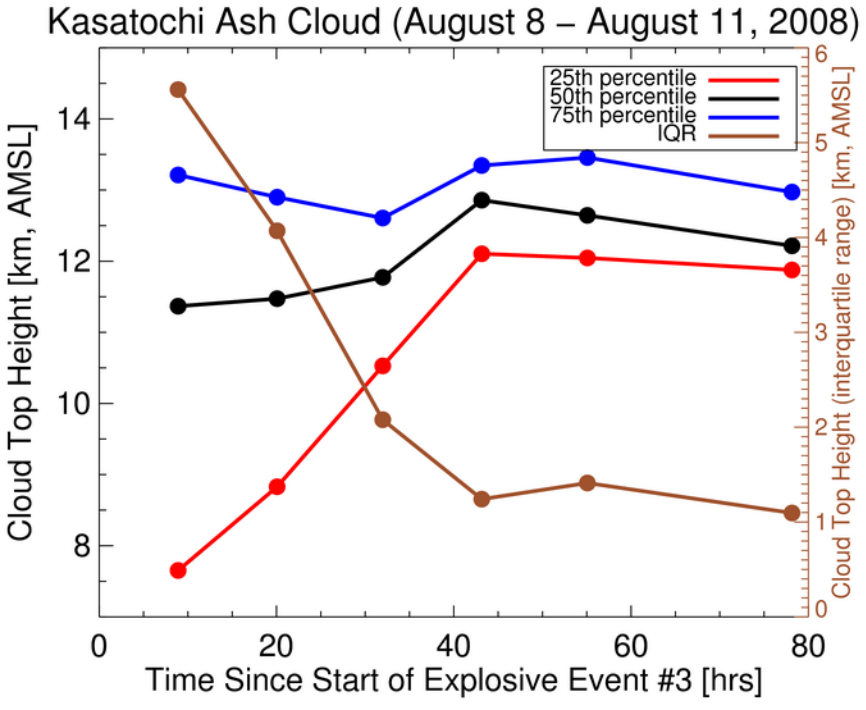
Total mass and area time series

The limited sensitivity to large optical depths in the IR likely causes the first total mass value to be underestimated





