Towards Operational Satellite-based Detection and Short Term Nowcasting of Volcanic Ash

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Volcanic Ash work at CIMSS

- Key activities:
- 1). development of an automated ash detection algorithms that are applicable to a large variety of satellite imagers
- 2). Pursuing methods to determine ash plume heights based on available spectral information

Key Interactions with NOAA

- The Extended Clouds from AVHRR (CLAVR-x) system offers one platform for operational implementation of the volcanic ash algorithms (A. Heidinger).
- Gridded Solar Insolation Project-full disk (GSIP-fd) offers a similar potential operational platform for the GOES imagers (A. Heidinger).
- CLAVR-x and GSIP-fd products include a cloud mask, cloud type, cloud top temperature, LWP, IWP, and much more. Ash products are currently being developed for the research versions of CLAVR-x and GSIP-fd.
- We are currently collaborating with the Washington VAAC and Gary Ellrod on these potential options within NOAA.

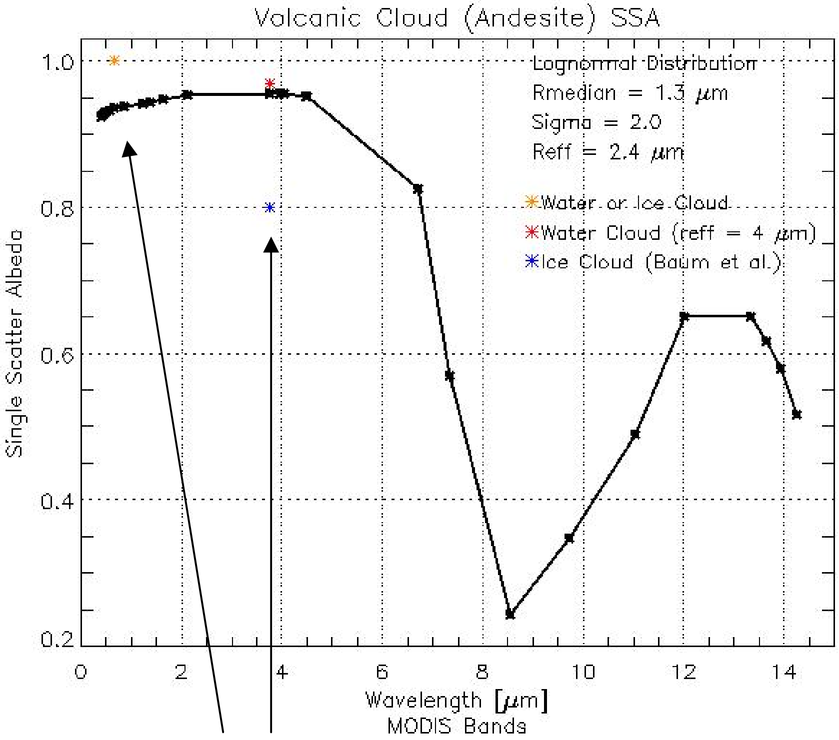
Ash Detection Techniques

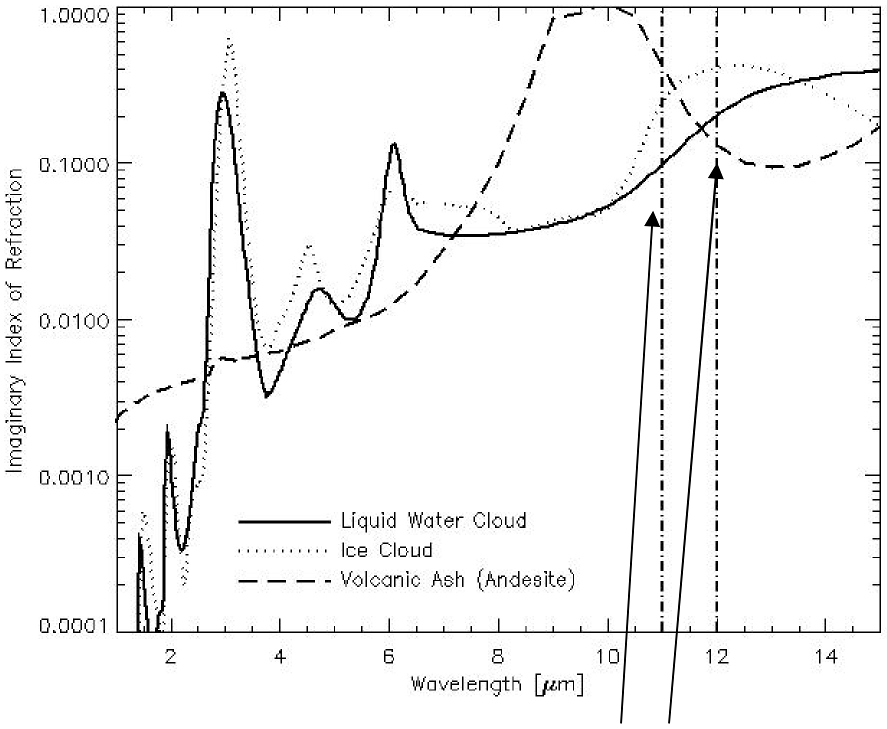
- Several Techniques have been presented in the literature. For instance:
- Reverse absorption (Prata et al., 1989; Yu and Rose, 2002)
- SO_2 detection using IR measurements in the 7 – 12 um range (Watson et al., 2004)
- Image enhancement techniques (Ellrod et al., 2003)

Why Develop New Techniques?

- Unfortunately, none of these techniques, alone, performs universally well (see Tupper et al., 2003).
- Thus, there is a need to improve upon these tests and combine several techniques to produce an optimal, rigorously tested, automated ash mask for various sensors.
- However, there will always be limitations (i.e. complete obstruction by meteorological cloud, very low ash content plumes, and very small-scale plumes relative to pixel size will still remain problematic).

Ash Cloud Properties

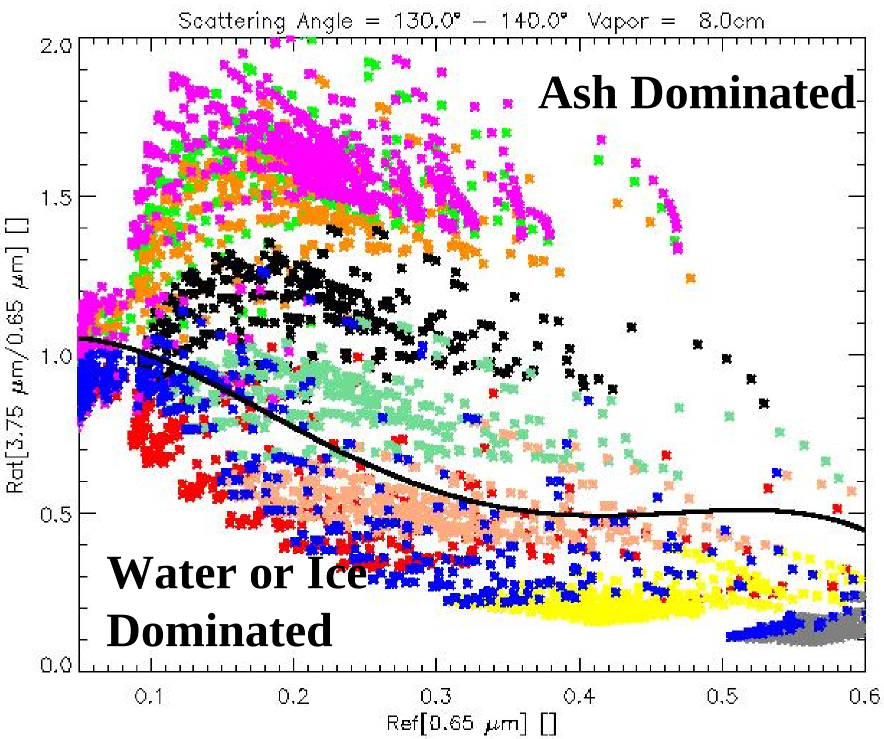


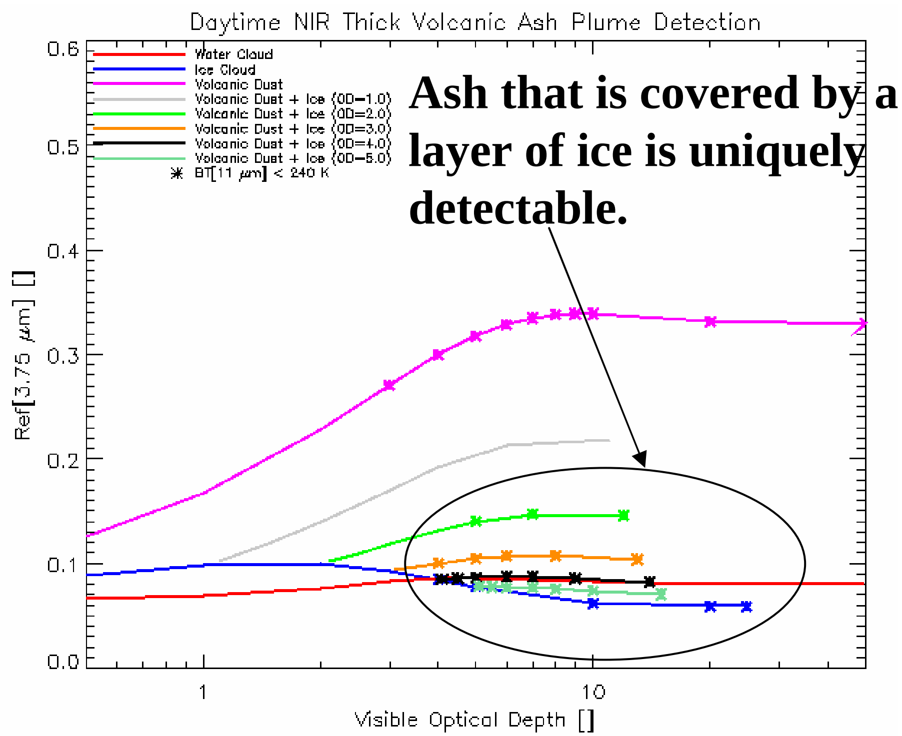


3.75/0.65 um reflectance ratio should be larger for ash than water or ice clouds.

