


Marco Fulle - www.stromboli.net

Development of a GOES-R Automated Volcanic Cloud Alert System

Mike Pavolonis

(NOAA/NESDIS)

Justin Sieglaff (UW-CIMSS)

Ron Thomas (New Mexico Tech)

Project Goal

Marco Fulle - www.stromboli.net

- ***Using the full capabilities of the GOES-R system (and other relevant data), develop a unique (and globally applicable) automated alert system that can detect nearly all types of volcanic clouds***

- ***Expected Operational Impacts:***
  - **Increase the timeliness and quality of volcanic ash advisories issued by VAAC's and SIGMET's issued by MWO's**
  - **Improve dispersion model forecasts by providing fully automated and high quality satellite products to initialize, constrain, and validate models (model output, however, is not very useful unless you first know an eruption is happening!)**

Project Goal

Marco Fulle - www.stromboli.net

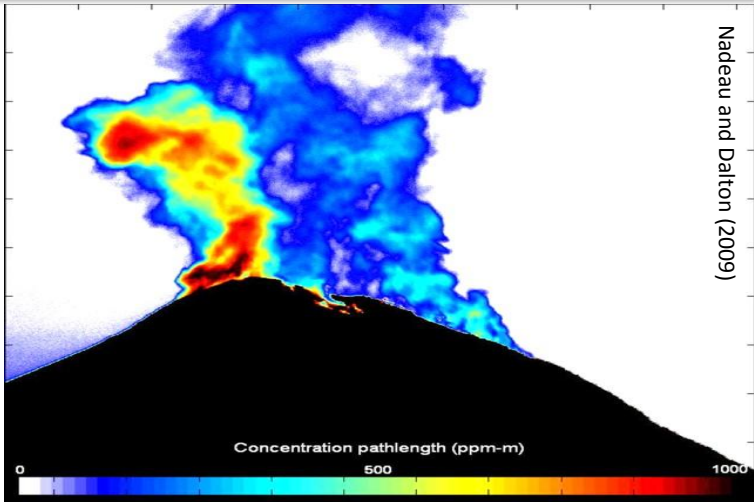
We are NOT developing a GOES-R only system. The algorithm science and software can be applied to a large variety of LEO and GEO instruments (and even ground instruments when relevant) laying the ground work for a fully integrated global volcanic cloud alerting and monitoring system that can be used to automatically kick off model simulations.

- **Increase the timeliness and quality of volcanic ash advisories issued by VAAC's and SIGMET's issued by MWO's**
- **Improve dispersion model forecasts by providing fully automated and high quality satellite products to initialize, constrain, and validate models (model output, however, is not very useful unless you first know an eruption is happening!)**

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.

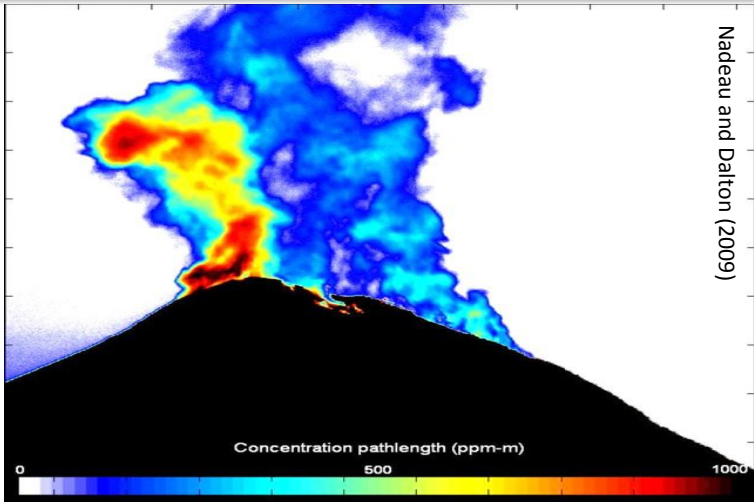
3). SO_2 clouds – Sulfur dioxide clouds (SO_2 gas is invisible to the eye) that may or may not contain volcanic ash. Some eruptions produce large amounts of SO_2 and very little ash and vice-versa.

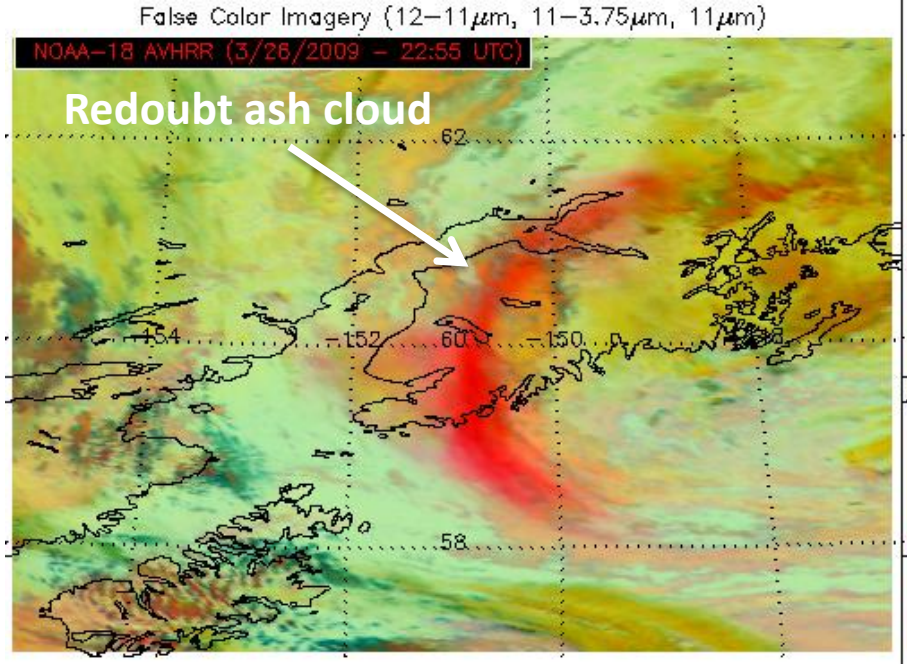


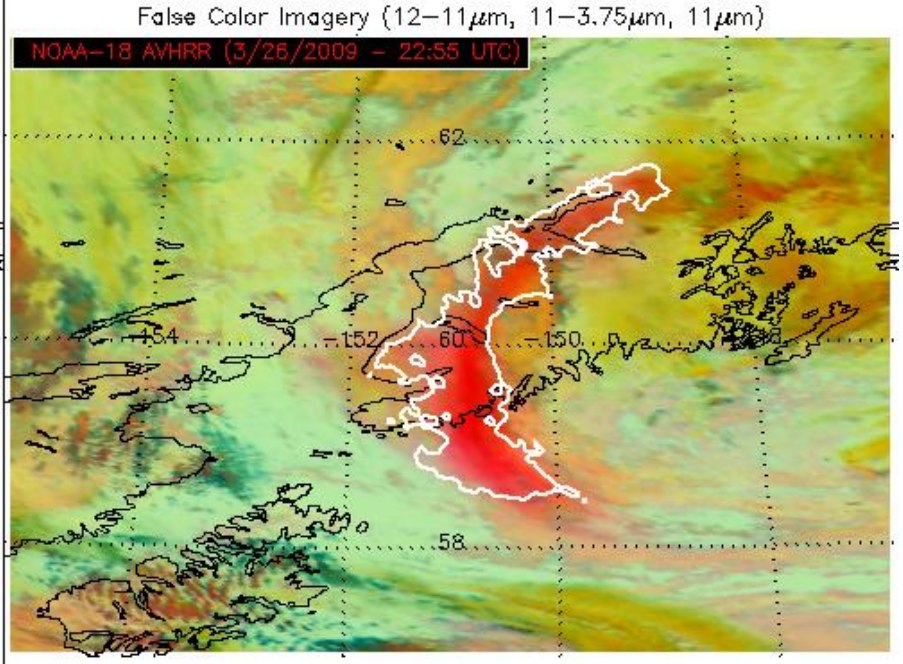
1). Ash dominated volcanic plumes – Semi-transparent clouds dominated by volcanic ash. Lightning is usually not present in these clouds.

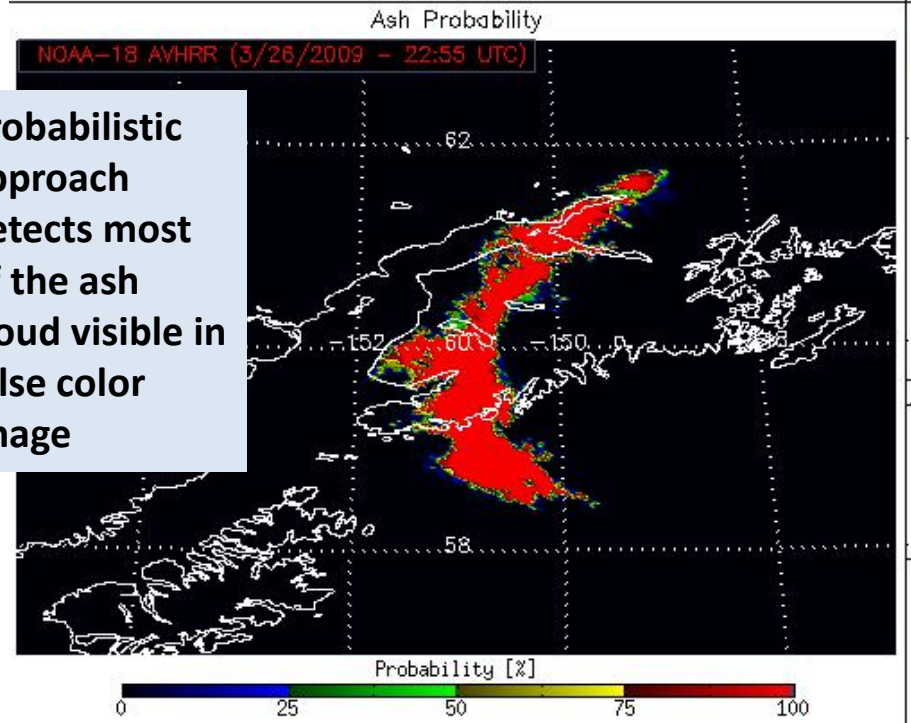
2). Ice topped umbrella clouds – These cloud are mostly observed during a major eruption. A spectral based volcanic ash signal is usually initially absent because the ash is encased in ice and/or the cloud is opaque. Lightning is often present in these clouds.

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.

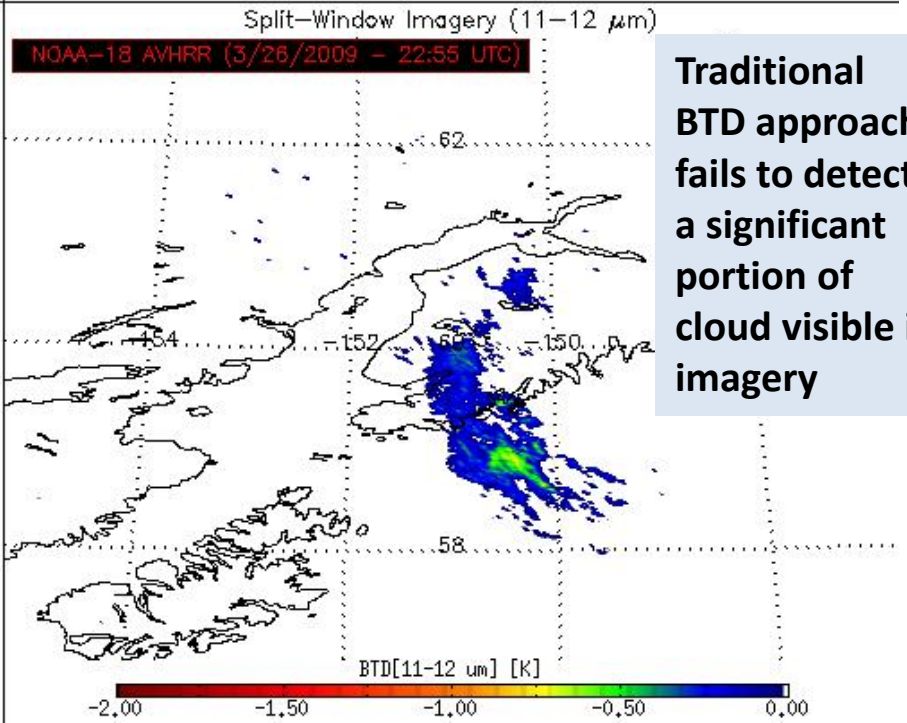






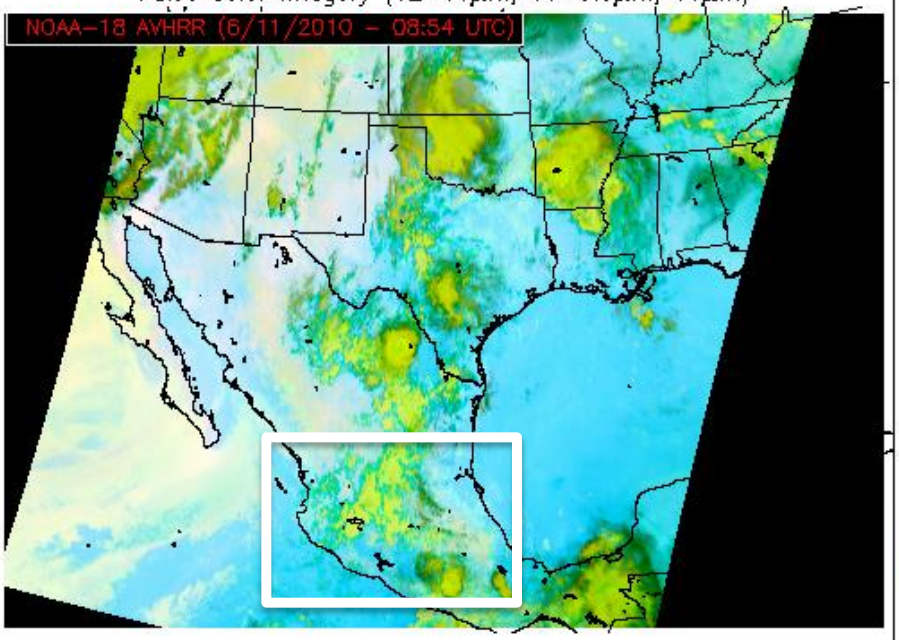


Probabilistic approach detects most of the ash cloud visible in false color image