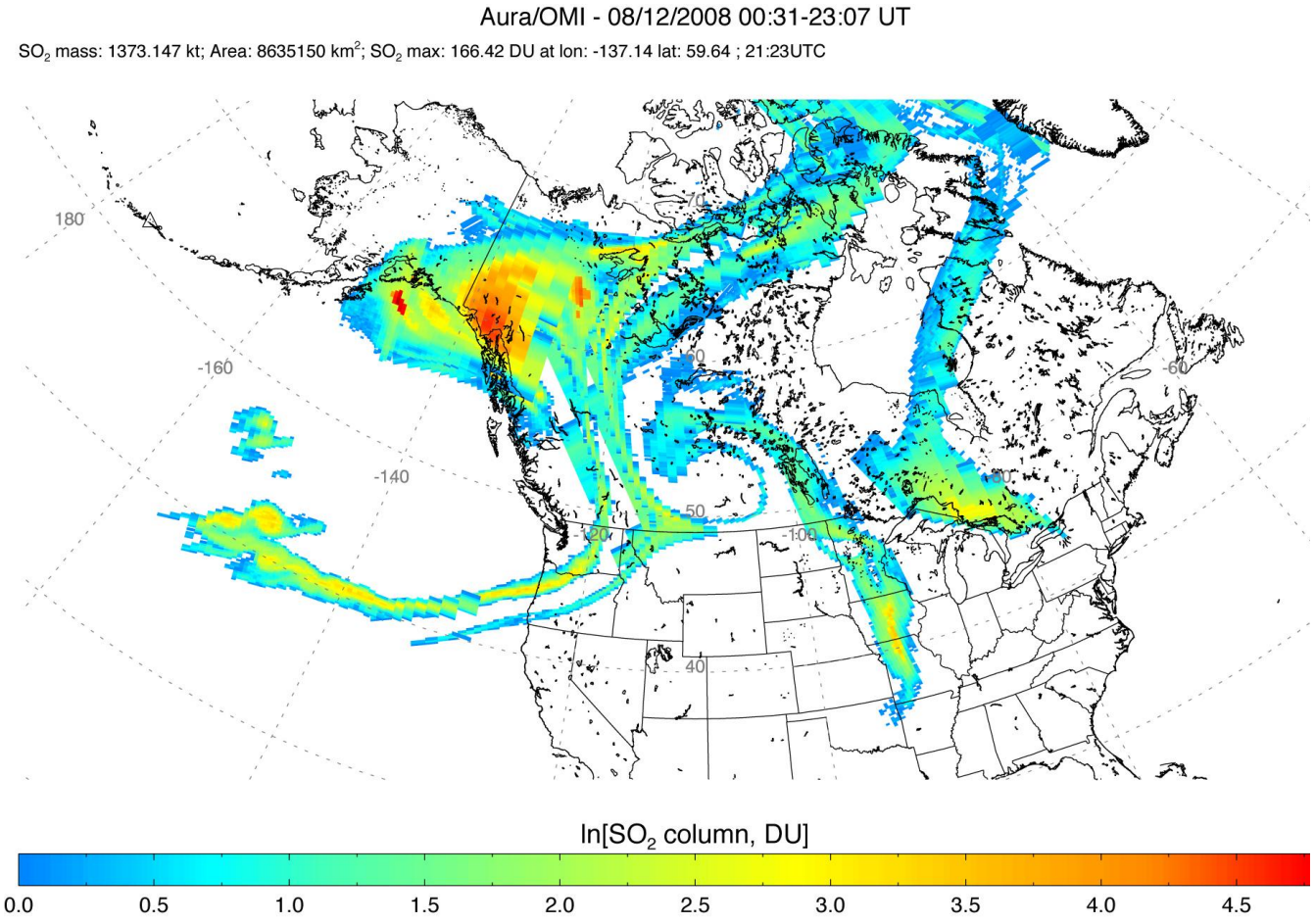


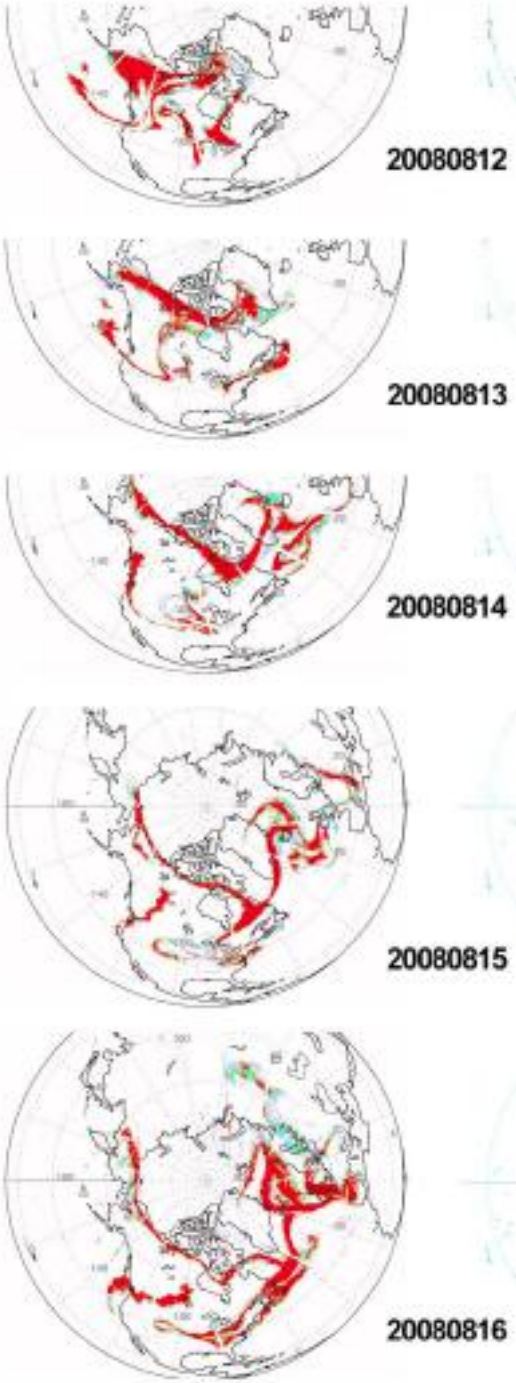


The temporal evolution of the 25th, 50th, and 75th percentiles of mass loading, effective radius, and ash cloud height also exhibit expected behavior