Split window "reverse absorption" feature

New Ash Detection Techniques





Strength: Little water vapor dependence.

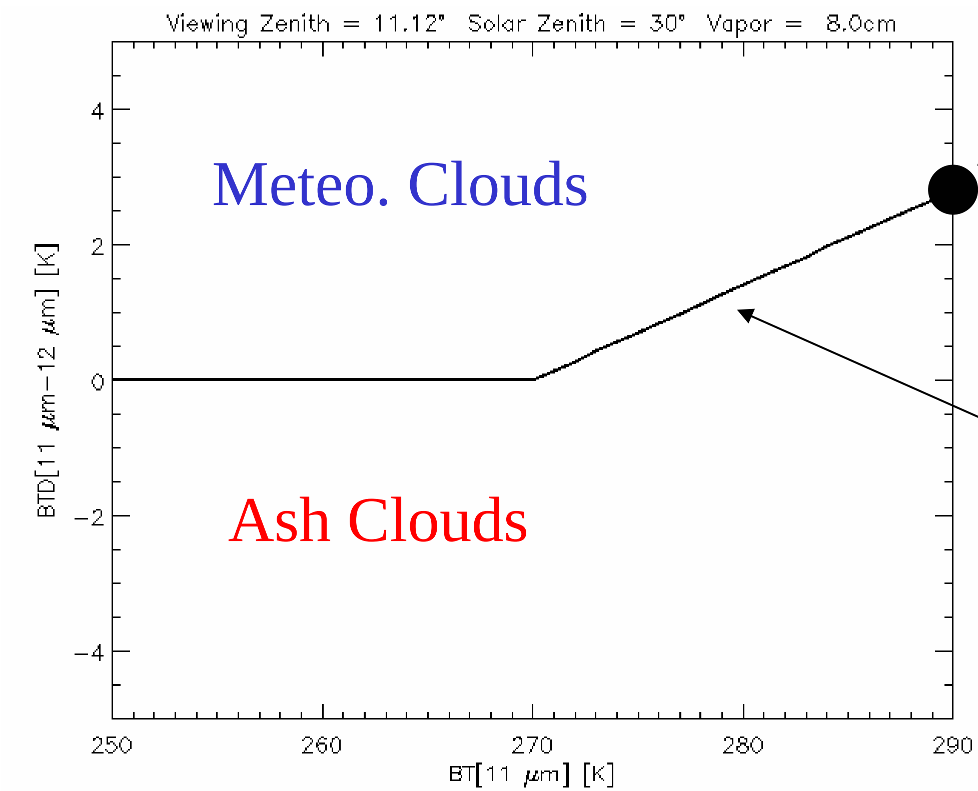
Weakness: Will not work in sun glint. So far, only defined for water surfaces. Daytime only.

Strength: Works well everywhere.

Weakness: Only applicable to explosive eruptions. Daytime only.

Nighttime Ash Detection Techniques

Atmospherically Corrected Reverse Absorption Technique



Clear sky calculation

Linearly roll down from clear sky calculation to 0.0 at 270 K in tropics.

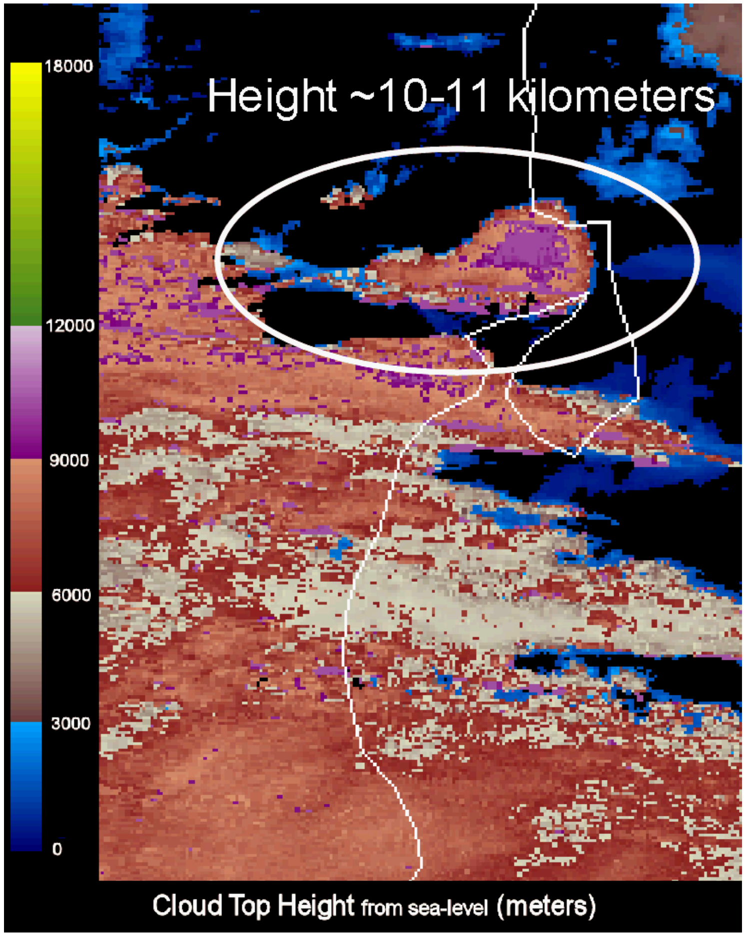
Meteorological and ash cloud simulations support this approach, which is similar to that shown in Yu and Rose (2002).

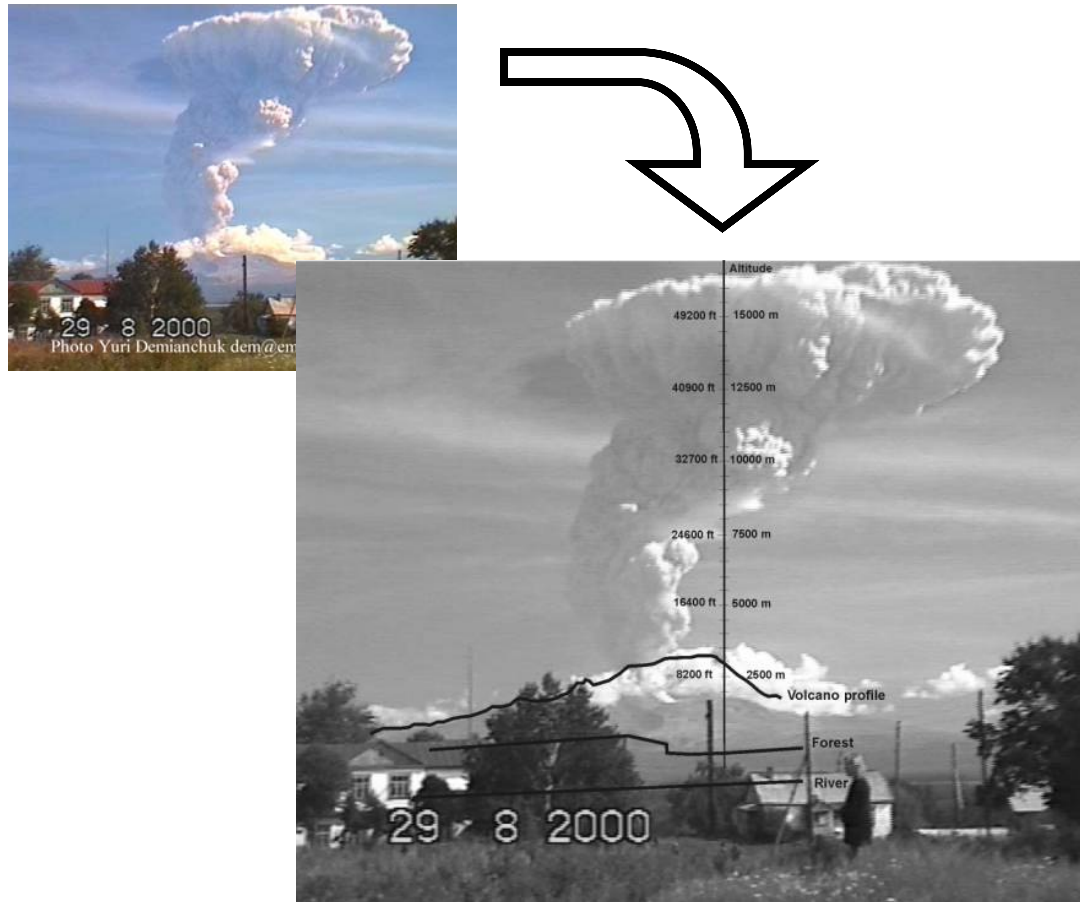
***Nighttime 3.75, 6.5, 11, and 12 um tests are also currently under development.