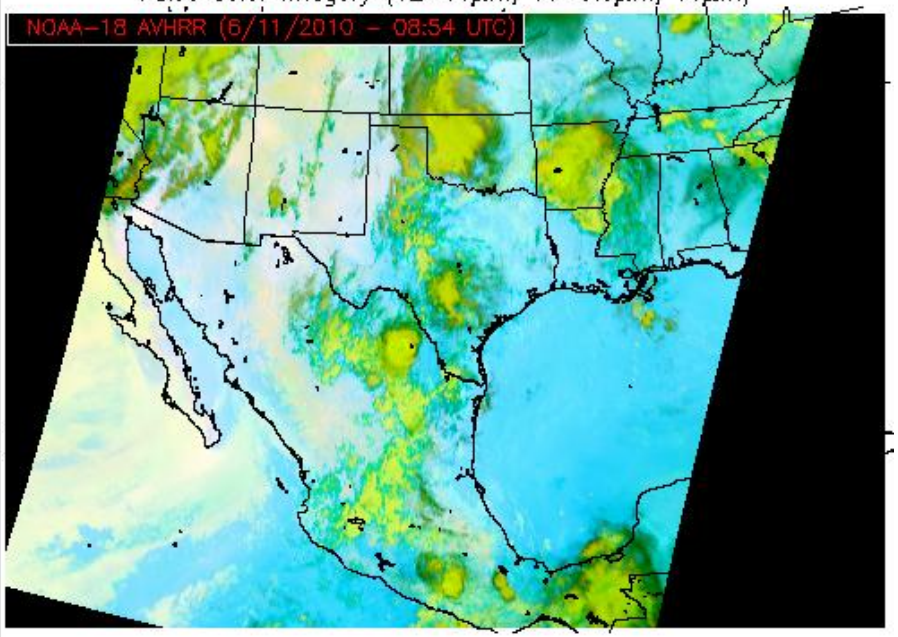


Traditional BTD approach fails to detect a significant portion of cloud visible in imagery

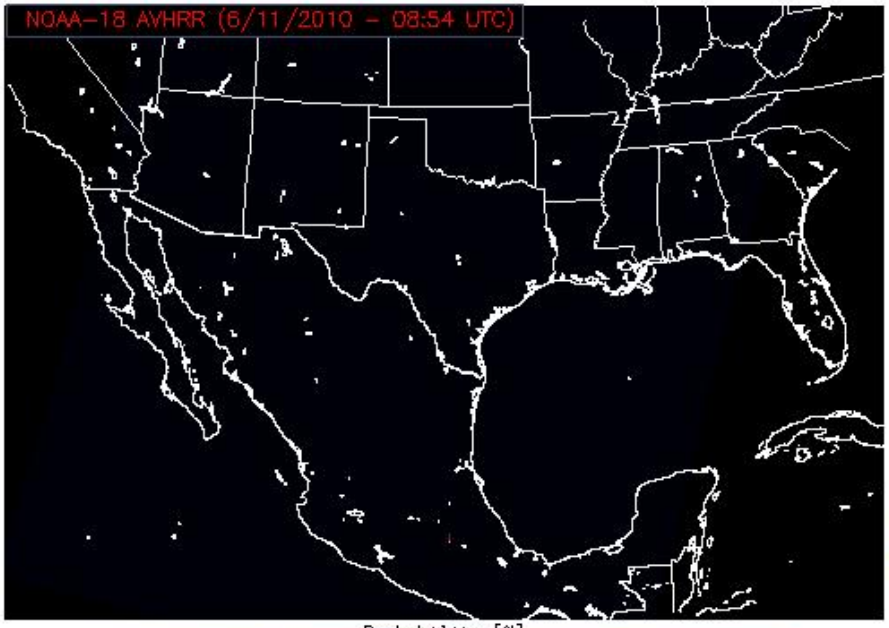
False Color Imagery (12−11μm, 11−3.9μm, 11μm)



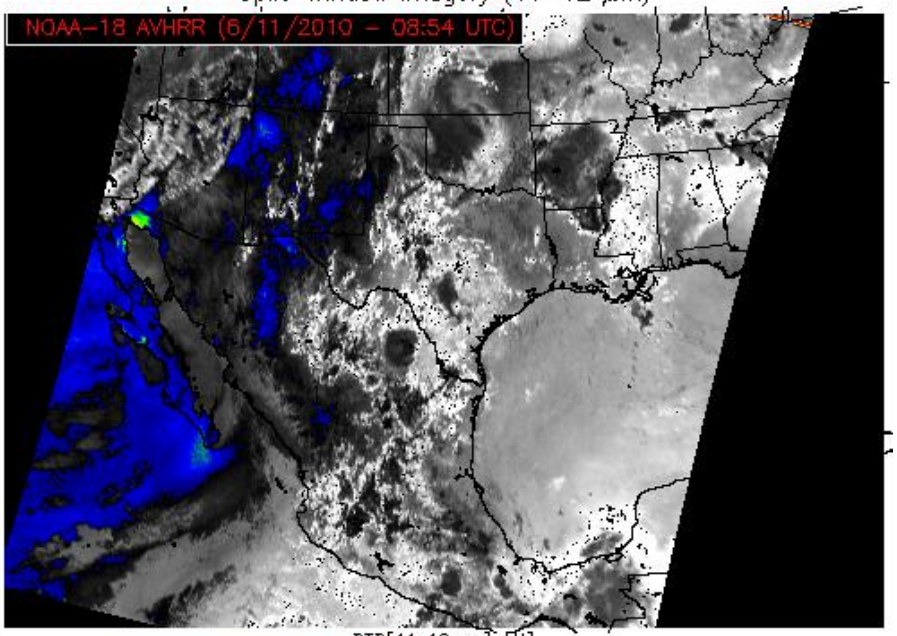
False Color Imagery (12−11μm, 11−3.9μm, 11μm)

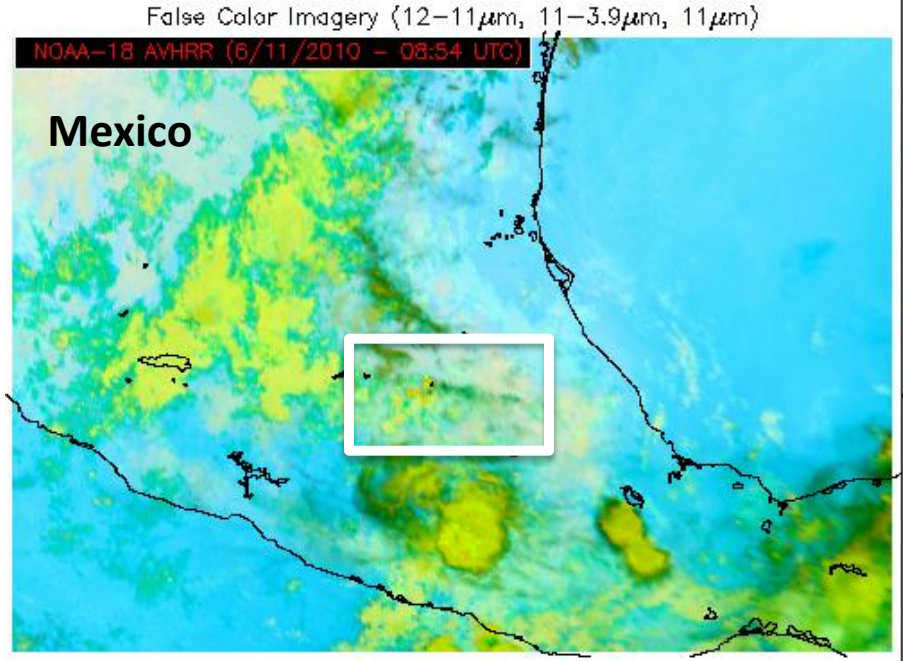


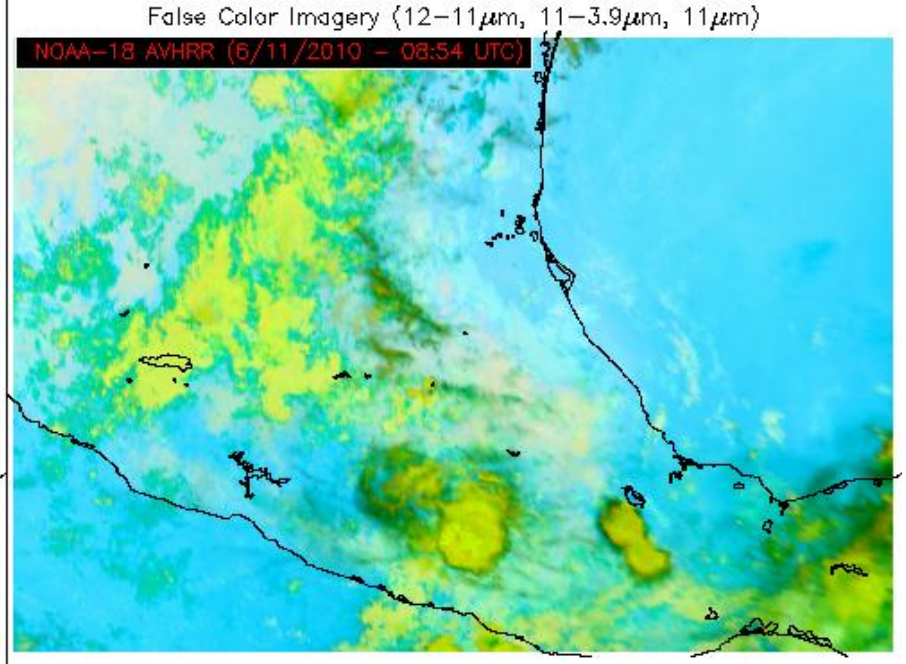
Ash Probability

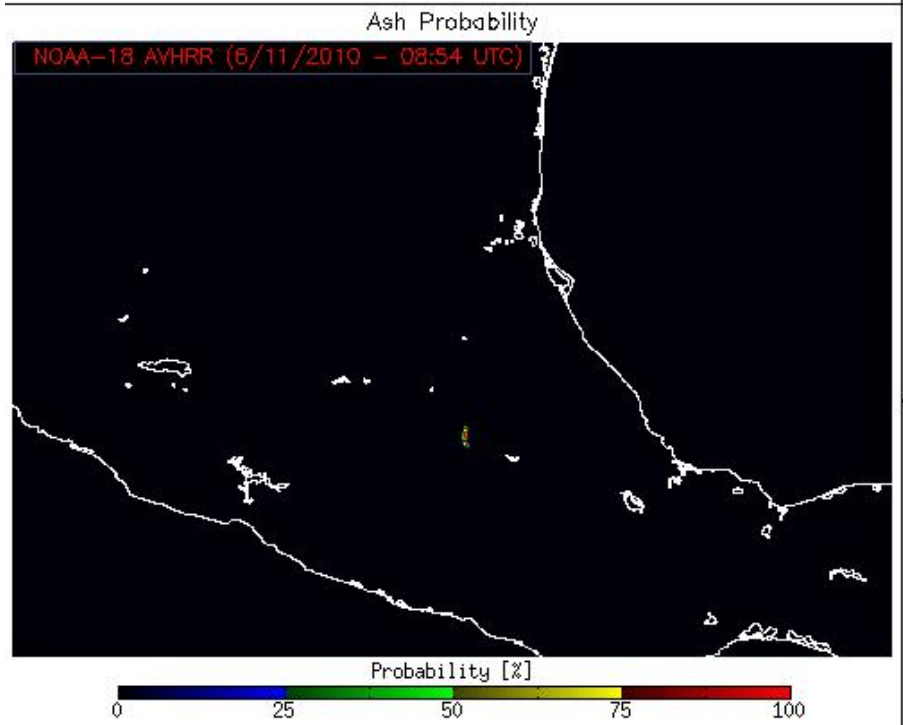


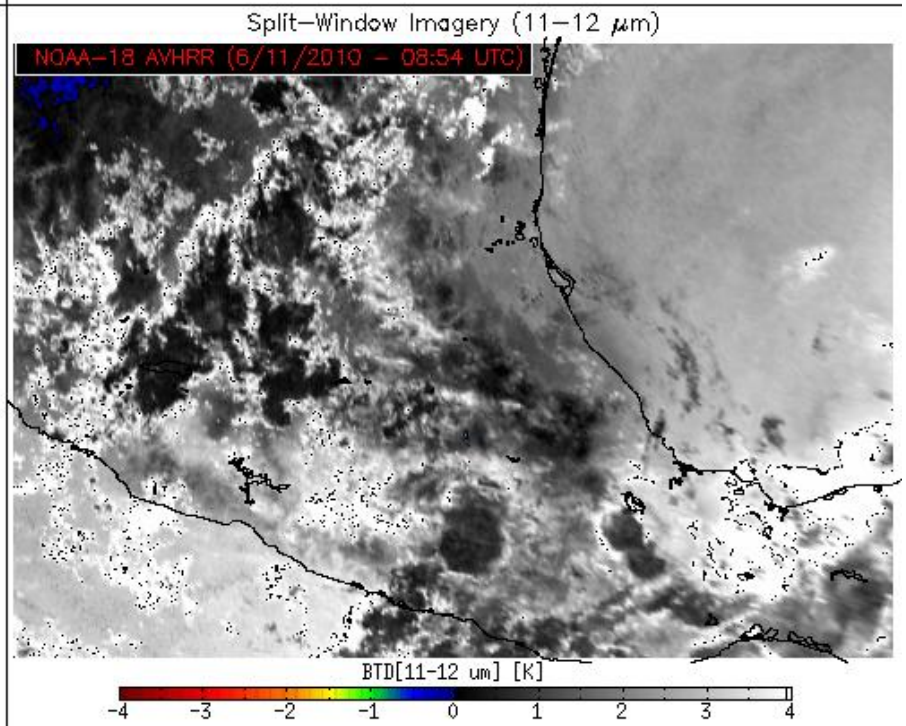
Split−Window Imagery (11−12 μm)