Mass loading (25th, 50th, and 75th percentiles), effective particle radius (25th, 50th, and 75th percentiles), and IQR of ash cloud height decreasing with time

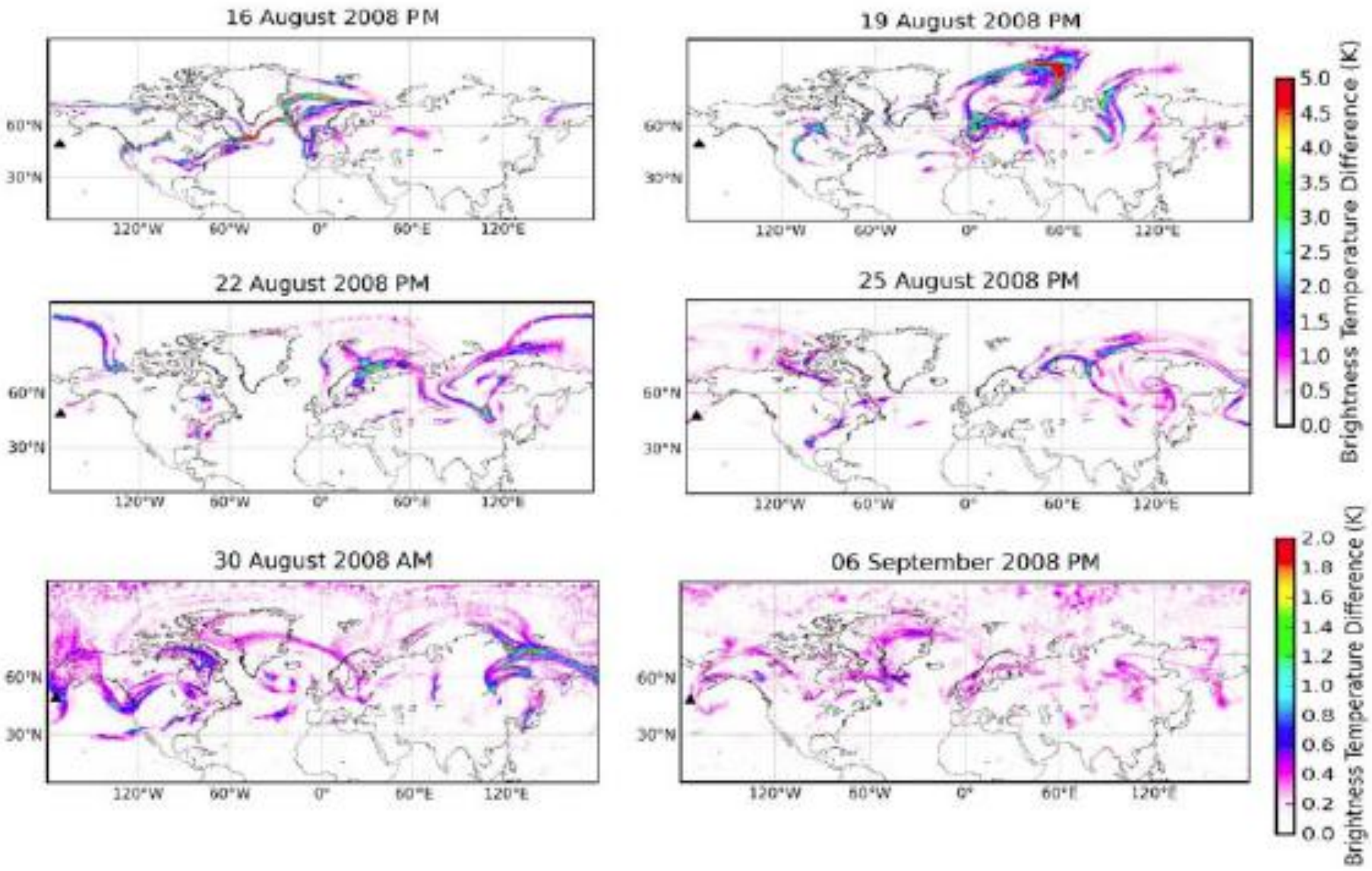
Primary particulate composition: Sulphate or ash?