Plume Height Estimation Techniques

- Shadow techniques (daytime only and under limited conditions)
- Aircraft/ground observations (daytime/sparse)
- 11 um brightness temperature lookup (thick plumes)
- Wind correlation (gives a rough estimate)
- CO_2 slicing (Tony Schreiner/Mike Richards/Steve Ackerman, very promising – see next slide)

Sheveluch, Russia – August 28, 2000 – Terra/MODIS 2355Z





•CO_2-slicing yields heights at approximately 10-11 km, video estimate is 14 to 16 km, MODIS is 80 minutes after eruption.

Credit: Mike Richards

CO_2 Slicing Summary

- Initial investigation looks promising
- CO_2 appears to be too low, as with clouds, since it retrieves an radiative height
- How to increase heights?
  - Emissivity adjustments
  - Error in assumed profiles
  - Statistical adjustment through calculations
  - Improve upper limit restrictions
- Validation continues, and simulation study begun.
- Additional examples will be shown later.

Why Develop New Techniques?

- CO_2 slicing should provide the best plume height estimate but…
- CO_2 channels are not available on all current sensors (e.g. MTSAT, GOES-10 imager, AVHRR) and will NOT be available on the MODIS-like VIIRS on NPOESS (2008 and beyond).
- There are also no CO_2 channels on the AVHRR and the AVHRR will be around until at least 2014.
- The VIIRS (0.75 km resolution) and the AVHRR (1-4 km resolution) provide detailed imagery that is useful for identifying volcanic plumes.

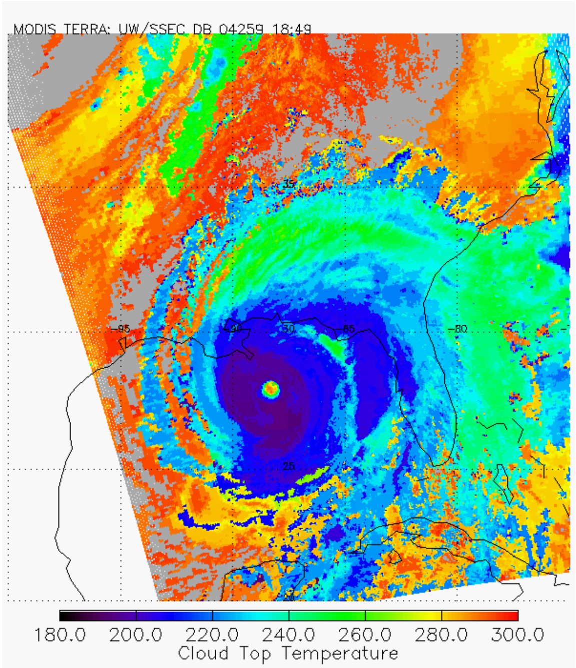
New Plume Height Retrieval

(Heidinger and Pavolonis, in prep.)

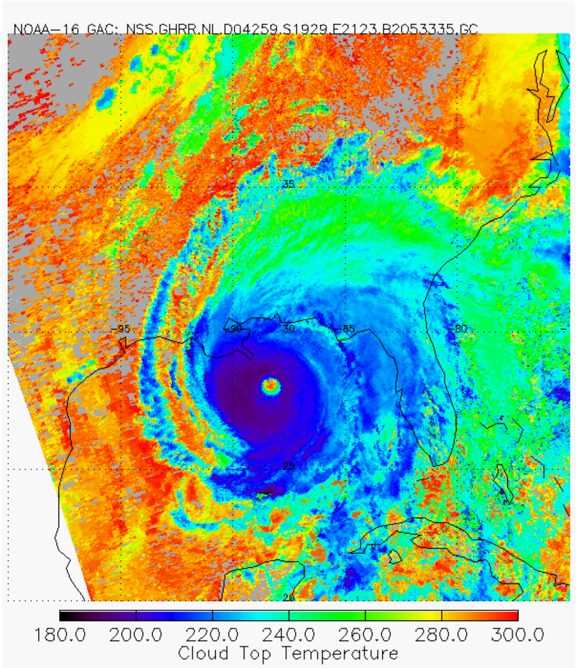
- •Split window 1DVAR-optimal estimation technique
- •Cloud top temperature/emissivity are retrieved simultaneously.
- •Day/night independent.
- •Currently used in CLAVR-x and GSIP.

Results are being validated against MODIS. Goal is to achieve *consistency with MODIS and VIIRS* for thin cirrus – difficult from AVHRR.

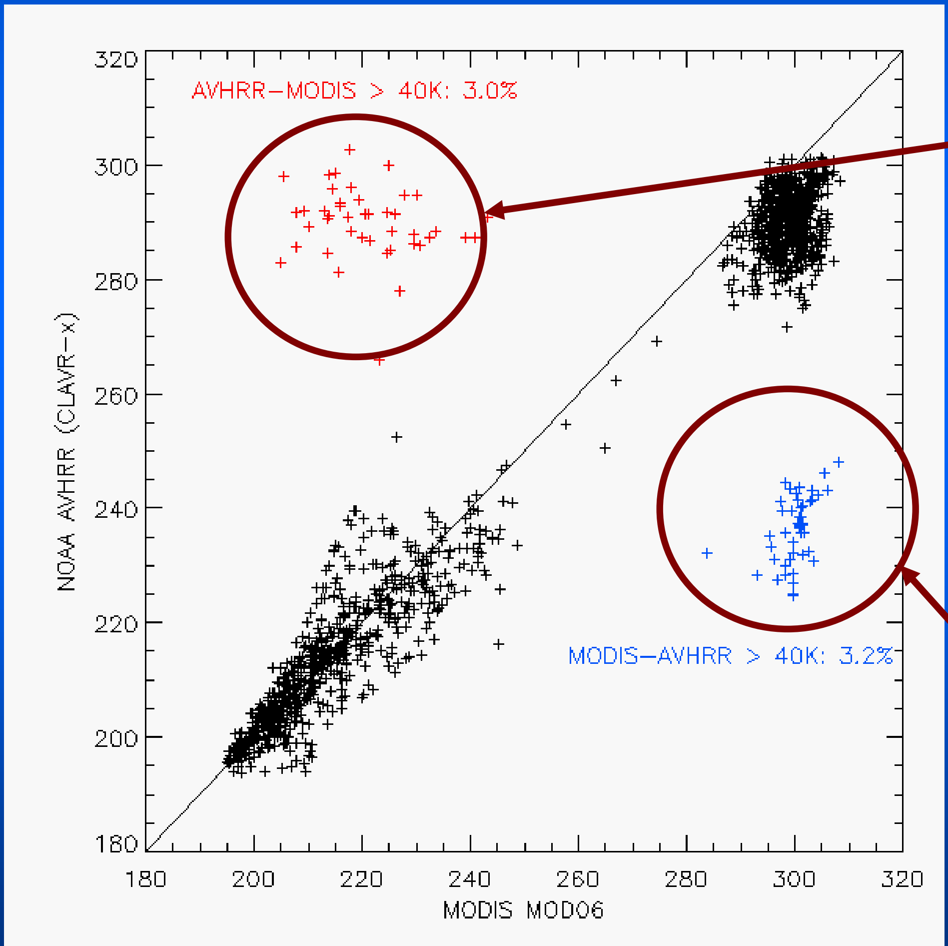
MODIS



AVHRR



Split Window vs CO_2 Slicing (meteorological clouds)



Very thin clouds (emissivity < 0.5)

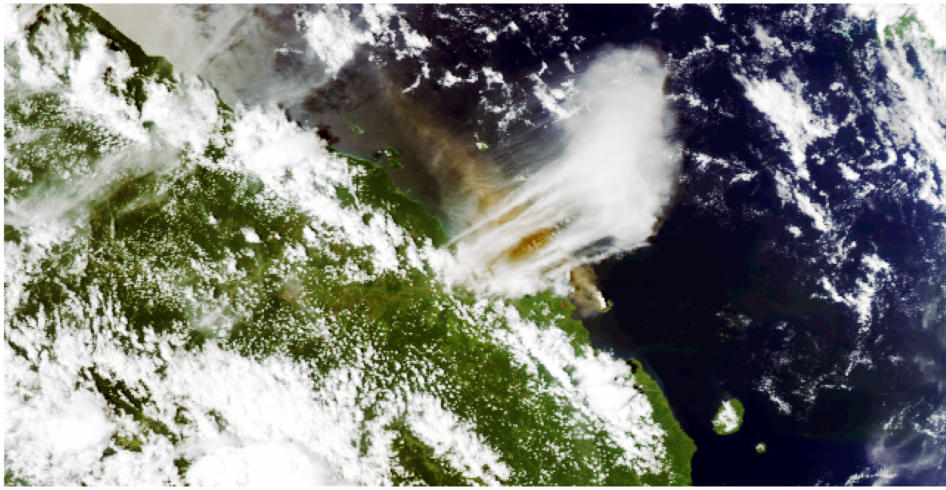
**Some differences may be due to 20 minute time difference between MODIS and AVHRR overpass.

