AUTOMATED MONITORING OF VOLCANIC ASH MICRO- AND MACRO-PHYSICAL PROPERTIES: A COMPARISON OF CURRENT AND FUTURE SATELLITE INSTRUMENT CAPABILITIES

Michael J. Pavolonis
NOAA/NESDIS/Center for Satellite Applications and Research

Introduction

Airborne volcanic ash is a major aviation, health, and infrastructure hazard. When ingested into aircraft engines, volcanic ash can cause engine damage or failure. For example, in December 1989, a 747 jetliner carrying 231 passengers encountered an ash cloud during an eruption of the Mount Redoubt volcano, located southwest of Anchorage, AK. Within 60 seconds of encountering the heavy ash cloud, all four engines of the aircraft had stalled. Fortunately, the pilot was able to restart the engines, narrowly avoiding a crash. Volcanic ash is extremely abrasive, and even small concentrations can cause severe damage to the aircraft. In addition, ash falls pose significant health and infrastructure threats to those on the ground. Breathing volcanic ash can result in serious illness or death, and ash falls can also pollute water supplies and damage or destroy buildings.

As airborne volcanic ash has significant aviation, health, infrastructure, and economic impacts, frequent observation of volcanic regions and prompt identification of ash clouds are necessary to minimize risk. Geostationary (GEO) and low earth orbit (LEO) satellite data are critical for monitoring volcanic ash clouds. Current satellite-based operational volcanic ash detection techniques used at the various Volcanic Ash Advisory Centers (VAACs) are generally qualitative and require manual analysis. Reliable satellite-based automated ash detection techniques are few and far between due to the difficult nature of separating volcanic clouds from meteorological clouds and other non-volcanic features using reflectance or brightness temperature measurements alone. In addition, to forecast the dispersion of volcanic ash clouds, an estimate of the cloud height, effective particle size, and mass loading is needed. This paper describes quantitative automated techniques for detecting volcanic ash clouds and retrieving the height, effective particle radius, and mass loading. While the basic physical concepts employed in these techniques are applicable to current and future GEO and low earth orbit imaging instruments, it will be shown that the next generation of GEO and LEO satellites (GOES-R and NPOESS) will offer improved capabilities.

Methodology

The volcanic ash detection technique makes heavy use of the concepts described in Pavolonis (2009a) and Pavolonis (2009b). In these papers it was shown that cloud composition could be inferred using infrared effective absorption optical depth ratios (β-ratios) as opposed to traditional brightness temperature differences (BTD's). The β-ratios offer improved sensitivity to cloud composition compared to BTD's because the background (e.g. surface emissivity, surface temperature, atmospheric temperature and water vapor) conditions are accounted for on a pixel-by-pixel basis. In addition, the ash detection algorithm makes advanced use of spatial information in that spatially connected candidate volcanic ash pixels are grouped into cloud objects and the final ash/no ash decision is based on cloud object statistics. It will be shown that the automated volcanic ash detection can be performed with high skill, and, as such, can be used to issue alerts to ash cloud forecasters. In addition, higher skill is possible when three or more infrared window channels are available, such as will be the case with GOES-R and NPOESS.

Once volcanic ash is detected, an infrared-based optimal estimation technique (e.g. Heidinger and Pavolonis, 2009) is used to retrieve the ash cloud temperature, emissivity, and a microphysical parameter. These retrieved parameters can be used to estimate the ash cloud height, mass loading, and effective particle radius, all of which are important for forecasting the ash cloud dispersion. Comparisons with spaceborne lidar indicate that the retrievals perform well under a variety of conditions. The retrievals are best performed, however, using a combination of measurements centered near 11, 12, and 13.3 μm, such as those that will be available on the next generation of GOES satellites (GOES-R).

Results and Conclusions

Automated volcanic ash detection along with micro- and macro-physical property retrievals are needed to track volcanic ash clouds and forecast their dispersion in a timely and accurate manner. Advanced algorithm development for the next generation of GOES satellite (GOES-R) has been leveraged, in part, to develop a combined GEO/LEO volcanic ash monitoring system capable of working with current and future satellite instruments. Example results are shown in the figures below. Figure 1 shows Advanced Very High Resolution Radiometer (AVHRR) ash retrievals for an eruption of Okmok. Figure 2 shows the same products generated for the Spinning Enhanced Visible-Infrared Imager (SEVIRI) for an eruption of Chaiten. SEVIRI data are being used as a proxy for GOES-R Advanced Baseline Imager (ABI) data. In summary, while useful quantitative volcanic ash products can be produced from today's instruments (e.g. Figure 1), more accurate products are possible from the next-generation of instruments (e.g. Figure 2). This paper will quantify the gain in skill and accuracy that can be expected with the next generation of satellites.