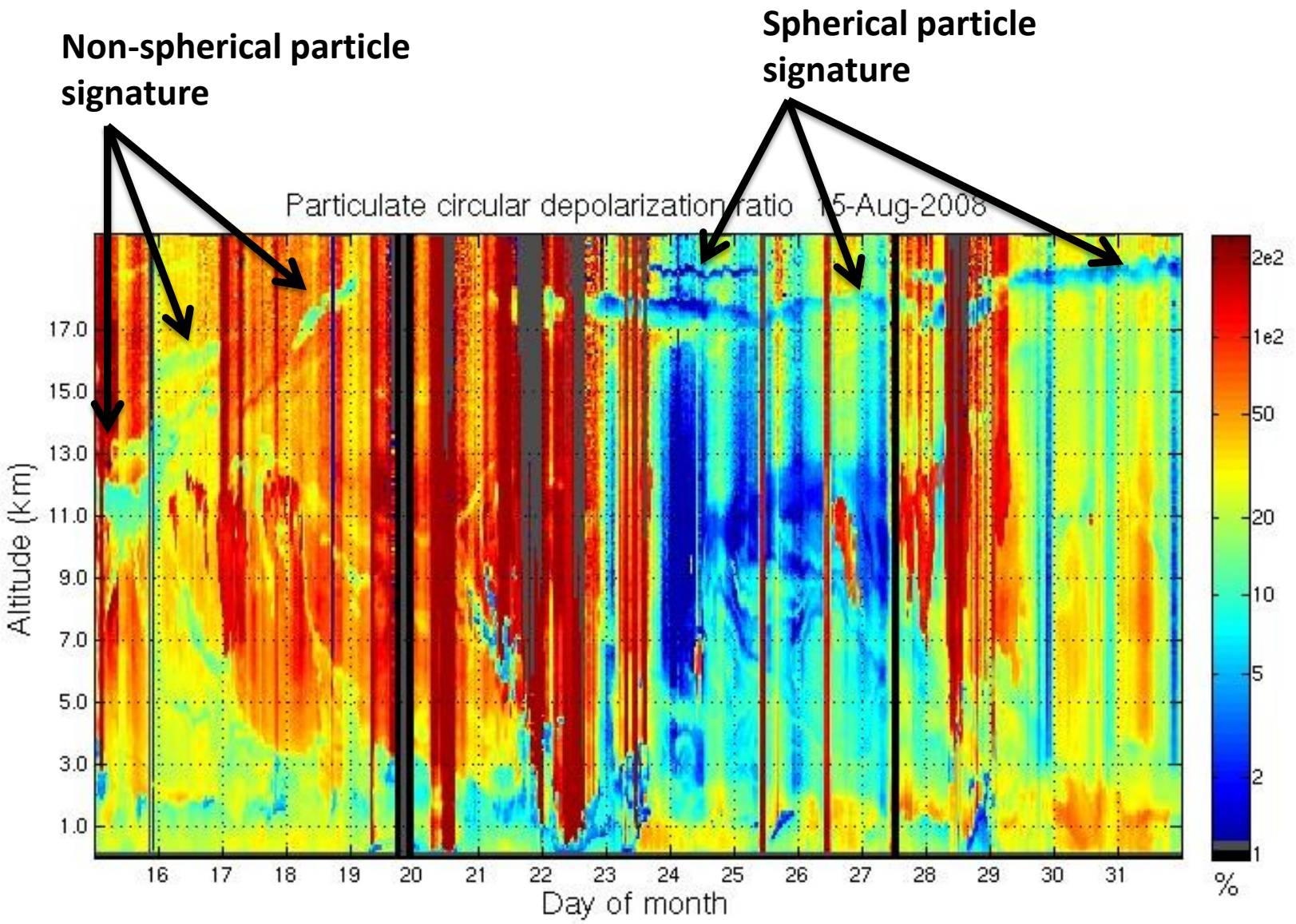
Krotkov et al., 2010