Likely due to a recent bug found in the MODIS algorithm.

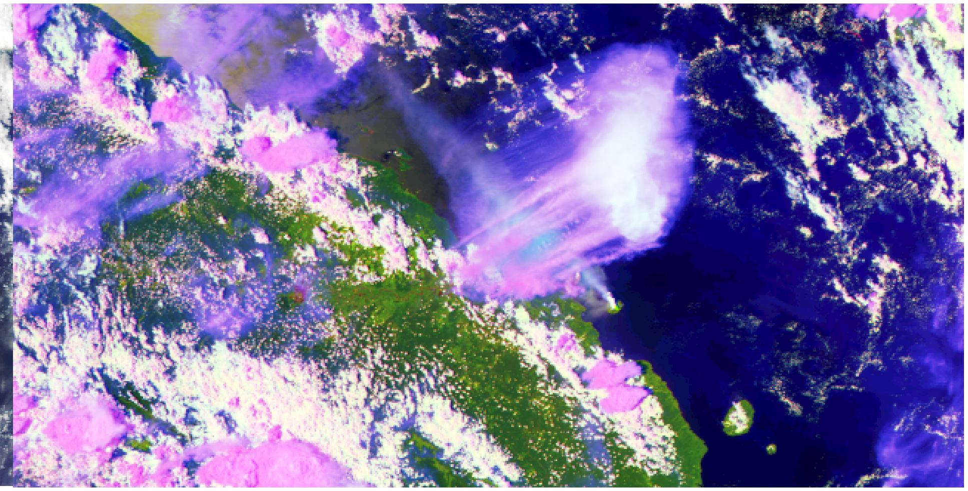
Some Results…

Manam, PNG October 24, 2004

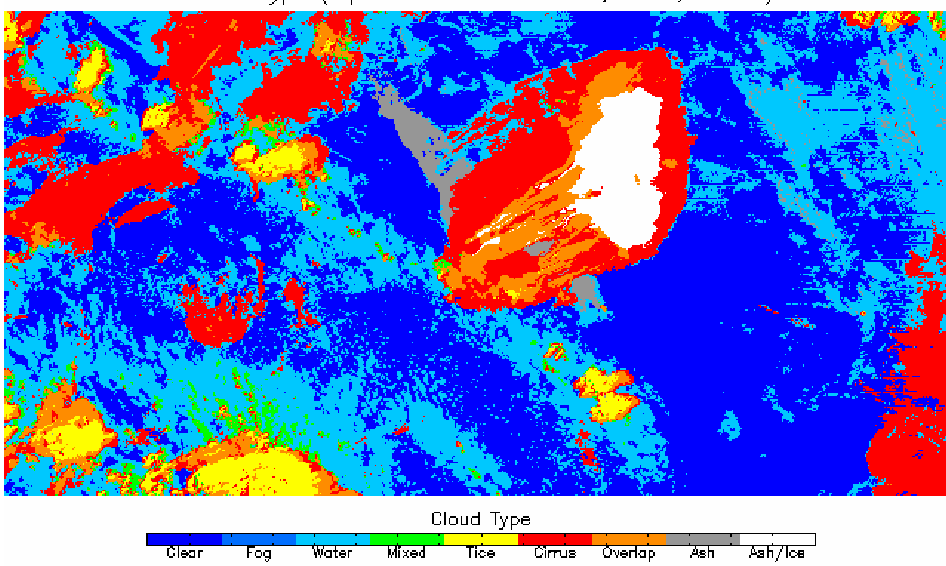
True Color Image (Aqua–MODIS October 24, 2004, 0355Z)



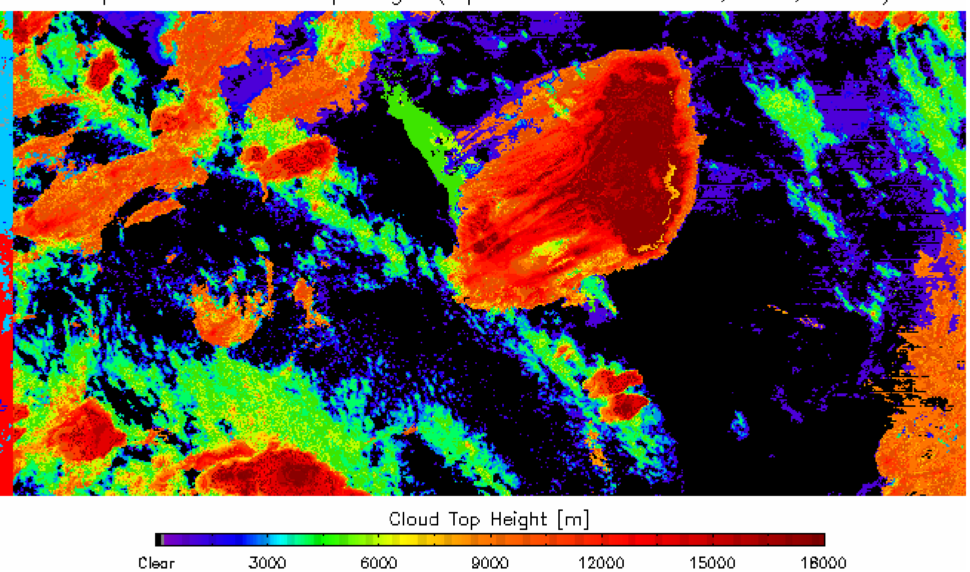
RGB Image (Aqua–MODIS October 24, 2004, 0355Z)



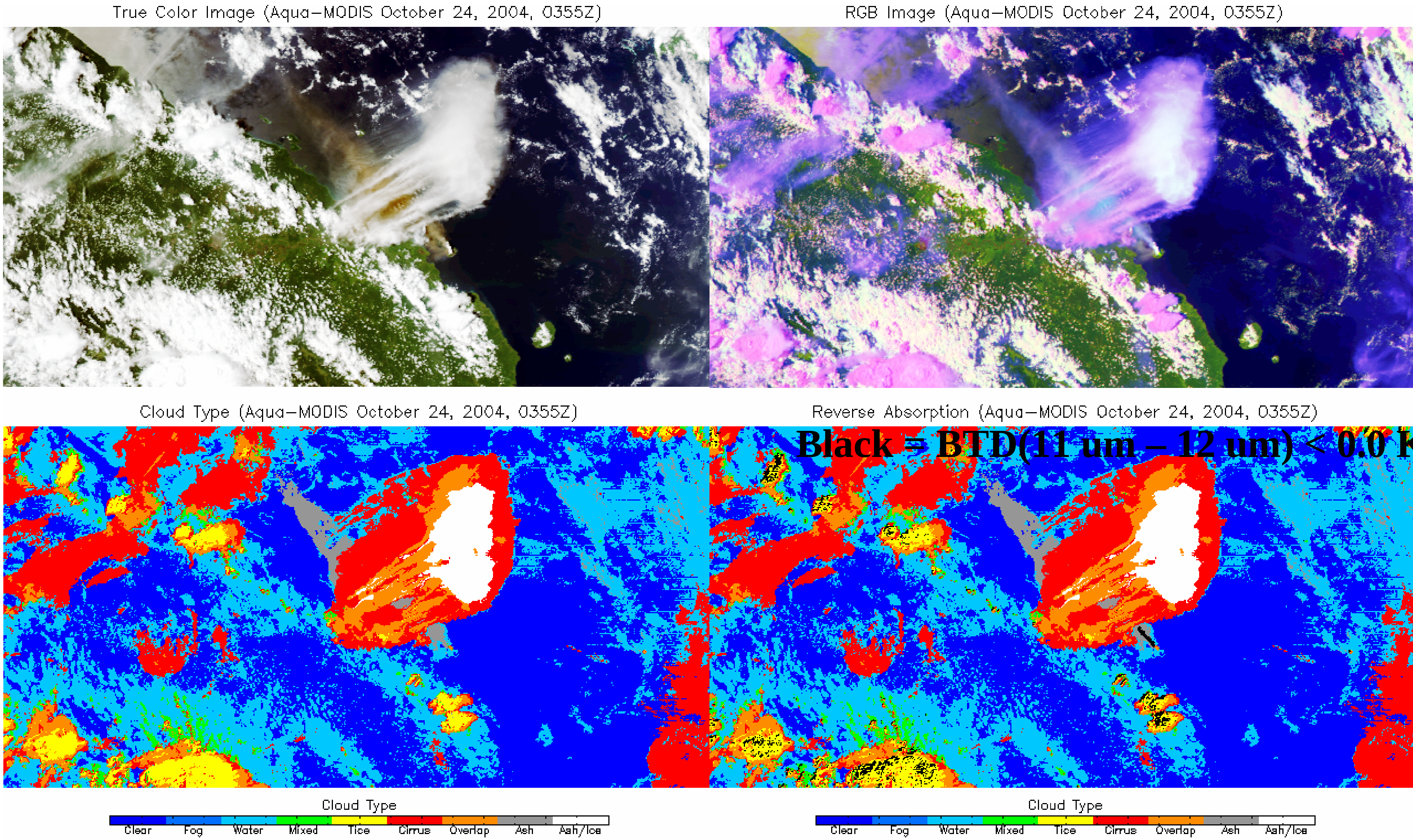
Cloud Type (Aqua–MODIS October 24, 2004, 0355Z)