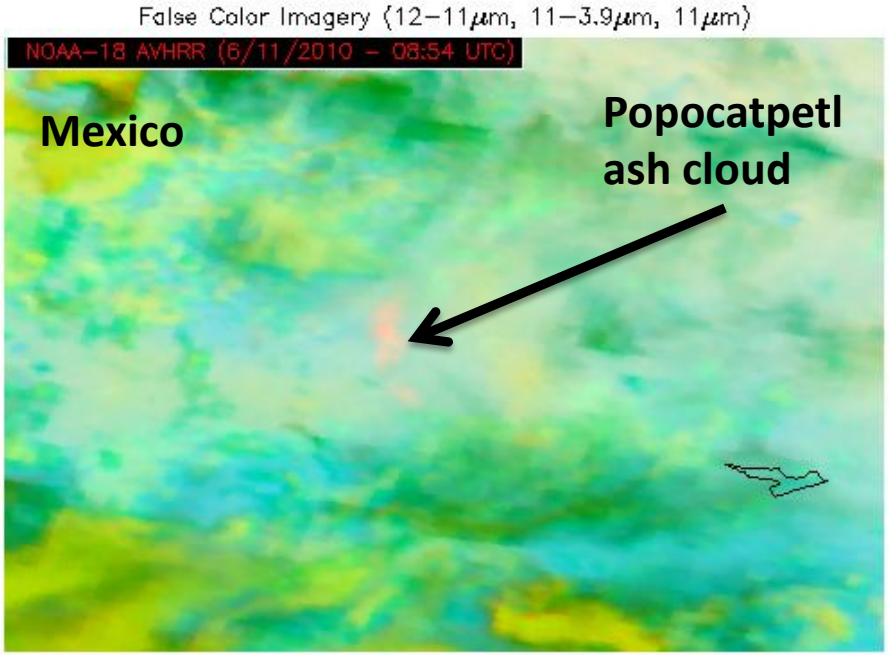


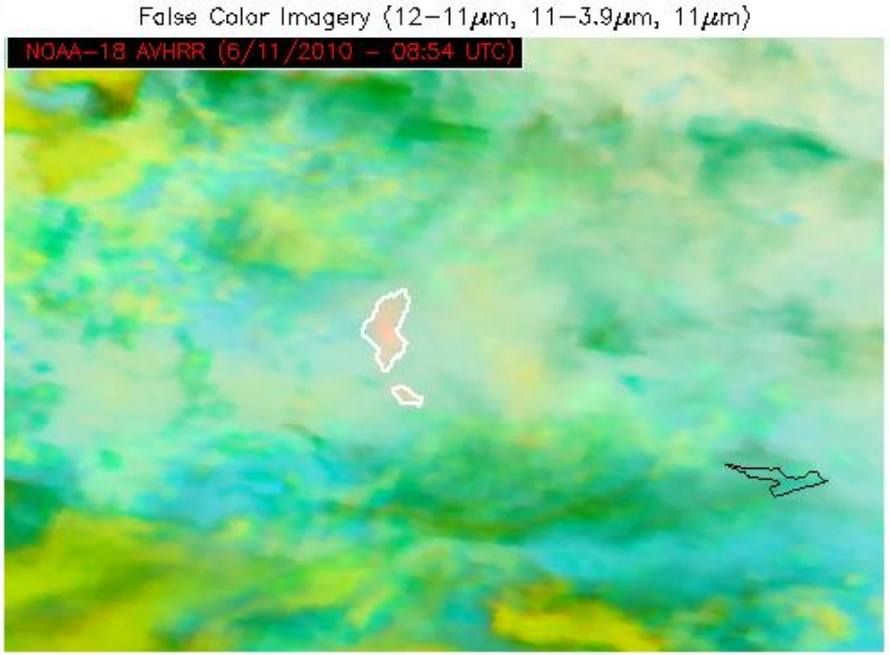

False Color Imagery (12−11μm, 11−3.9μm, 11μm)
NOAA-18 AVHRR (6/11/2010 - 08:54 UTC)
Mexico

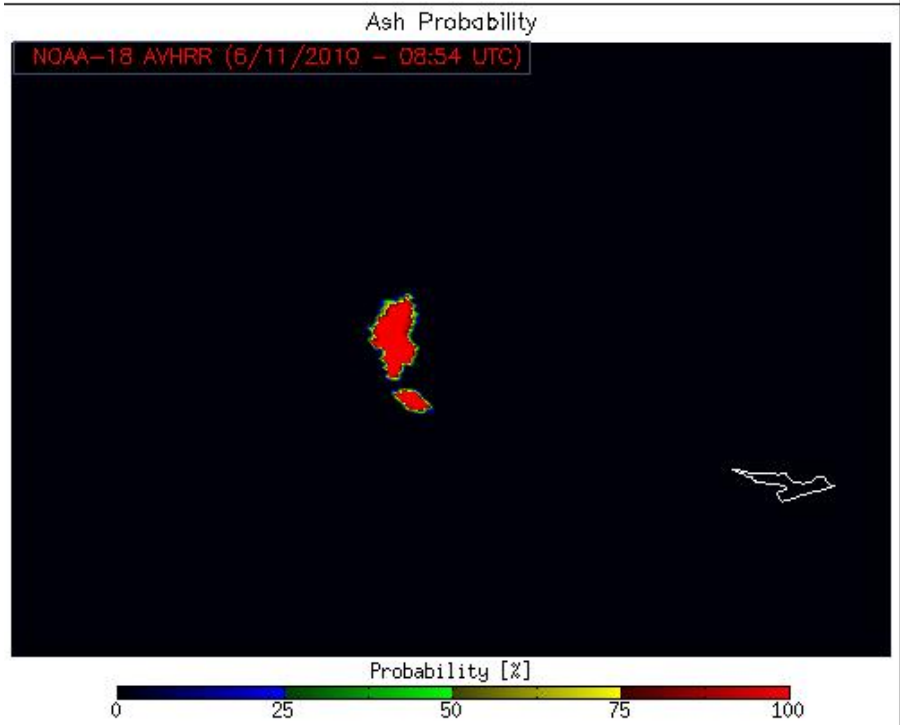

False Color Imagery (12−11μm, 11−3.9μm, 11μm)
NOAA-18 AVHRR (6/11/2010 - 08:54 UTC)

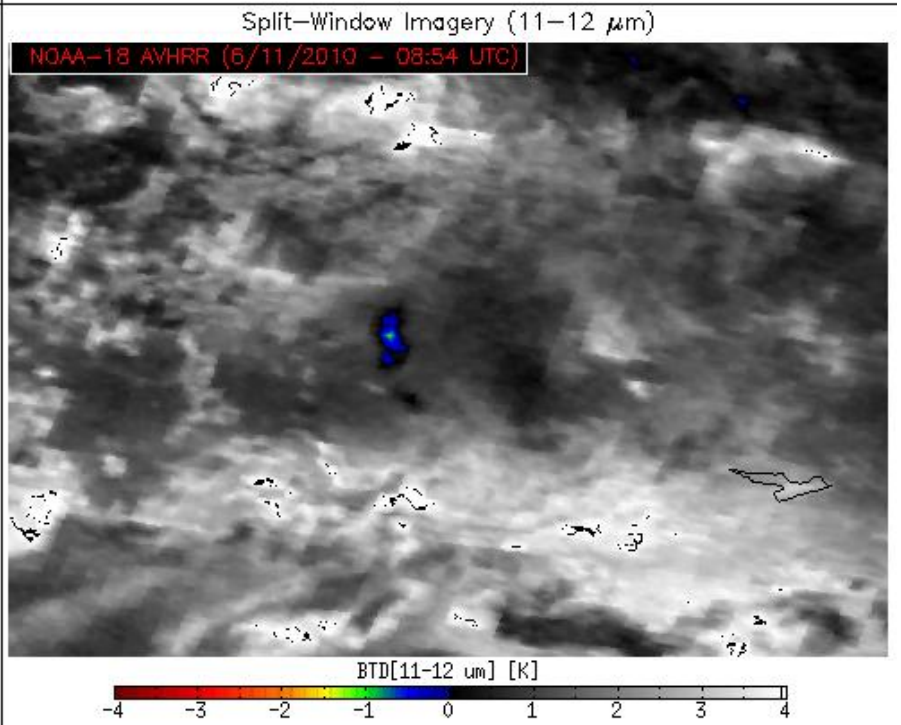

Ash Probability
NOAA-18 AVHRR (6/11/2010 - 08:54 UTC)
Probability [%]
0
25
50
75
100


Split−Window Imagery (11−12 μm)
NOAA-18 AVHRR (6/11/2010 - 08:54 UTC)
BTD[11-12 um] [K]
-4
-3
-2
-1
0
1
2
3
4


False Color Imagery (12−11μm, 11−3.9μm, 11μm)
NOAA-18 AVHRR (6/11/2010 - 08:54 UTC)
Mexico
Popocatpetl
ash cloud


False Color Imagery (12−11μm, 11−3.9μm, 11μm)
NOAA-18 AVHRR (6/11/2010 - 08:54 UTC)


Ash Probability
NOAA-18 AVHRR (6/11/2010 - 08:54 UTC)
Probability [%]
0
25
50
75
100


Split−Window Imagery (11−12 μm)
NOAA-18 AVHRR (6/11/2010 - 08:54 UTC)
BTD[11-12 um] [K]
-4
-3
-2
-1
0
1
2
3
4

@**********GENERATING VOLCANIC CLOUD ALERTS**********
DATE: 06/11/2010
TIME: 08:54 UTC
PRIMARY INSTRUMENT: AVHRR/3
LOCATION/ORBIT: LEO
L1 FILE: NSS.HRPT.NN.D10162.S0854.E0904.B2606161.MI
NUMBER OF ASH CLOUD ALERTS: 1
NUMBER OF VOLCANIC Cb ALERTS: 0
NUMBER OF VOLCANIC THERMAL ANOMALY ALERTS: 0
NUMBER OF SO2 CLOUD ALERTS: 0

VOLCANIC ASH CLOUD FOUND
Radiative Center (Lat, Lon): 19.225, -98.871
Mean Viewing Angle (degrees): 32.67
Mean Solar Zenith Angle (degrees): 124.39
Nearby Volcanoes (meeting alert criteria):
Papayo(20.19 km)
Iztacchuatl(24.62 km)
Chichinautzin(31.68 km)
Popocatpetl(34.54 km)
Overall Ash Cloud Object Probability: 0.00035%
Mean Ash Probability of Object Pixels: 84.37414%
Area of Robust Ash Pixels: 13.51 km^2
Maximum Height [AMSL]: 6.1 km (19875.33 ft)
1-sigma Uncertainty of Maximum Height [AMSL]: 1.6 km (5268.06 ft)
Mean Tropopause Height [AMSL]: 16.5 km (54162.19 ft)
Total Mass: 0.26 ktons
Median effective particle radius: 3.55 um
Total Area: 142.46 km^2

```
@**********GENERATING VOLCANIC CLOUD ALERTS**********
DATE: 06/11/2010
TIME: 08:54 UTC
PRIMARY INSTRUMENT: AVHRR/3
LOCATION/ORBIT: LEO
L1 FILE: NSS.HRPT.NN.D10162.S0854.E0904.B2606161.MI
NUMBER OF ASH CLOUD ALERTS: 1
NUMBER OF VOLCANIC Cb ALERTS: 0
NUMBER OF VOLCANIC THERMAL ANOMALY ALERTS: 0
NUMBER OF SO2 CLOUD ALERTS: 0


-----------------------------------------
VOLCANIC ASH CLOUD FOUND
Radiative Center (Lat, Lon): 19.225, -98.871
Mean Viewing Angle (degrees): 32.67
Mean Solar Zenith Angle (degrees): 124.39
Nearby Volcanoes (meeting alert criteria):
                    Papayo(20.19 km)
               Iztacchuatl(24.62 km)
            Chichinautzin(31.68 km)
               Popocatpetl(34.54 km)
Overall Ash Cloud Object Probability: 0.00035%
Mean Ash Probability of Object Pixels: 84.37414%
Area of Robust Ash Pixels: 13.51 km^2
Maximum Height [AMSL]: 6.1 km (19875.33 ft)
1-sigma Uncertainty of Maximum Height [AMSL]: 1.6 km (5268.06 ft)
Mean Tropopause Height [AMSL]: 16.5 km (54162.19 ft)
Total Mass: 0.26 ktons
Median effective particle radius: 3.55 um
Total Area: 142.46 km^2
-----------------------------------------
```

Alerts are fully user configurable based on volcano and probability information

Important information from GOES-R volcanic ash retrieval

Automated Alert Generated for Eruption of Cleveland on December 28, 2011

Text Alert

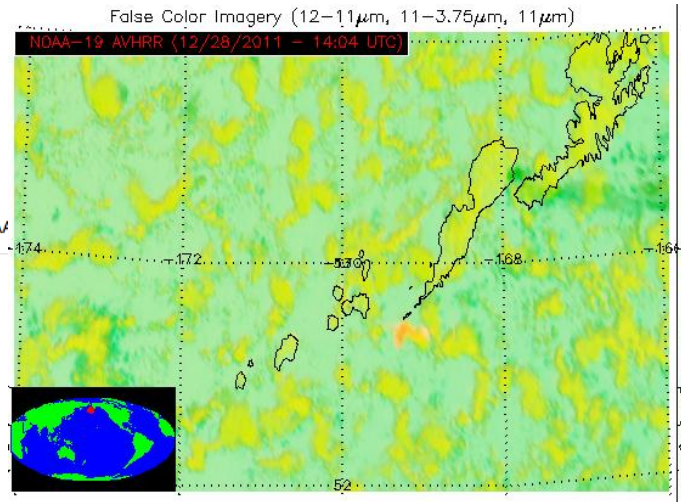
From: Mike Pavolonis <mpav@ssec.wisc.edu>
Subject: **VOLCANIC CLOUD ALERT**
Date: December 29, 2011 8:34:03 AM CST
To: Mike Pavolonis <mpav@ssec.wisc.edu>, Justin Sieglaff, NOAA