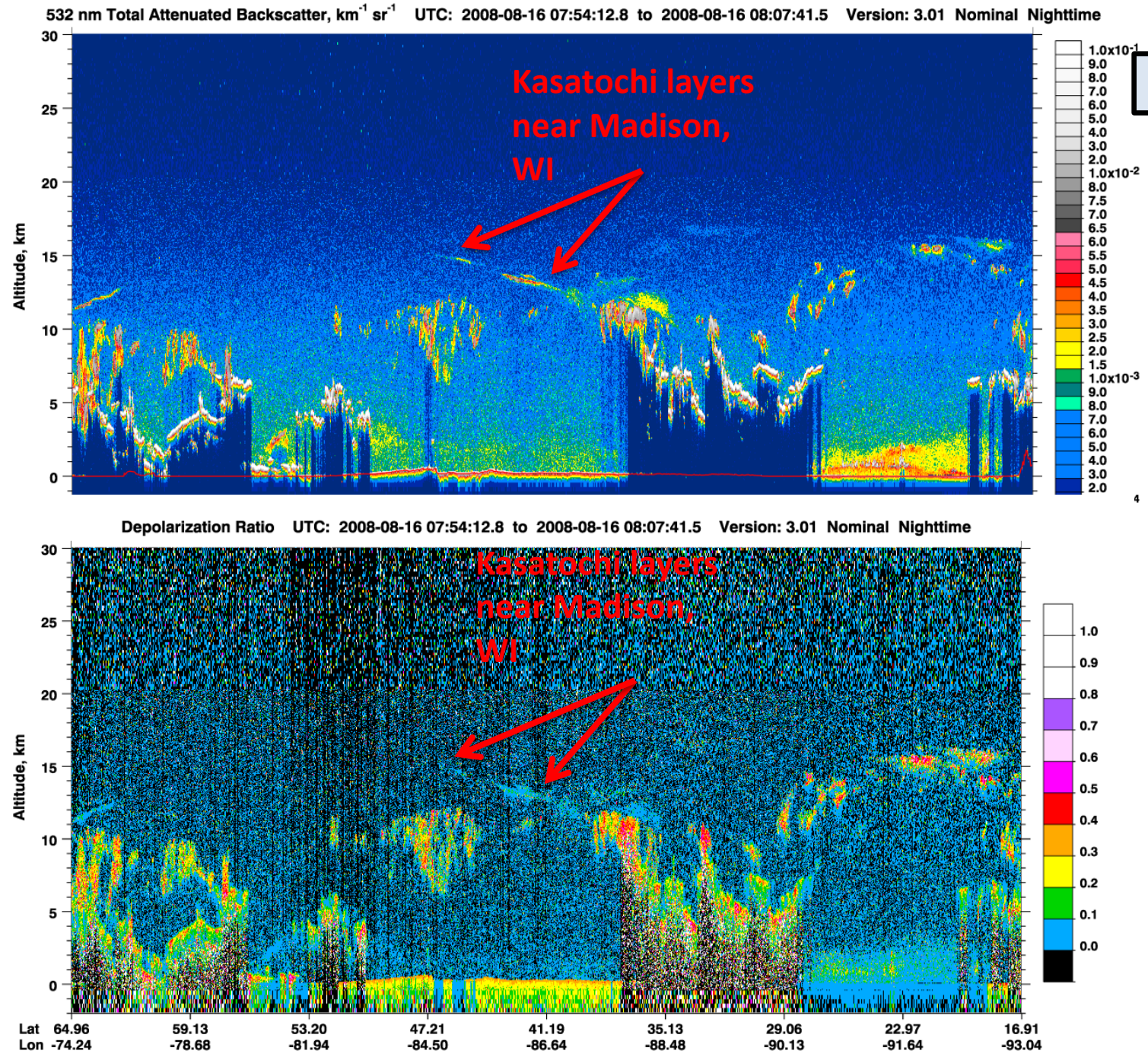
Primary particulate composition: Sulphate or ash?