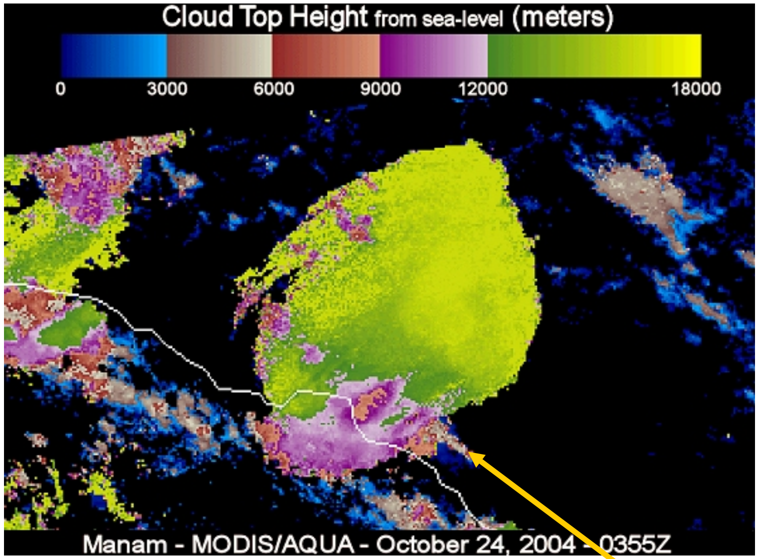
Split Window Cloud Top Height (Aqua–MODIS October 24, 2004, 0355Z)



Manam, PNG October 24, 2004



Comparison to MODIS CO_2



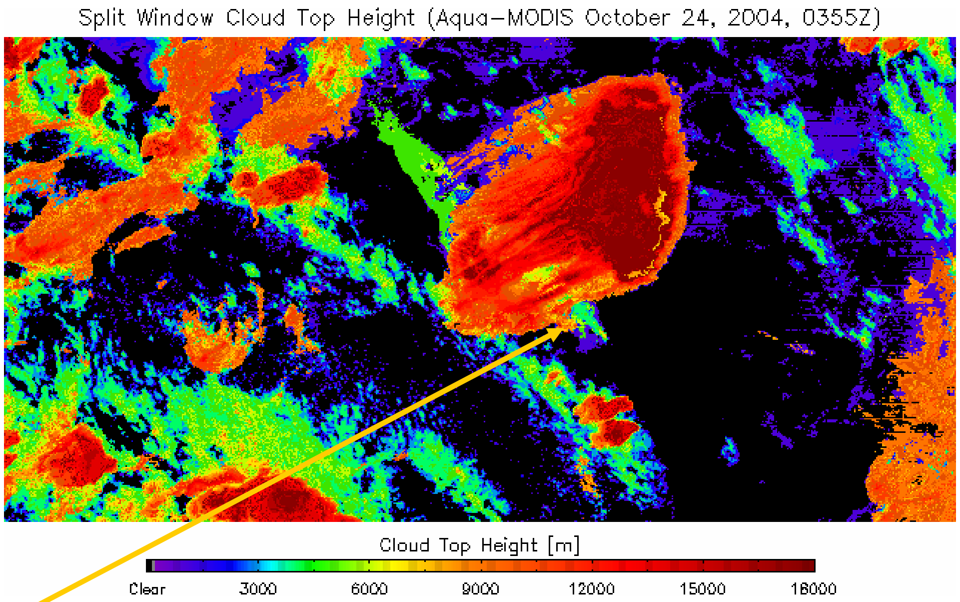
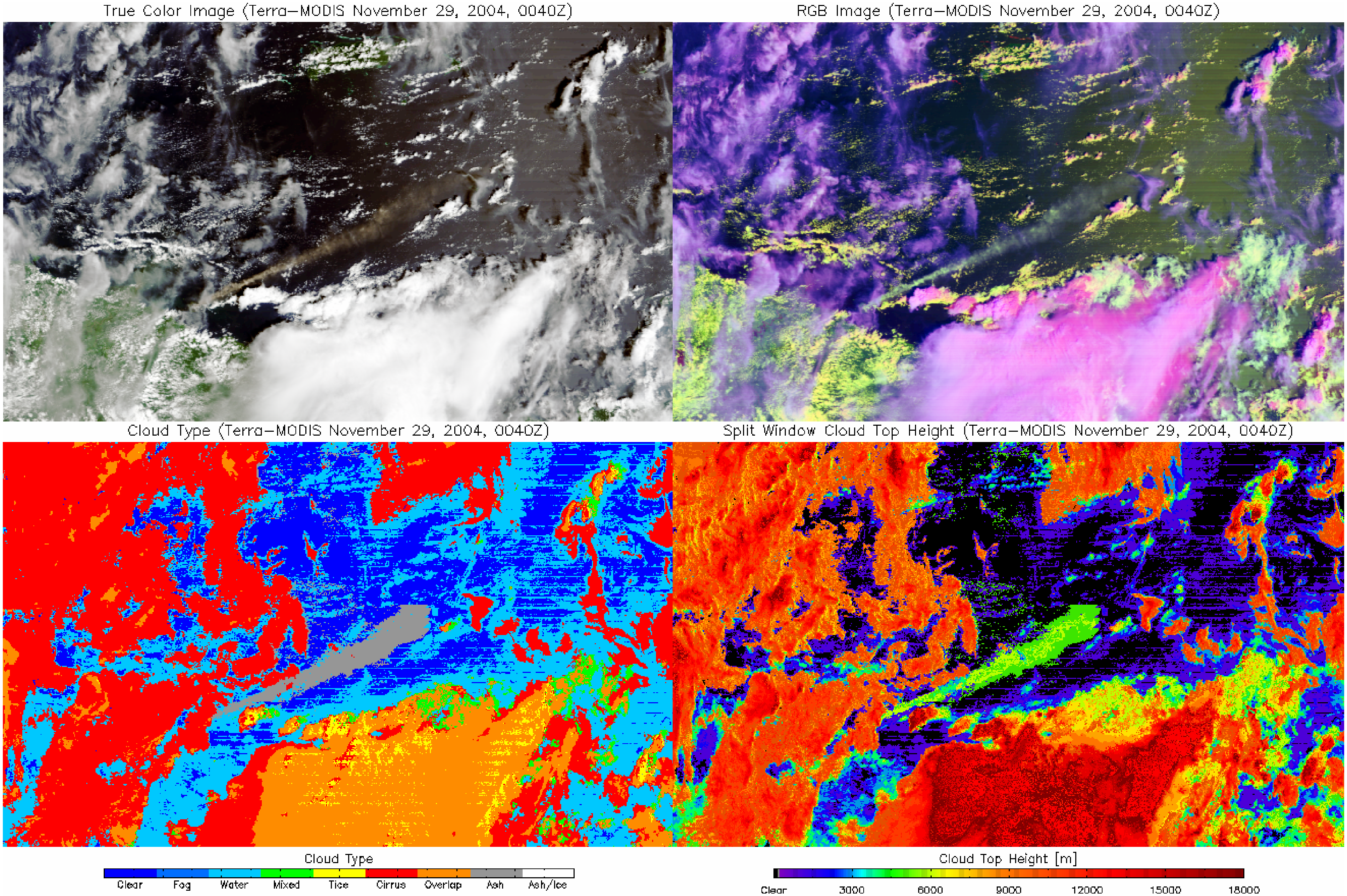