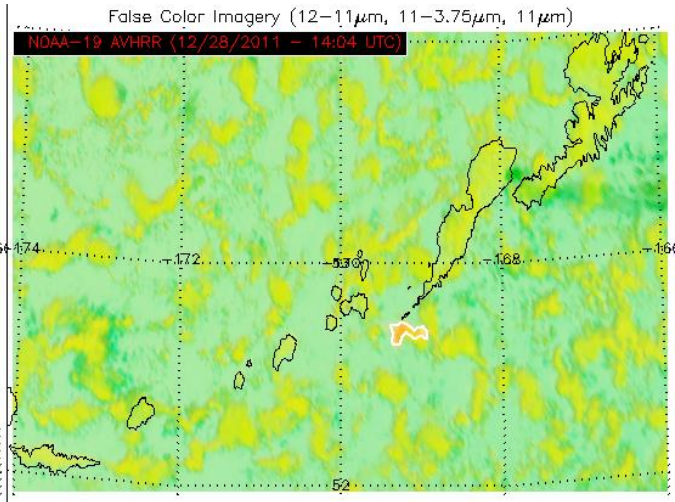
@**********GENERATING VOLCANIC CLOUD WARNINGS**********
DATE: 12/29/2011
TIME: 14:04 UTC
SATELLITE: NOAA-19 AVHRR
L1B FILENAME: NSS.HRPT.NP.D11363.S1404.E1418.B1489494.GC
ORBIT NUMBER: 1489494
NUMBER OF ASH CLOUD WARNINGS: 1
NUMBER OF VOLCANIC Cb WARNINGS: 0
NUMBER OF VOLCANIC HOT SPOT WARNINGS: 0

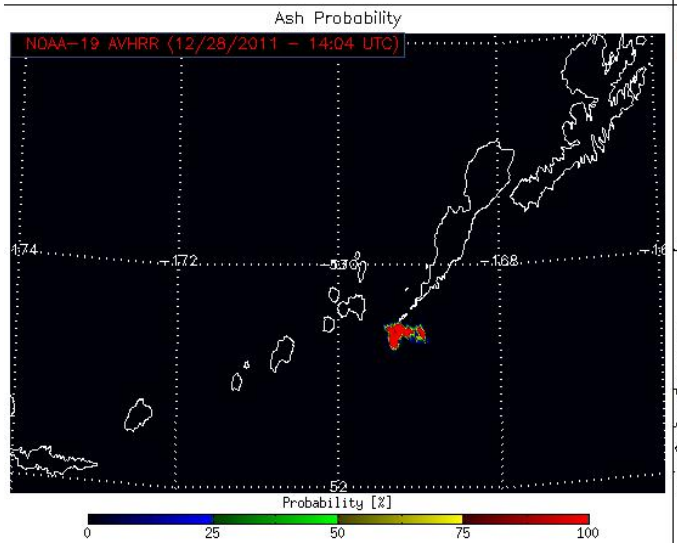
****

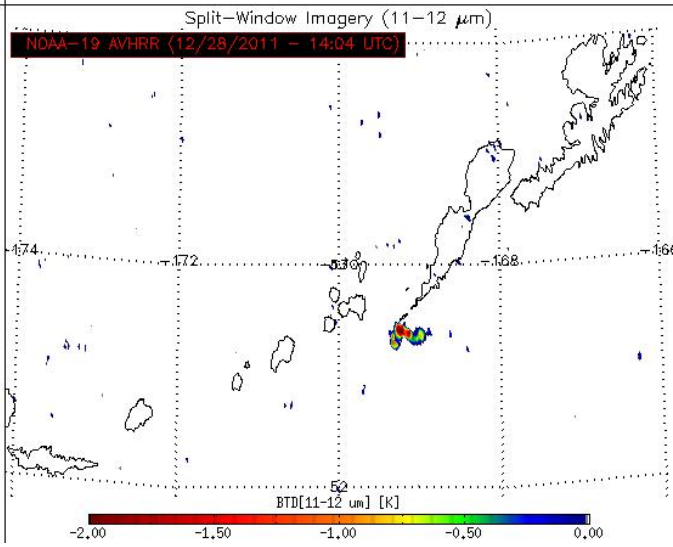
VOLCANIC ASH CLOUD FOUND
Radiative Center (Lat, Lon): 52.681, -169.109
Mean Viewing Angle (degrees): 41.83
Mean Solar Zenith Angle (degrees): 135.49
Nearby Volcanoes:
Tana(47.54 km)
Kagamil(52.48 km)
Vsevidof(57.21 km)
Cleveland(58.51 km)
Uliaga(61.66 km)
False Alarm Potential: 0 out of 276994
Maximum Height: 3.5 km (11567.35 ft)
Mean Tropopause Height: 8.5 km (27831.94 ft)
Median Effective Radius: 5.06 micron
Total Mass: 0.84 ktons
Total Mass of Fine Ash: 0.00 ktons
Total Area: 173.00 km^2
****

Ash Probability Images

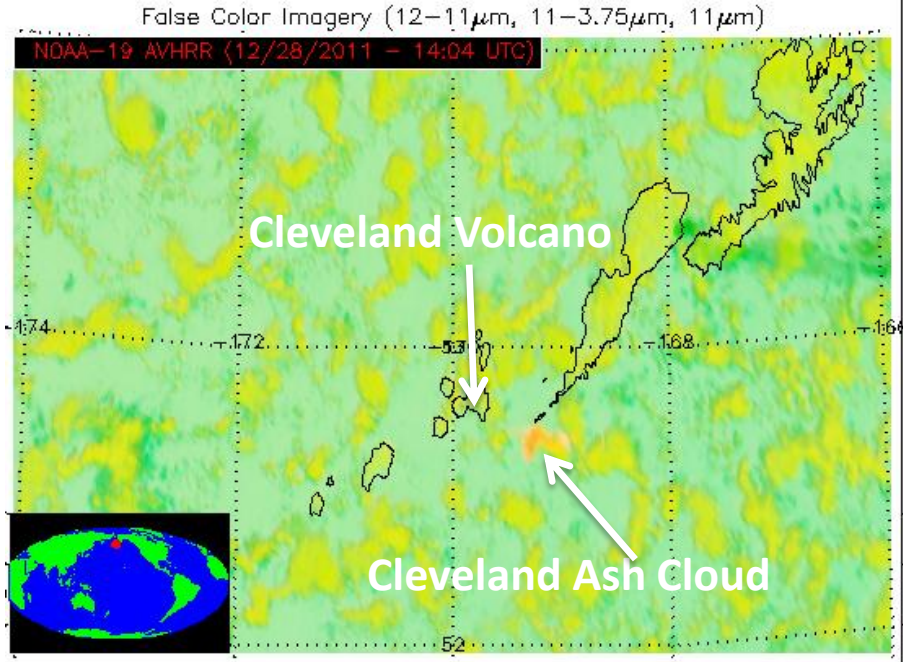


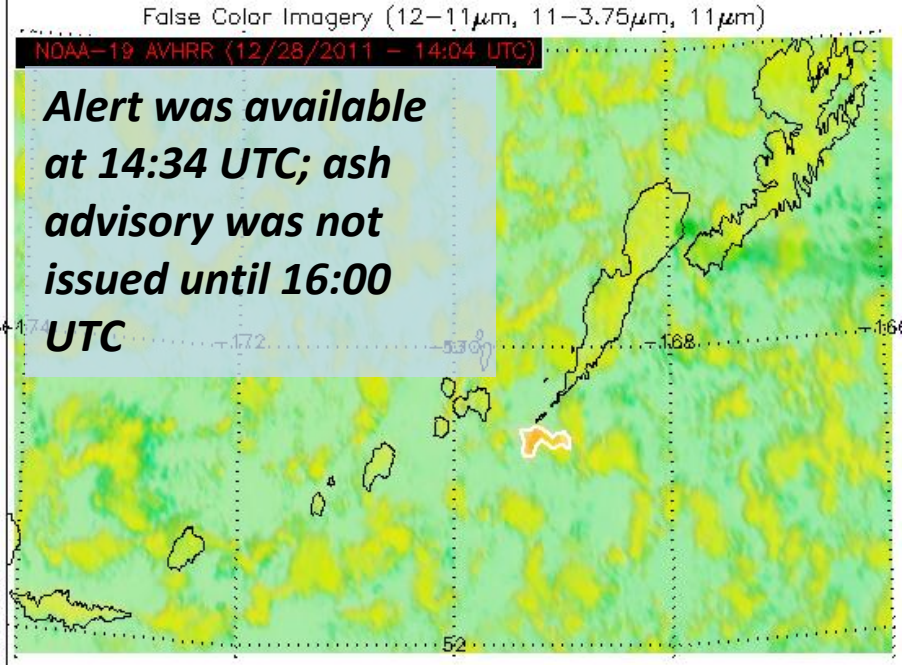


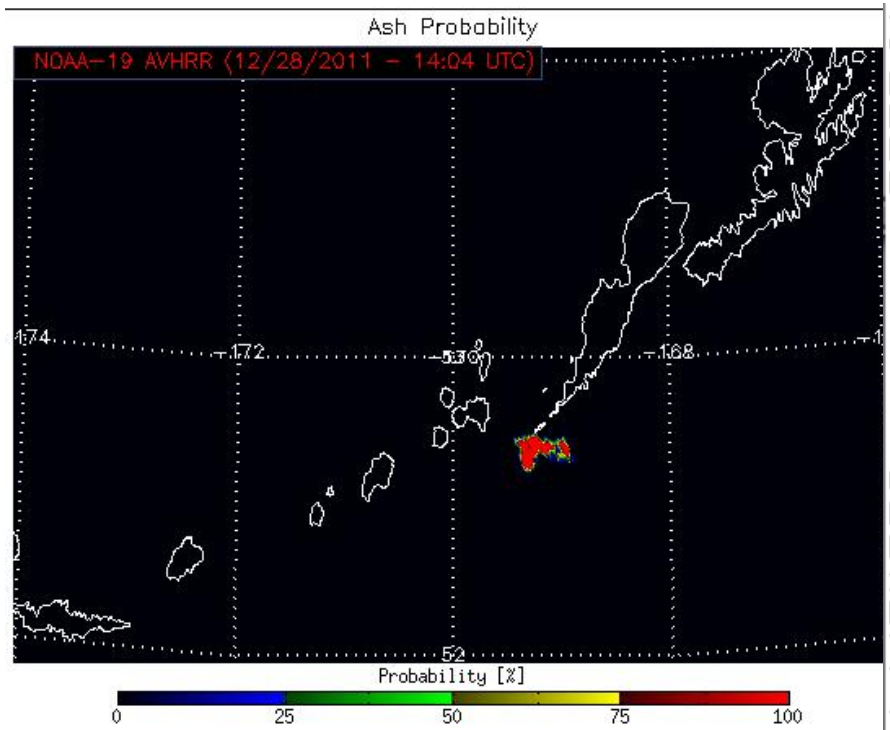




These alerts are currently being distributed to the USGS in Alaska and will soon be distributed to the Anchorage VAAC, Washington VAAC, and Air Force Weather Agency







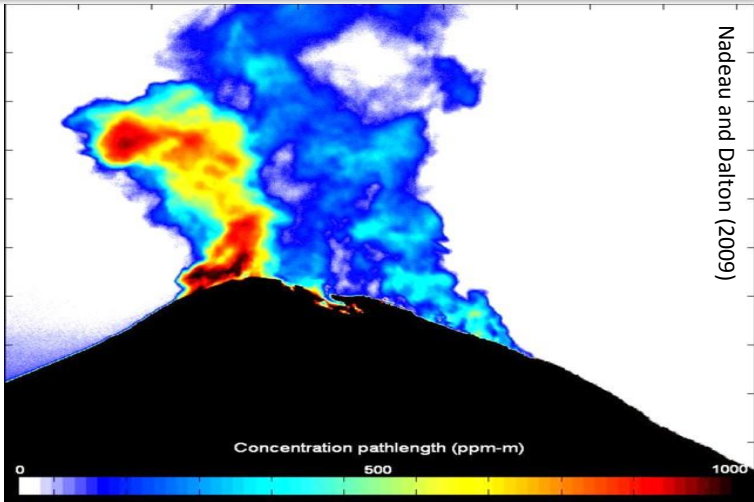

```
-------------------------------------------
VOLCANIC ASH CLOUD FOUND
Radiative Center (Lat, Lon): 52.681, -169.109
Mean Viewing Angle (degrees): 41.75
Mean Solar Zenith Angle (degrees): 135.50
Nearby Volcanoes (meeting alert criteria):
                Tana(47.51 km)
                Kagamil(52.45 km)
                Vsevidof(57.26 km)
                Cleveland(58.48 km)
                Uliaga(61.63 km)
              Recheschnoi(65.36 km)
                Carlisle(67.88 km)
                Herbert(67.90 km)
Overall Ash Cloud Object Probability: 100.00000%
Mean Ash Probability of Object Pixels: 79.27190%
Maximum Height [AMSL]: 3.6 km (11657.62 ft)
1-sigma Uncertainty of Maximum Height [AMSL]: 1.1 km (3682.33 ft)
Mean Tropopause Height [AMSL]: 8.5 km (27830.83 ft)
Total Mass: 0.88 ktons
Total Area: 305.20 km^2
-------------------------------------------
```