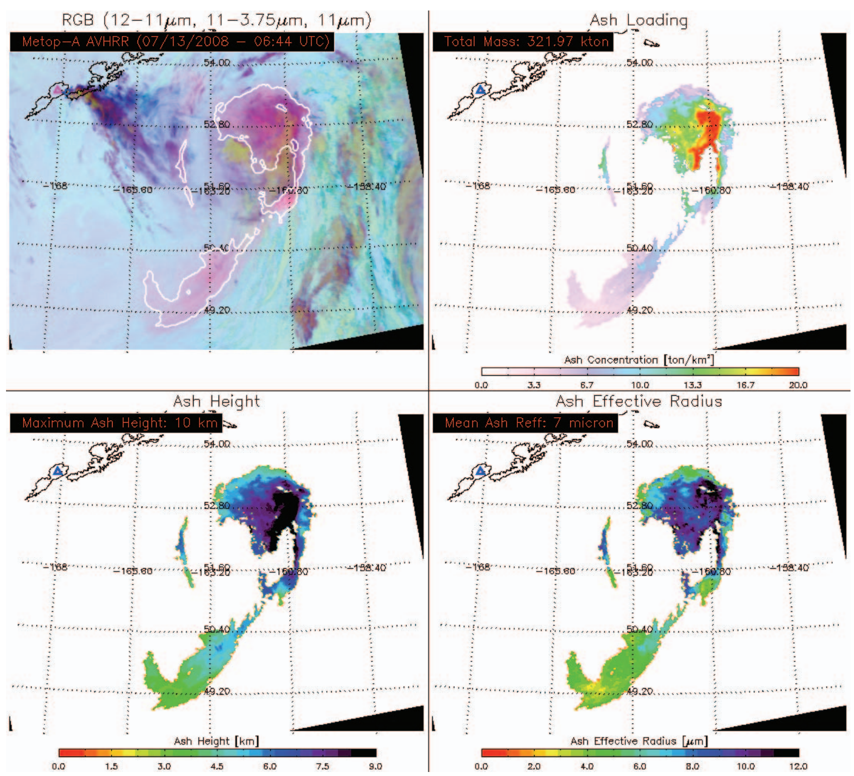

Figure 1: Retrievals of mass loading (upper, right), ash cloud height (lower, left), and effective particle radius (lower, right) performed using Advanced Very High Resolution Radiometer data of an ash cloud produced by Okmok in July 2008. A false color image is shown in the upper, left panel for reference.

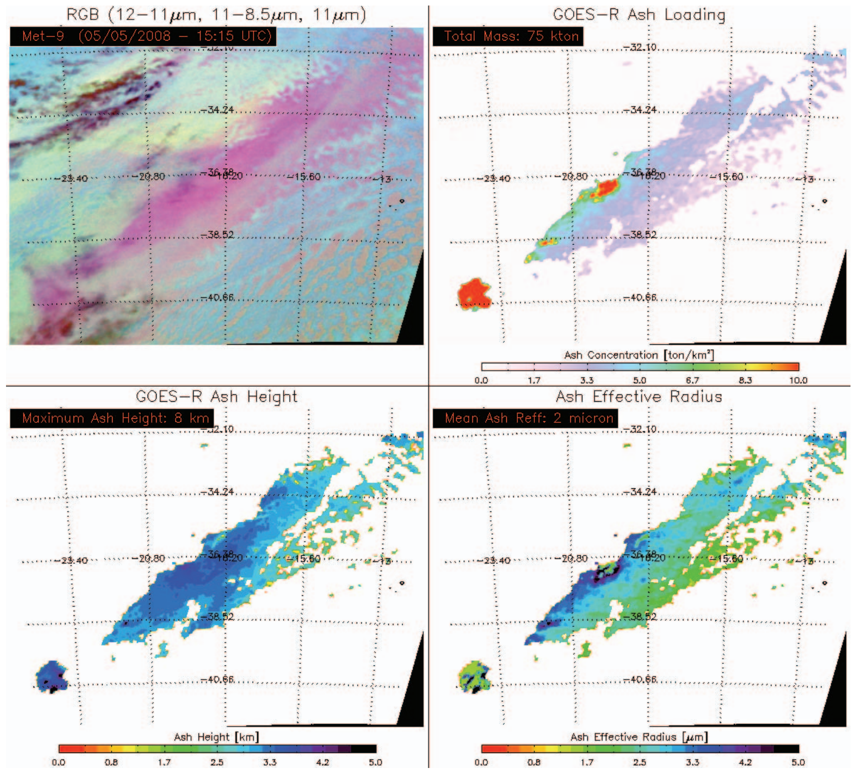

Figure 2: Retrievals of mass loading (upper, right), ash cloud height (lower, left), and effective particle radius (lower, right) performed using Spinning Enhanced Visible-Infrared Imager data of an ash cloud produced by Chaiten in May 2008. A false color image is shown in the upper, left panel for reference.

References

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