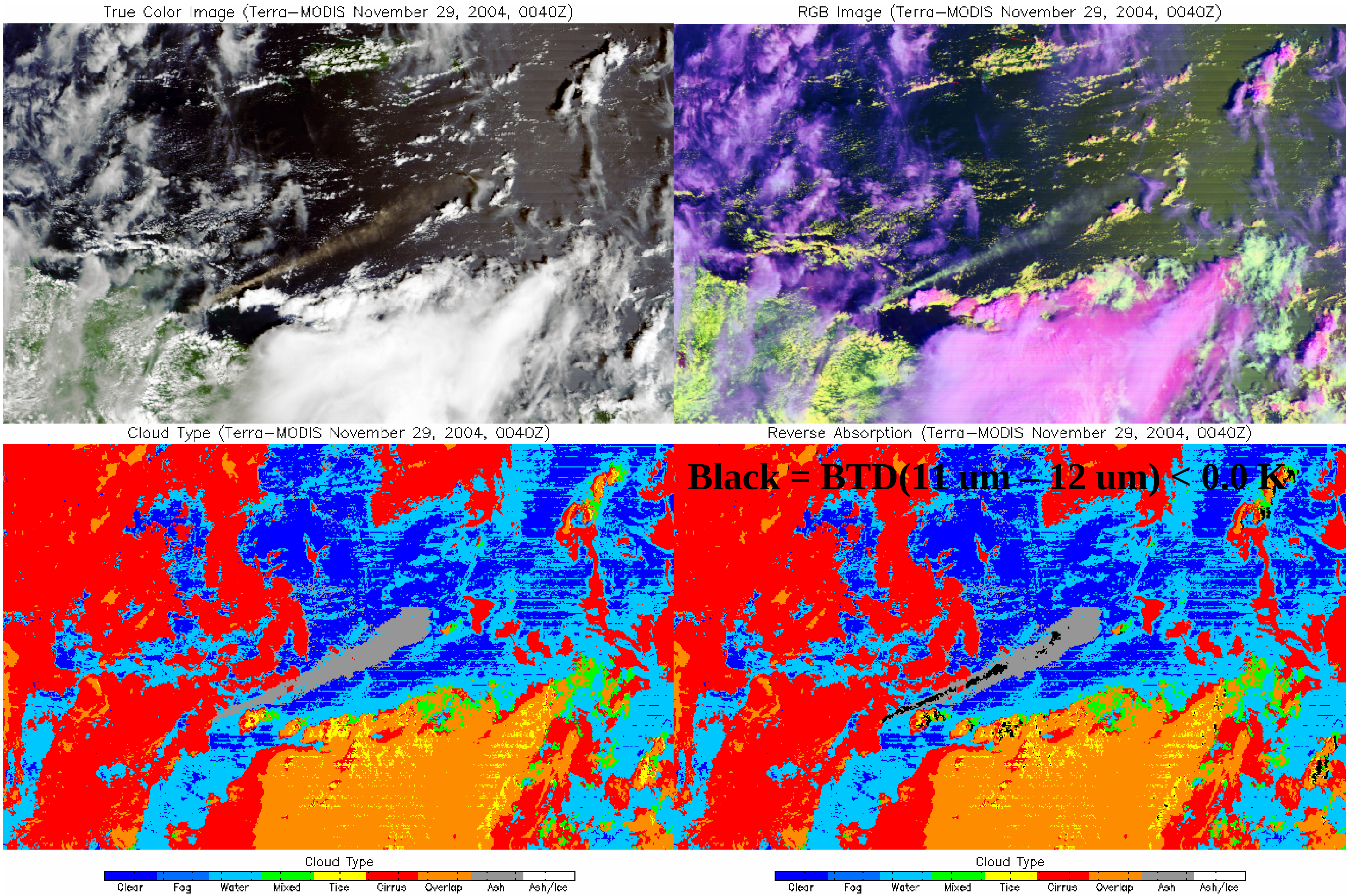
**Image area and color scales are different.

Darwin VAAC estimated lower plume to be at about 18,000 feet (~5000-6000 m).

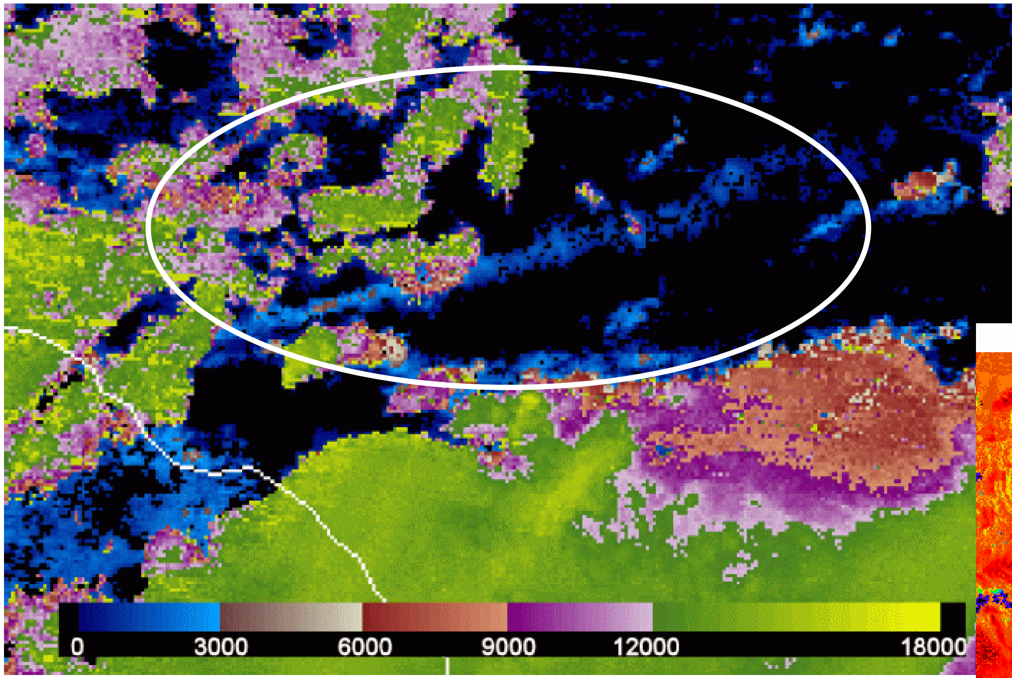
Manam, PNG November 29, 2004



Manam, PNG November 29, 2004



Comparison to MODIS CO_2



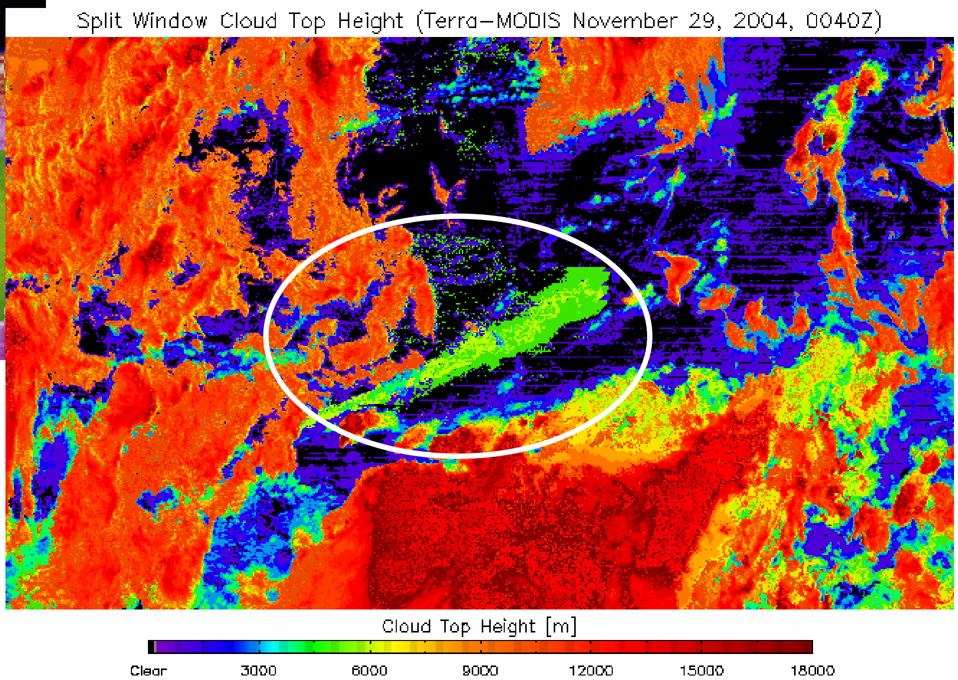
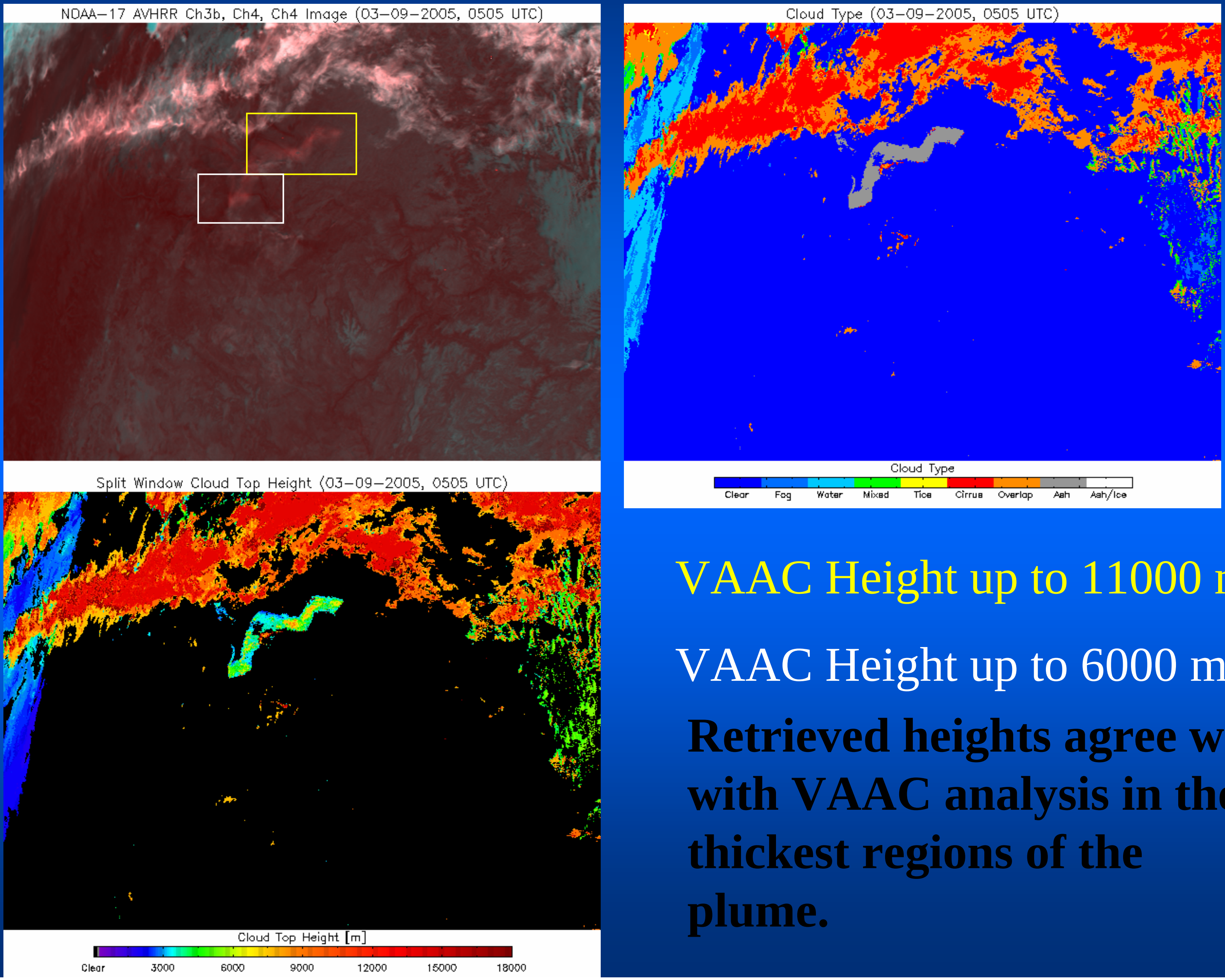