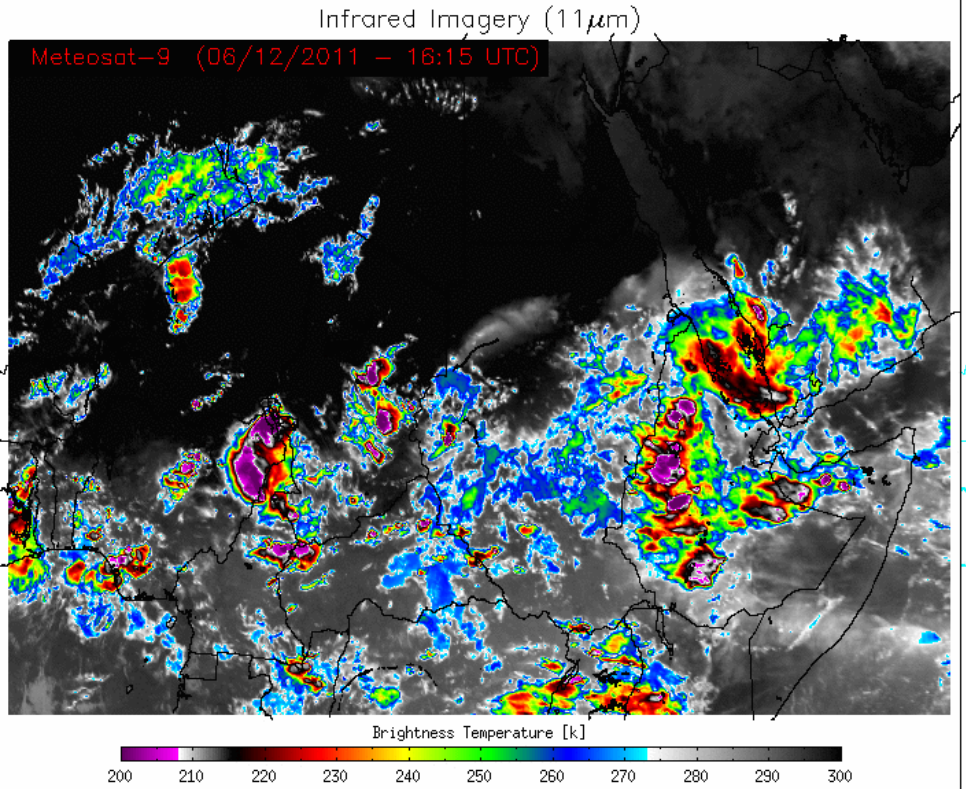
Auto-generated text alert

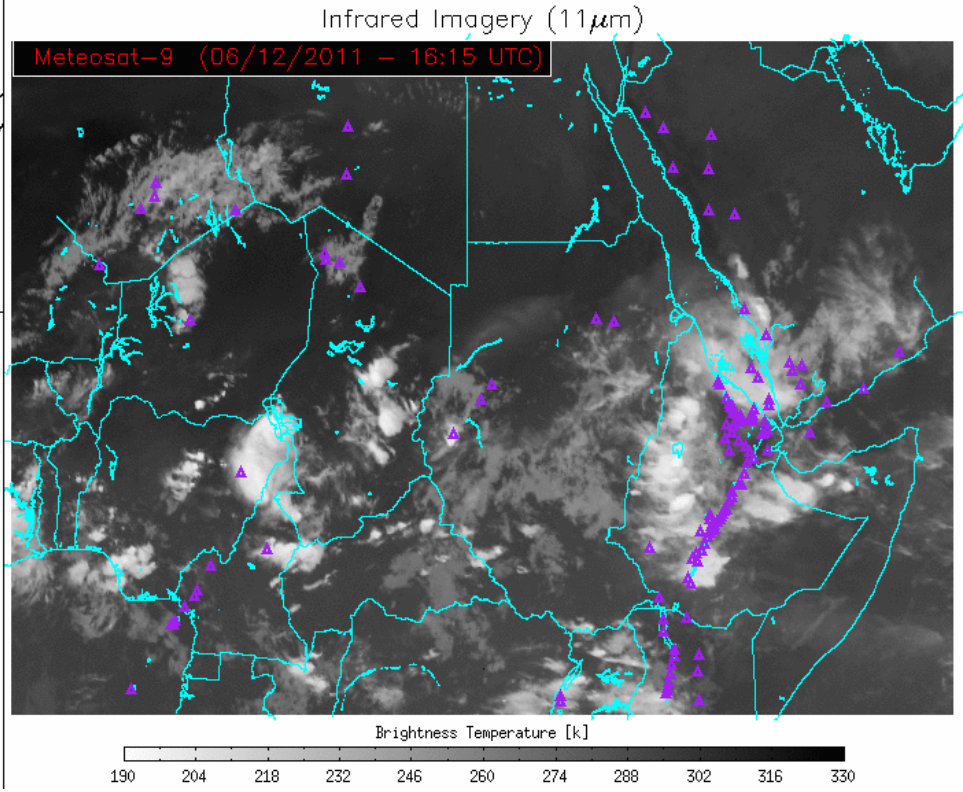
1). Ash dominated volcanic plumes – Semi-transparent clouds dominated by volcanic ash. Lightning is usually not present in these clouds.

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.

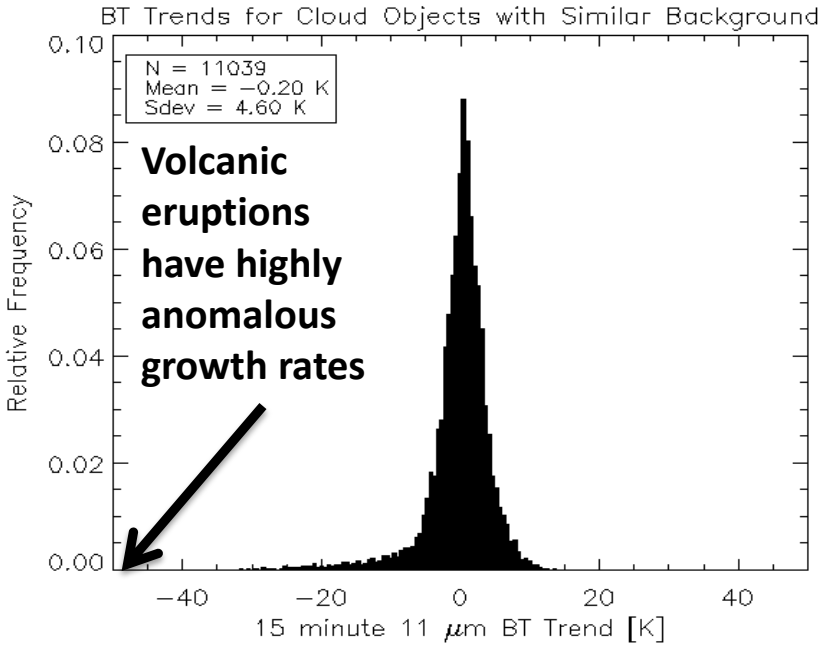


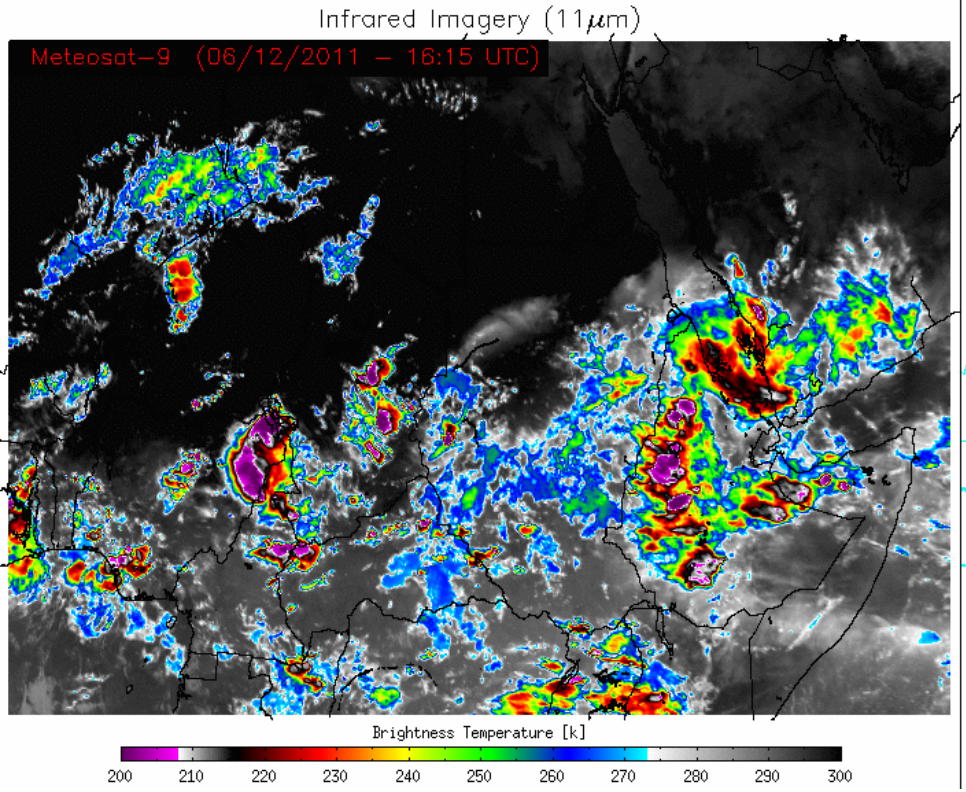


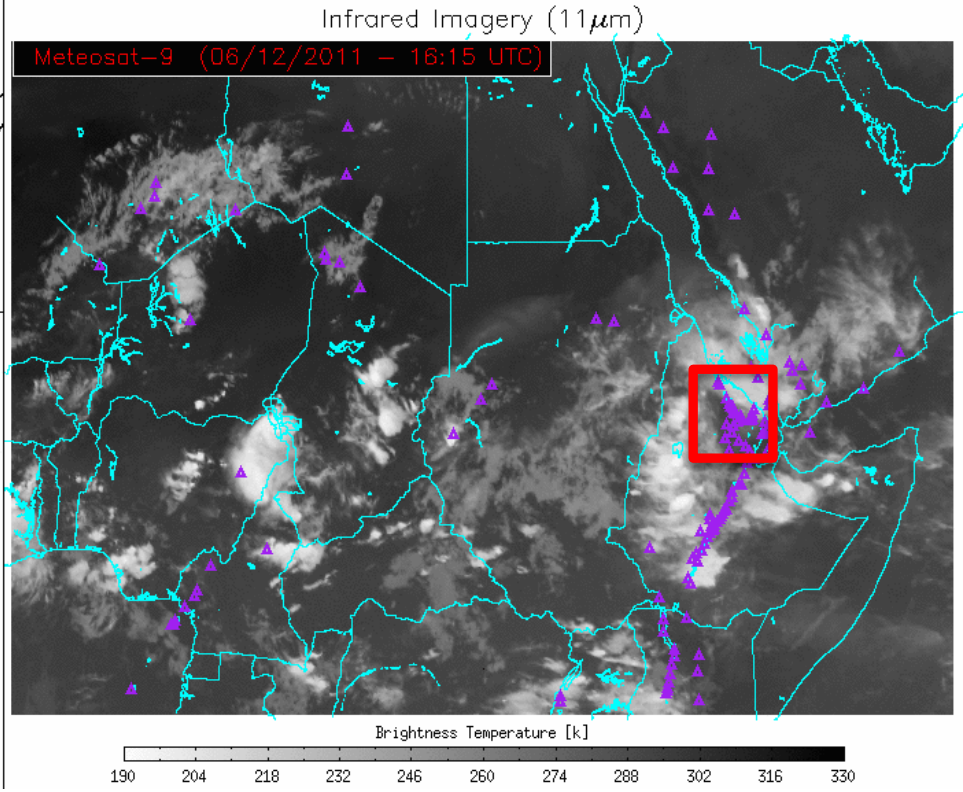


- **A fully automated cloud object identification and tracking procedure was developed to calculate cloud vertical growth metrics as a function of background conditions and the time between images.**

- **Alerts can then be issued if a highly anomalous growth rate is found near a volcano.**