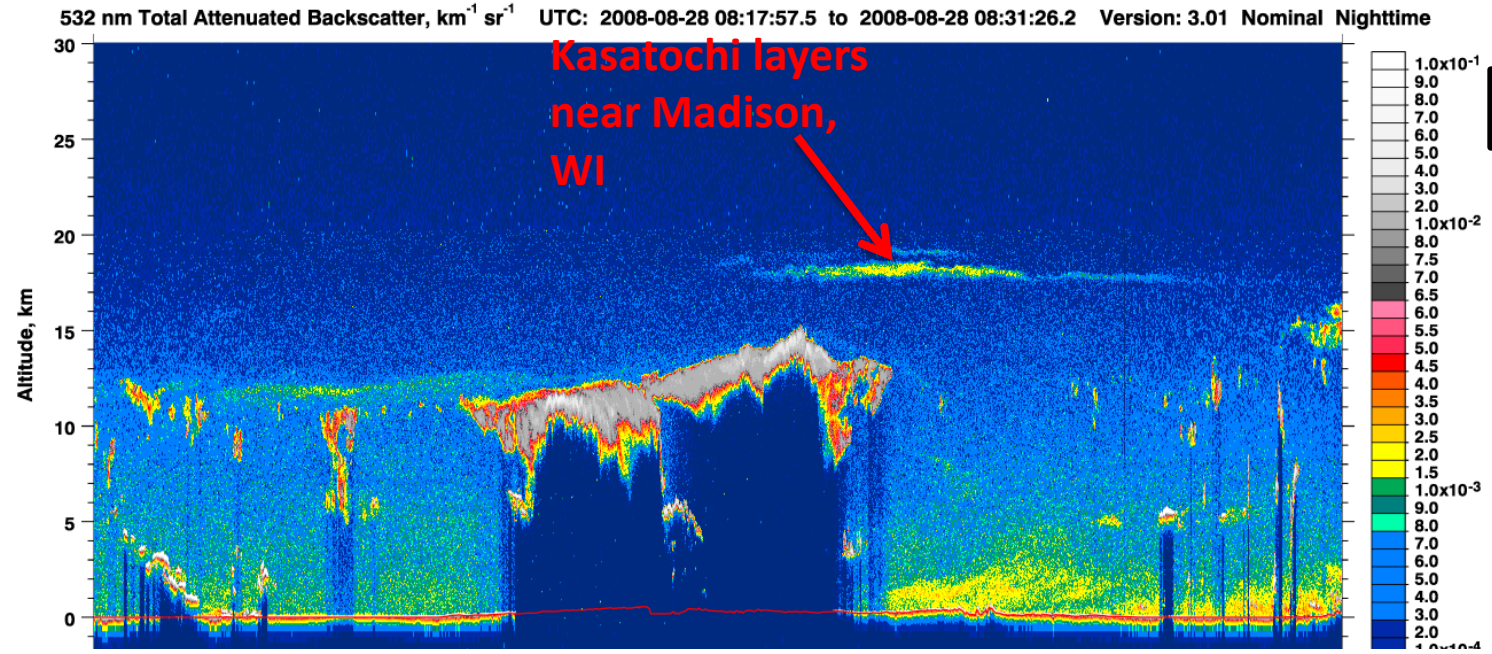
Karagulian et al., 2010

Primary particulate composition: Sulphate or ash?