**Image area and color scales are different.

Darwin VAAC estimated plume to be at about 15,000 feet (~4000-5000 m).

Mount St. Helens AVHRR Example



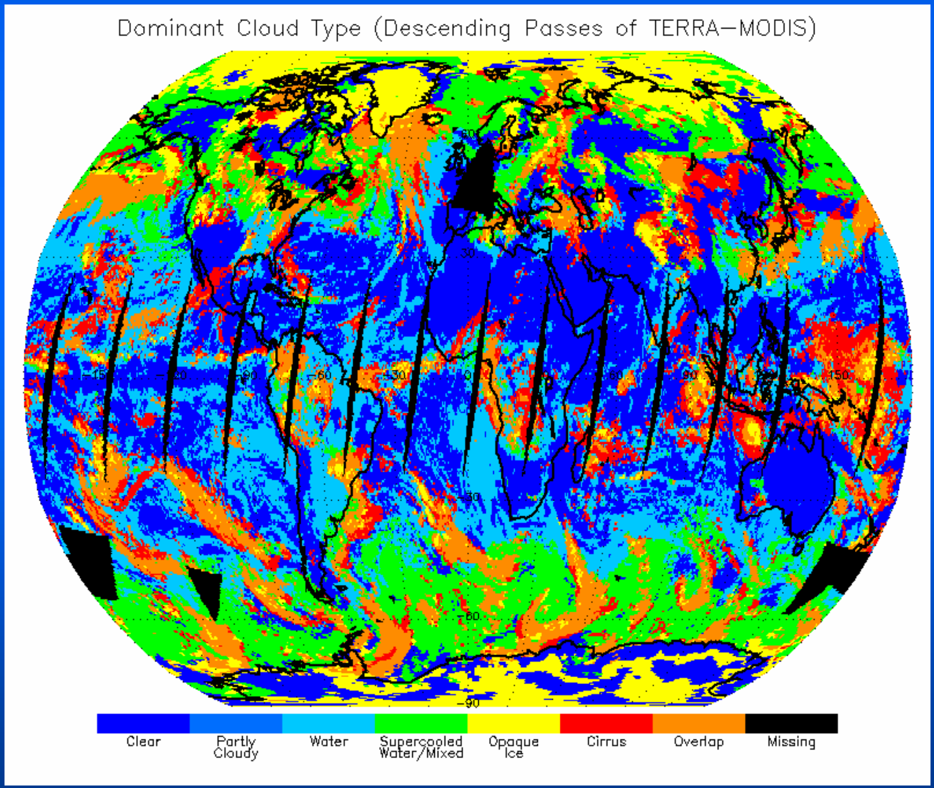
VAAC Height up to 11000 m

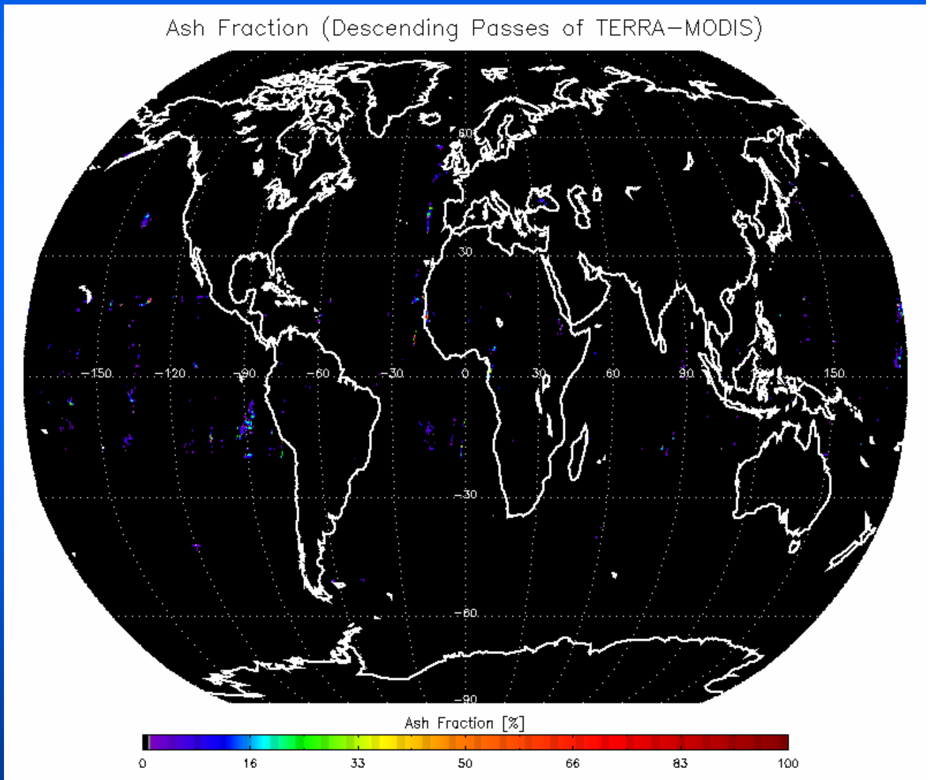
VAAC Height up to 6000 m

Retrieved heights agree well with VAAC analysis in the thickest regions of the plume.

False Alarm Rate

The ash detection algorithm was applied to 1 day of descending node (mainly daytime) *Terra* MODIS data. Little or no ash was reported by the VAAC's on this day (April 4, 2003). A closer examination of pixel level data reveals that most false alarms were caused by water cloud edges.