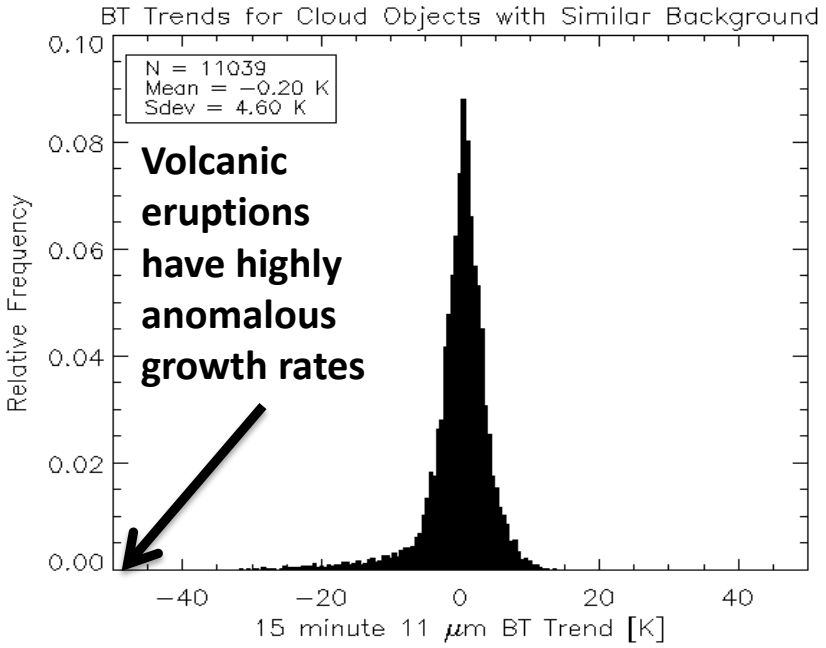




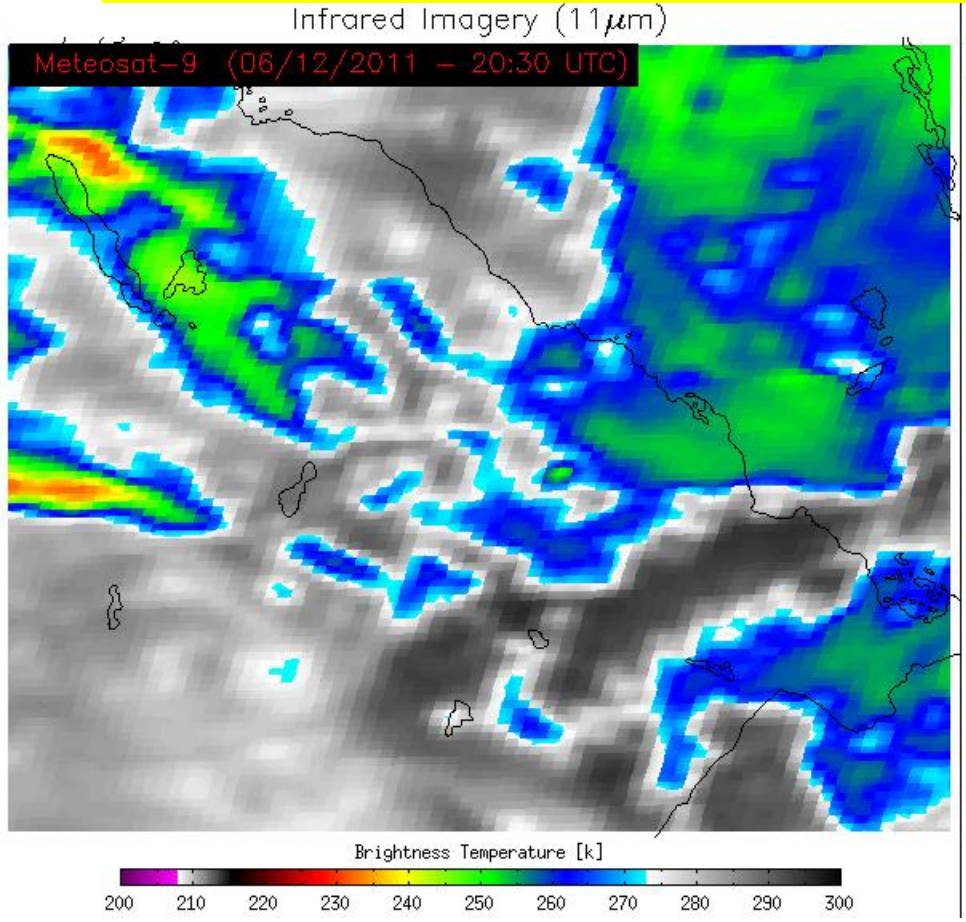


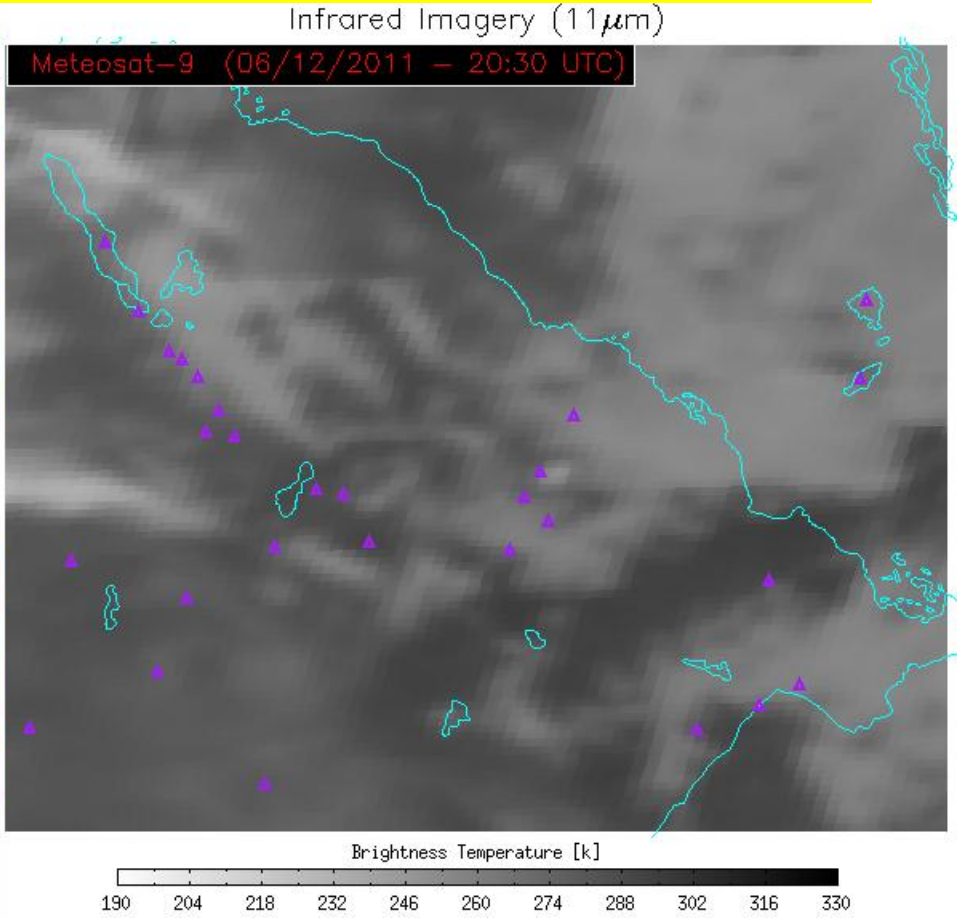
- **A fully automated cloud object identification and tracking procedure was developed to calculate cloud vertical growth metrics as a function of background conditions and the time between images.**

- **Alerts can then be issued if a highly anomalous growth rate is found near a volcano.**

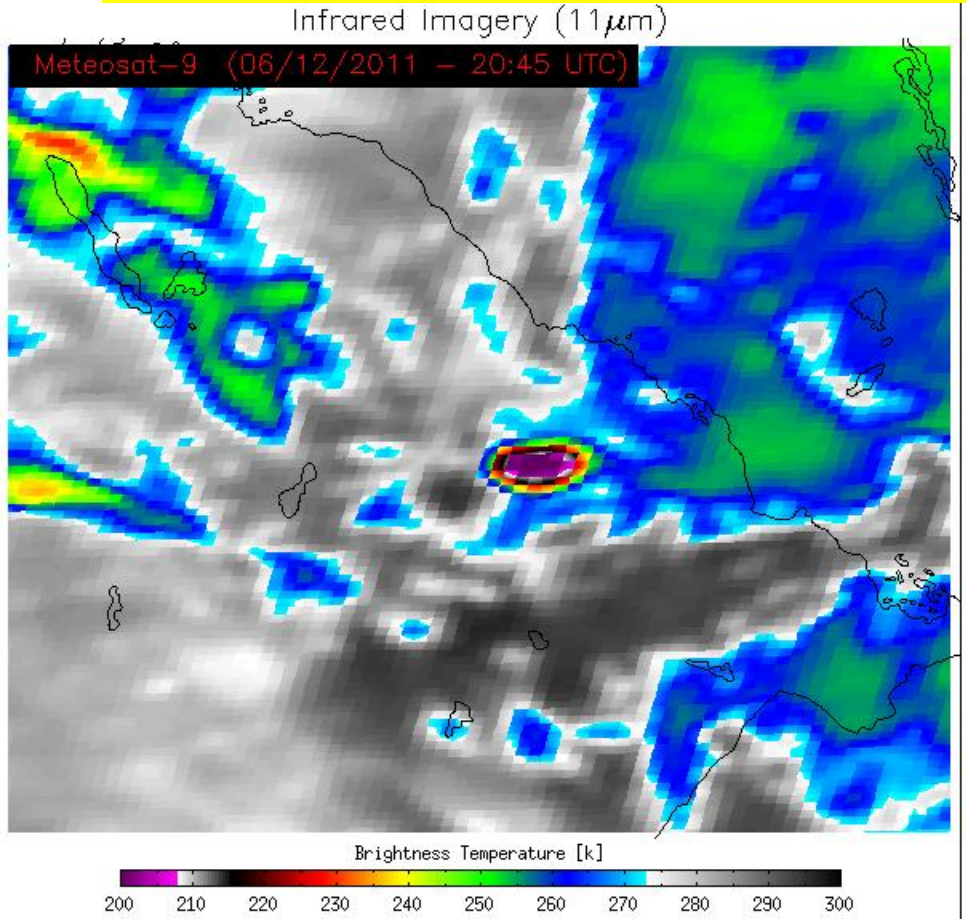


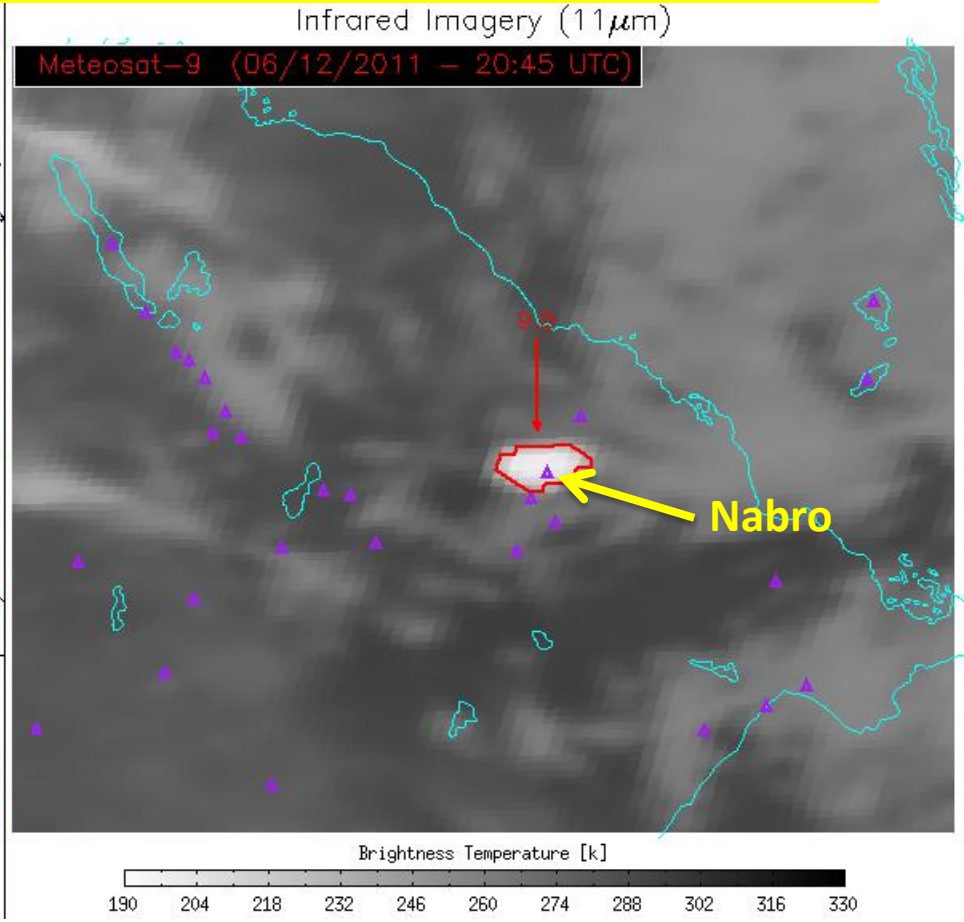
June 12, 2011 (20:30 UTC)





June 12, 2011 (20:45 UTC)





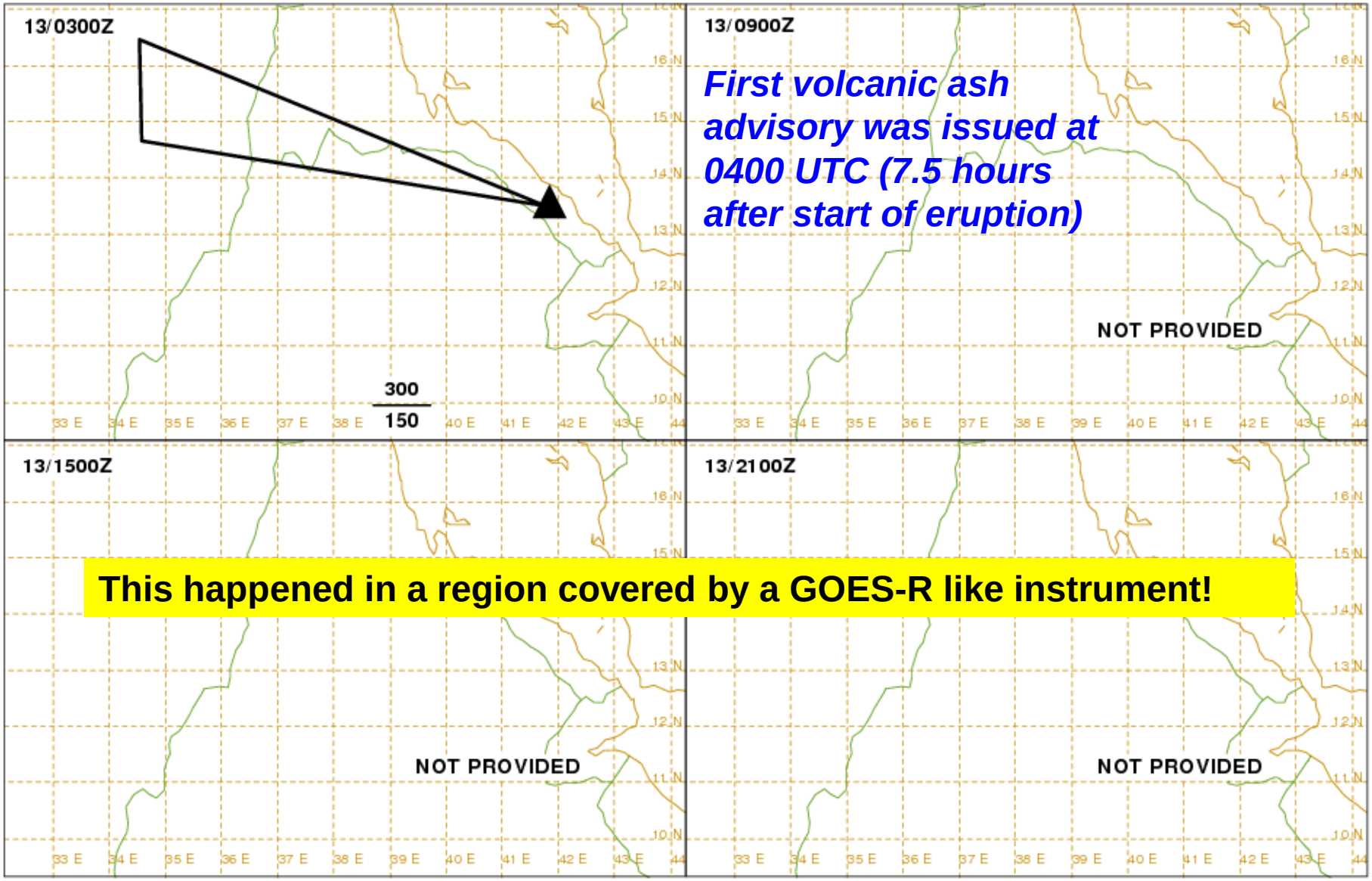
- **The 15 minute decrease in the minimum cloud object 11 μm BT was 45 K, which is ~10 standard deviations above the mean for the background conditions present!**

- **Our algorithm automatically determines the deviation from the mean for all tracked cloud objects**

Automated alert would have been issued after 20:45 UTC image

```
@**********GENERATING VOLCANIC CLOUD ALERTS**********
DATE: 06/12/2011
TIME: 20:45 UTC
PRIMARY INSTRUMENT: MET-9 SEVIRI
LOCATION/ORBIT: GEO
L1 FILE: met9_2_2011_164_2045.area
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


-----------------------------------------
POSSIBLE VOLCANIC ERUPTION DETECTED
Radiative Center (Lat, Lon): 13.409, 41.672
Nearby Volcanoes (meeting alert criteria):
                 Nabro(5.3 km)
Observable Vertical Growth Rate Anomaly (number of stddev above mean): 9.8
Maximum Height [AMSL]: 18.8 km (61679.79 ft)
1-sigma Uncertainty of Maximum Height [AMSL]: 1.2 km (3937.00 ft)
-----------------------------------------
```



VOLCANIC ASH ADVISORY

DTG: 20110613/0400Z

VAAC: TOULOUSE

VOLCANO: DUBBI 0201-10

AREA: ETHIOPIA

SUMMIT ELEV: 1625M

METEO FRANCE

ADVISORY NR: 2011/01

INFO SOURCE: METEOSAT IMAGERY

AVIATION COLOUR CODE: UNKNOWN

ERUPTION DETAILS: ERUPTION STARTED AROUND 23UTC

RMK: SEEMS NOW DECREASING

NXT ADVISORY: 20110613/1000Z

As the WWLLN science team has shown, lightning can be useful for detecting vigorous volcanic eruptions (VEI 3 or above), especially in regions that experience little lightning (many false alarms in convectively active regions). We are using ground-based lightning data from New Mexico Tech to incorporate GLM like lightning flash information into the alert system.