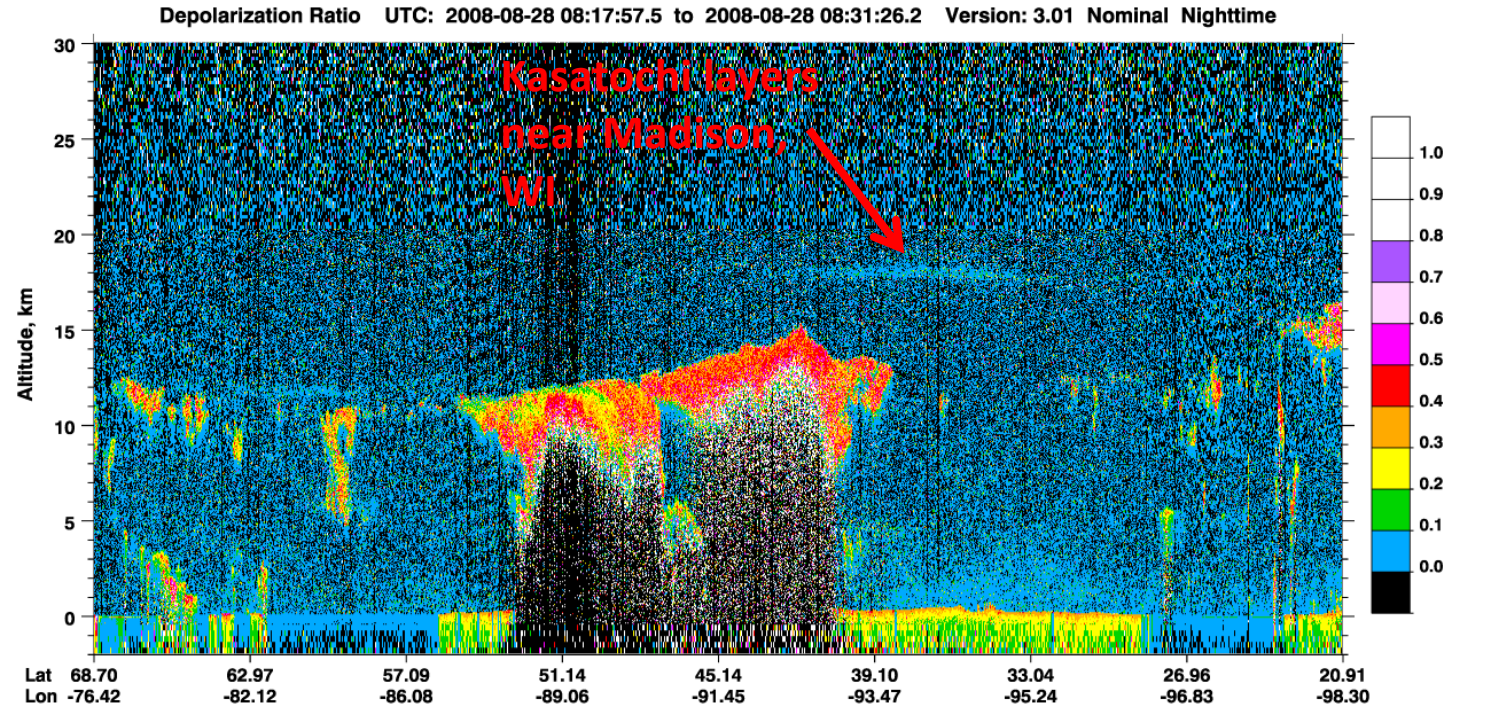




August 16, 2013



August 28, 2013



Kasatochi Conclusions

- **MODIS and GOES both showed spatially and temporally consistent volcanic ash signatures in the NIR and IR (channels without significant SO_2 absorption) well after August 10, 2008**
- **Particulate matter collected from a commercial jet aircraft flying in a region with significant amounts of SO_2 was consistent with Kasatochi ash (Guffanti et al., 2010), the NOAA algorithm detected ash in this same region**
- **Small ($r < 2$ μm) particles of ash would take about 2 to 9 weeks to fall (under gravity only) from 12 to 10 km (ICAO manual)**
- **Small amounts of ash were collected by research aircraft in Europe (Martinsson et al., 2009)**
- **The University of Wisconsin HSRL clearly showed a stratospheric cloud dominated by non-spherical particles prior to August 20, 2008**
- **The CALIOP depolarization ratios, especially for optically thin clouds, must be interpreted with care**
- **The NOAA data set indicates that the stratospheric ash cloud (composed mainly of small particles) may have dispersed over a very large area consistent with the location of the SO_2 cloud**
- **The location of the ash cloud relative to a mid-latitude cyclone played an important role in the dispersion (portions of the cloud may have been impacted by tropopause folds caused by jet stream dynamics)**