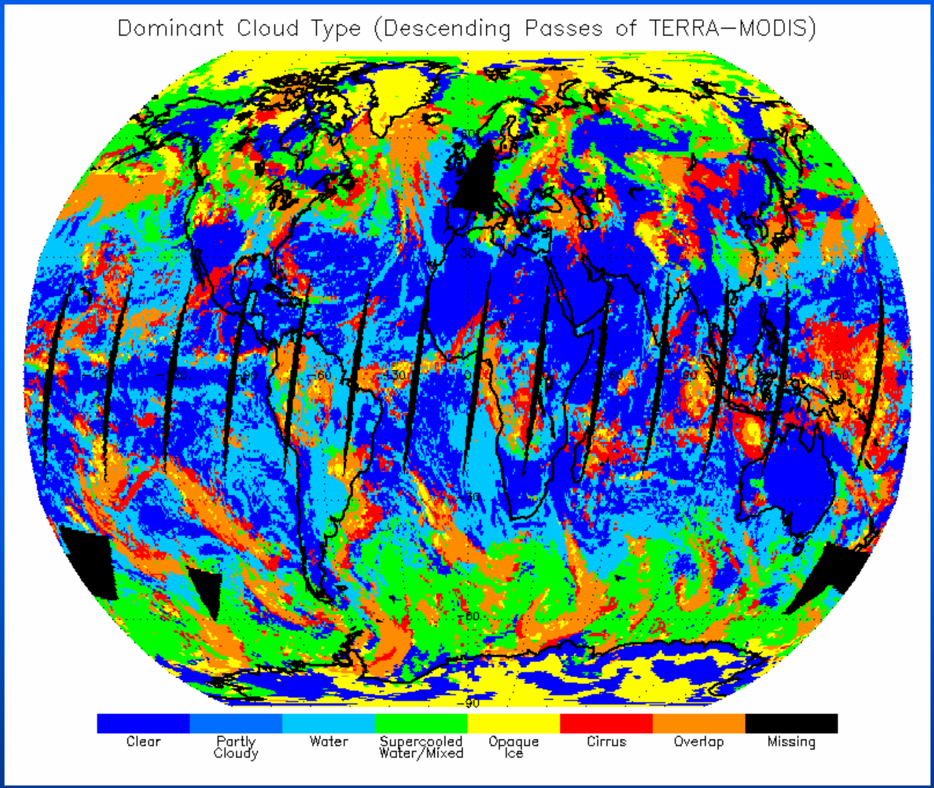
This is NOT a suggested product, but it is an effective diagnostic tool.

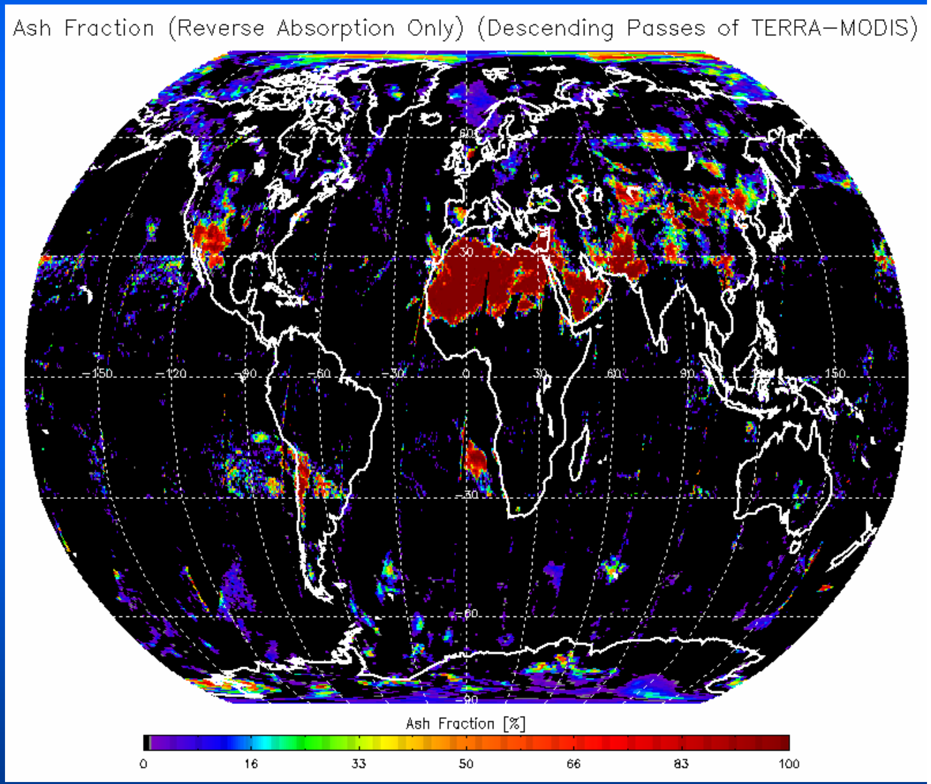
False Alarm Rate

Here is what the false alarm rate looks like is you use the following test for ash:

BTD (11 um – 12 um) < 0.0 K (30^{o}S-30^{o}N)

BTD (11 um – 12 um) < -0.2 K (elsewhere)

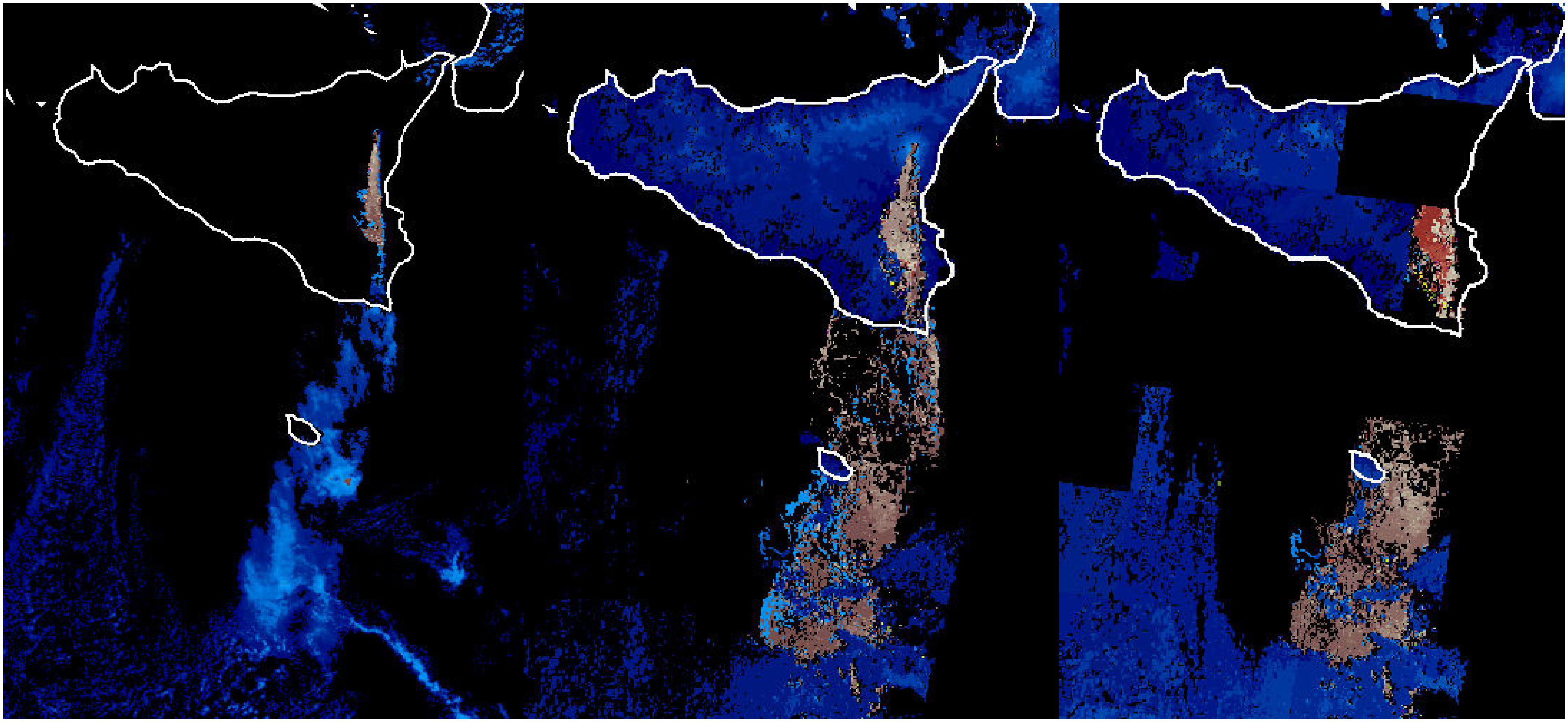




Bottom line: the reverse absorption technique is often useful, but should be supplemented with additional spectral information for optimal results.

Future Work

- Complete transfer of the algorithm from MODIS to AVHRR and GOES.
- Work with Mike Richards to perform more robust split window/CO_2 slicing plume height comparisons. GOAL: try to achieve consistency with CO_2 slicing (as much as possible).
- Continue collaboration with Gary Ellrod and SAB.
- Continue algorithm refinement/characterization and "validation" while keeping in mind the global aspect of the problem.
- Develop quality flags.
- Compare with UAH MODIS clustering technique.



MODIS Co2 Heights

MISR No Wind Correction Heights

MISR With Wind Correction Heights

Etna, Oct. 27, 2002 TERRA 1000Z

Credit: Mike Richards

Current Imagers

- GEO: GOES-9, GOES-10, GOES-12, MSG, and MTSAT-1R
- LEO: AVHRR, ATSR-2, and MODIS
- MODIS and MSG have the best spectral capabilities. But…
- With the exception of GOES-12, all of the above have visible (0.65 um), near-infrared (1.6 um or 3.8 um), 11 um, and 12 um channels, which are vital for automated ash detection.
- GOES-12 does not have a 12 um channel.