Expected Year 2 Accomplishments

- 1). Refine volcanic convection methodology and make it real-time capable; generate conditional ash probability tables for more sensors
- 2). Continue to modify AWG developed SO_2 detection to produce probabilistic output
- 3). Using ground-based lightning as a proxy for GLM, incorporate lightning flash information into alert system
- 4). Provide false alarm cleared GOES-R volcanic ash height, mass loading, and effective radius data to U. Alaska Fairbanks to help validate WRF model simulations

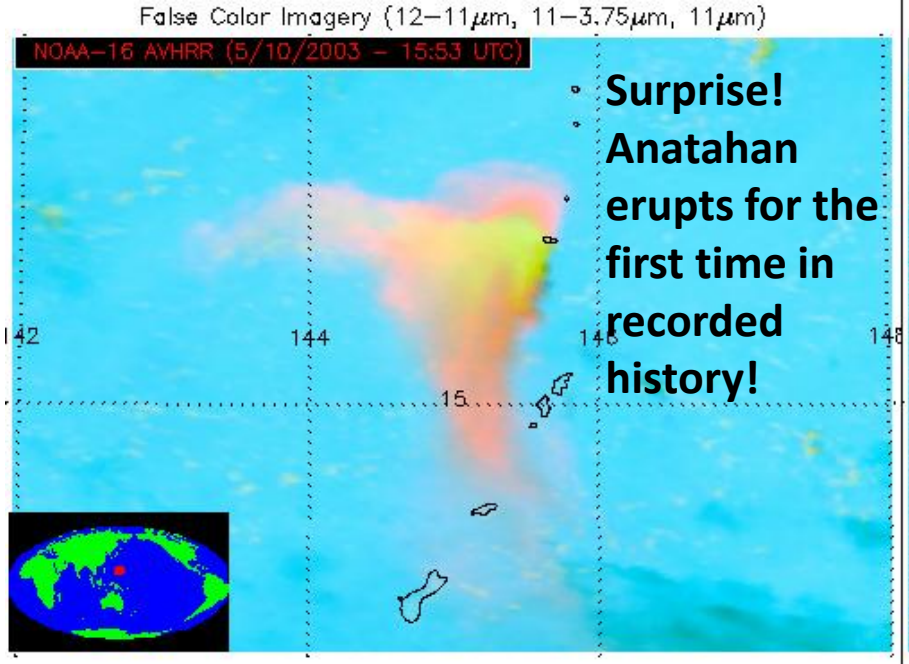
Expected Year 3 Accomplishments

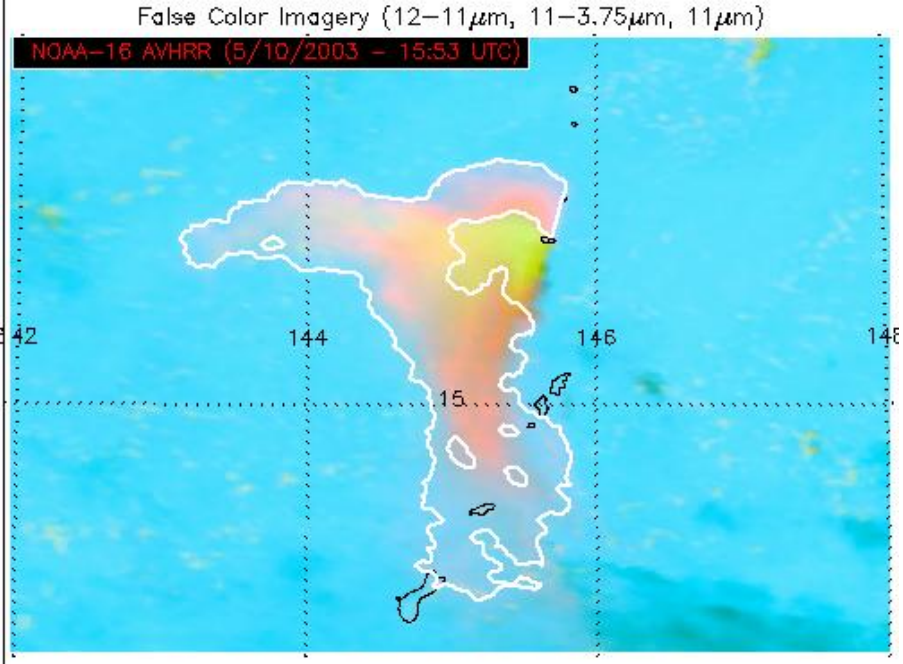
- ***Main demonstration of alert system at Anchorage and Washington VAAC's, collect feedback, and make improvements as needed***
- **Integration of JPSS (VIIRS) volcanic cloud alerting capabilities (in addition to MODIS, GOES, and SEVIRI) into system**
- **Support model assimilation and validation studies by providing refined ash cloud products**

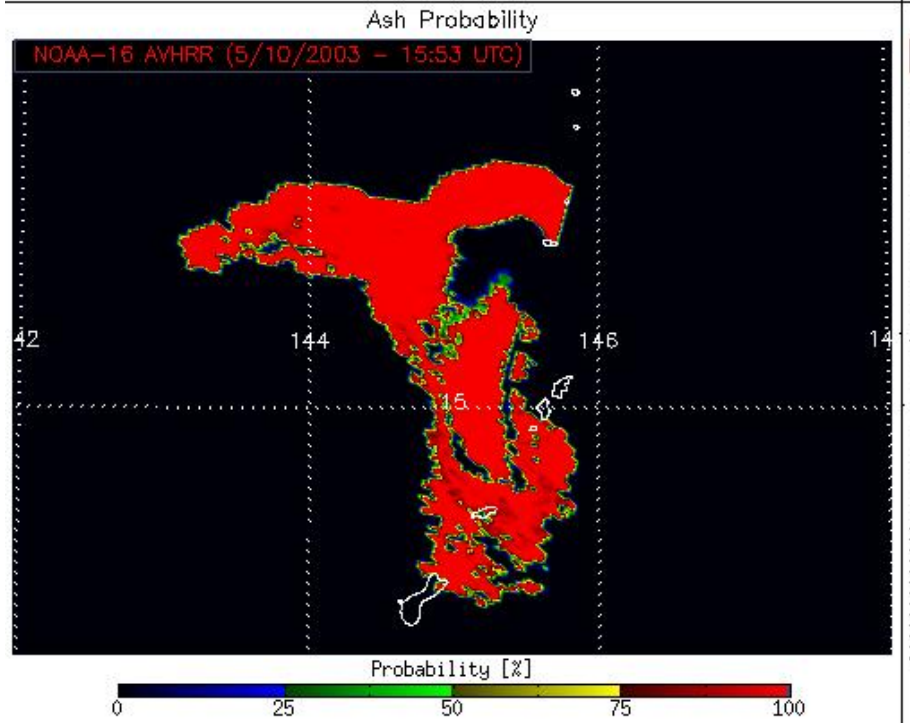
Summary

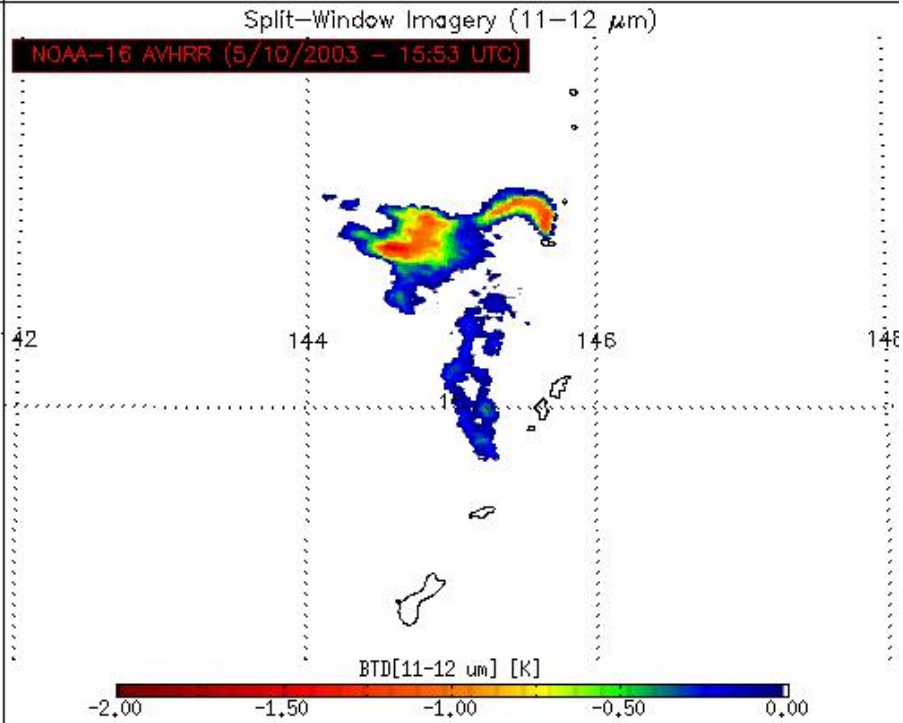
- ***The quantitative nature of the alerts and the relatively straightforward nature of the validation (did a volcanic eruption occur or not?) allow the impact on operations to be clearly determined (this is not the case for many products).***

- *****In the absence of an automated alert system, the capabilities of GOES-R (and satellites in general) will be greatly under-utilized for volcanic cloud monitoring.******


False Color Imagery (12–11μm, 11–3.75μm, 11μm)
NOAA-16 AVHRR (5/10/2003 - 15:53 UTC)
Surprise! Anatahan erupts for the first time in recorded history!
142
144
146
15


False Color Imagery (12–11μm, 11–3.75μm, 11μm)
NOAA-16 AVHRR (5/10/2003 - 15:53 UTC)
142
144
146
15


Ash Probability
NOAA-16 AVHRR (5/10/2003 - 15:53 UTC)
142
144
146
15
Probability [%]
0
25
50
75
100

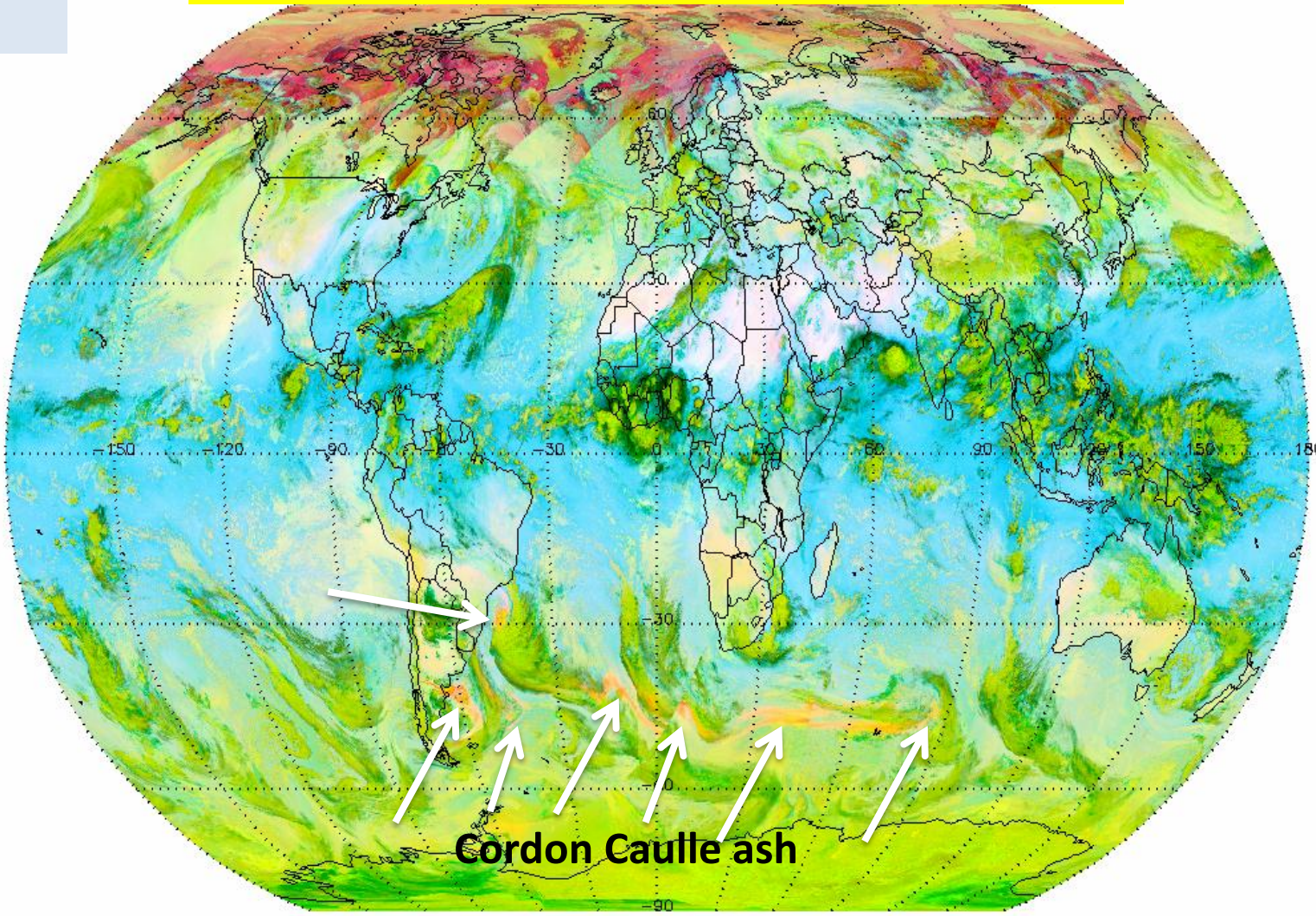

Split-Window Imagery (11–12 μm)
NOAA-16 AVHRR (5/10/2003 - 15:53 UTC)
142
144
146
BTD[11-12 um] [K]
-2.00
-1.50
-1.00
-0.50
0.00

Back-up Slides

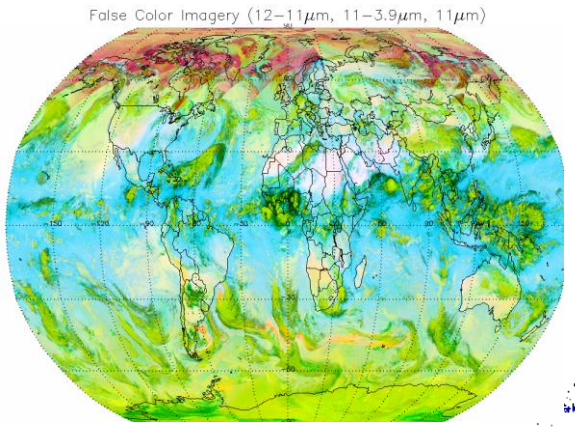
NOAA-18 AVHRR: June 8, 2011

Global assessment of probabilistic ash detection

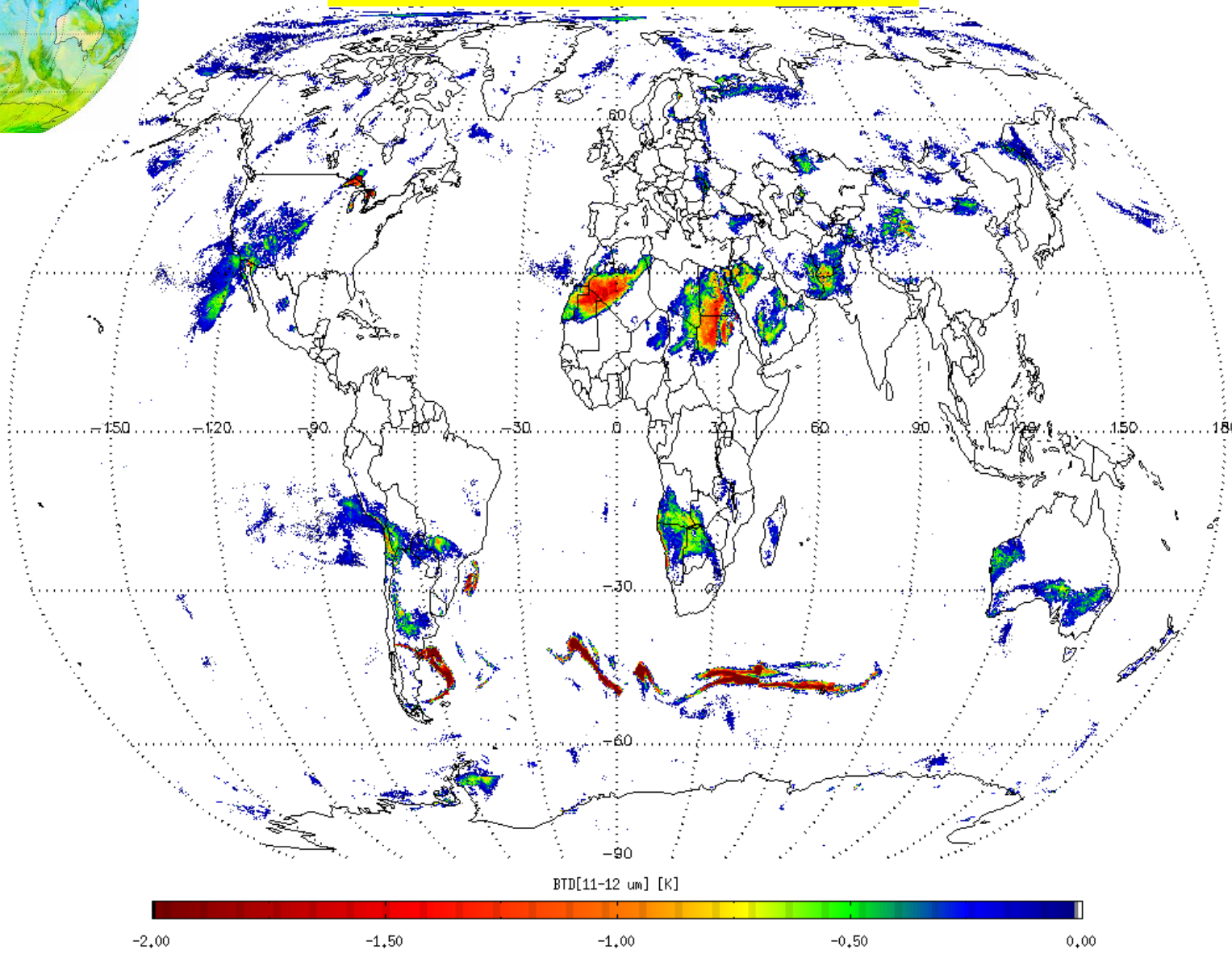
False Color Image



NOAA-18 AVHRR: June 8, 2011

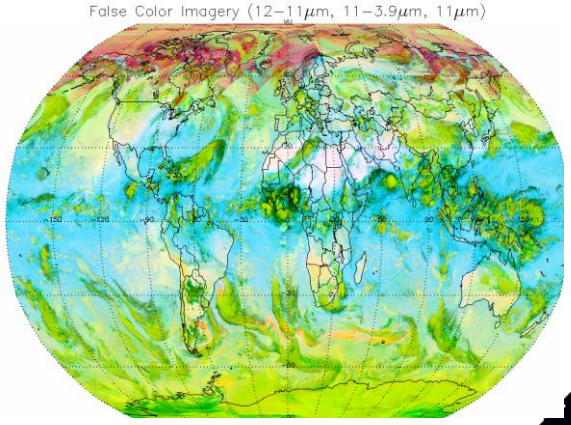


Split-window BTD



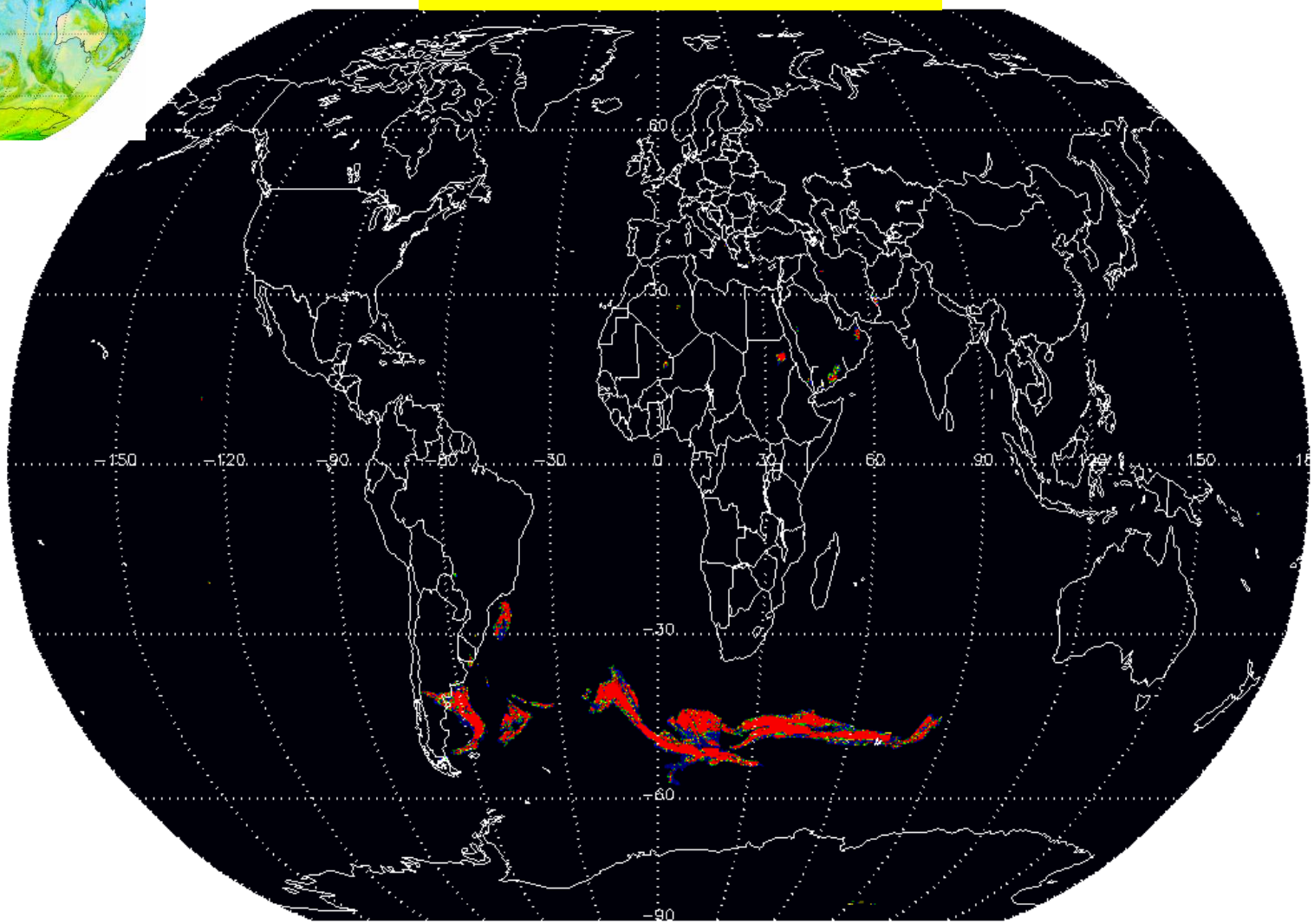
The traditional 11-12 µm BTD shows the Cordon Caulle ash cloud, but on a global scale false alarms are unavoidable

NOAA-18 AVHRR: June 8, 2011



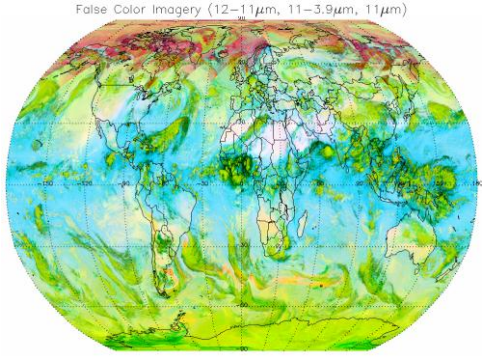
Ash Probably

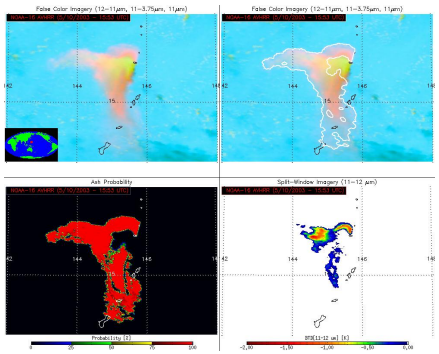
- The probabilistic method's depiction of the Cordon Caulle ash cloud is consistent with multi-spectral imagery
- Other than the Cordon Caulle ash cloud, only small areas of desert dust are depicted

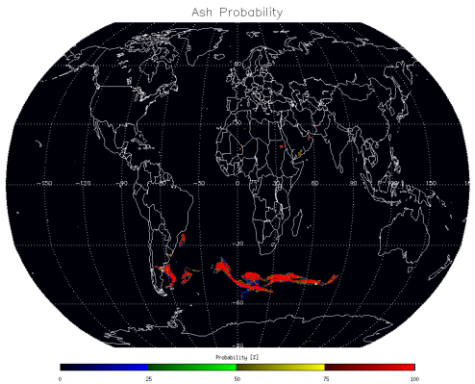


Automated Ash Detection and Alerting

- A Naïve Bayes framework is used to determine the probability that an ash cloud is present.
- Robust predictors are used (including a correction for surface emission and background absorbing atmospheric gases like water vapor) so the method is globally applicable (e.g. Pavolonis et al., 2006; Pavolonis 2010).
- The end results are used to automatically issue ash cloud alerts to users (the alert criteria are highly configurable) and to construct a very accurate and objective depiction of ash cloud location that is critical for real-time model validation and data assimilation applications.
- The algorithm can be applied to a large number of sensors while taking full advantage of each sensor's capabilities. We are working to transfer an AVHRR version of the system to OSPO operations and the same method is being used to develop the ash alert component of the GOES-R volcanic cloud alert system







Benefits of Automated Probabilistic Ash Detection

- Merge output from one sensor with another with less artifacts since sensor differences are explicatively accounted for in Naïve Bayes model and all pixels are scaled to the same range of values and have the same mathematical meaning – automatically generate global geostationary composites!
- An objective measure of horizontal location of volcanic ash that is much better suited (higher POD and lower POF) to compare with models than traditional methods
- Will allow for more objective estimation of total mass of fine ash as a function of time
- Alert quality detection; No reliance on negative BTD
- Fully automated so an archive of past cases can be constructed
- More readily relate ash cloud properties to meteorology