Producing quantitative forecasts of volcanic ash using the HYSPLIT transport and dispersion model.

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INTRODUCTION

The HYSPLIT transport and dispersion model is run operationally by the NOAA National Weather Service (NWS) to provide forecast guidance to the NOAA-operated U.S. Volcanic Ash Advisory Centers (VAACs). The current operational HYSPLIT model output product is a set of maps that show the forecast location of ash. Because one arbitrary unit of mass represents the eruption, they do not provide quantitative information on concentration or mass loading of the ash. Quantitative forecasts will be needed in the future because parts of the aviation sector are moving from an ash avoidance approach to a risk-based approach. Inputs to HYSPLIT are meteorological data (provided by a meteorological model) and the source term which consists of the initial positions, amounts, and sizes of ash particles. The initial position of ash particles can be determined since the latitude, longitude and summit height of the volcano are known and an estimate of the plume height is usually available. It is more difficult to determine the amount of ash present in the eruption column and its size distribution. A meaningful quantitative ash concentration forecast cannot be achieved without a reliable quantitative source term. Several approaches to achieving a reliable estimate of the source term are being investigated. Indirect methods look at past relationships between plume height and mass eruption rate to predict the source term. Direct methods use satellite retrievals of volcanic ash to estimate the source term. Verification and model output examples are presented for the eruption of Kasatochi (Aleutian Islands) in 2008.

HYSPLIT Transport and Dispersion model.
http://www.arl.noaa.gov/HYSPLIT_info.php
Lagrangian model designed for simple air parcel trajectory AND complex dispersion/deposition simulations using puff or particle approaches. Here we use a particle approach to model transport and dispersion of volcanic ash. We use a grid with cells 0.05° latitude x 0.1° longitude x 2 km high to calculate mass loading.

METHODOLOGY

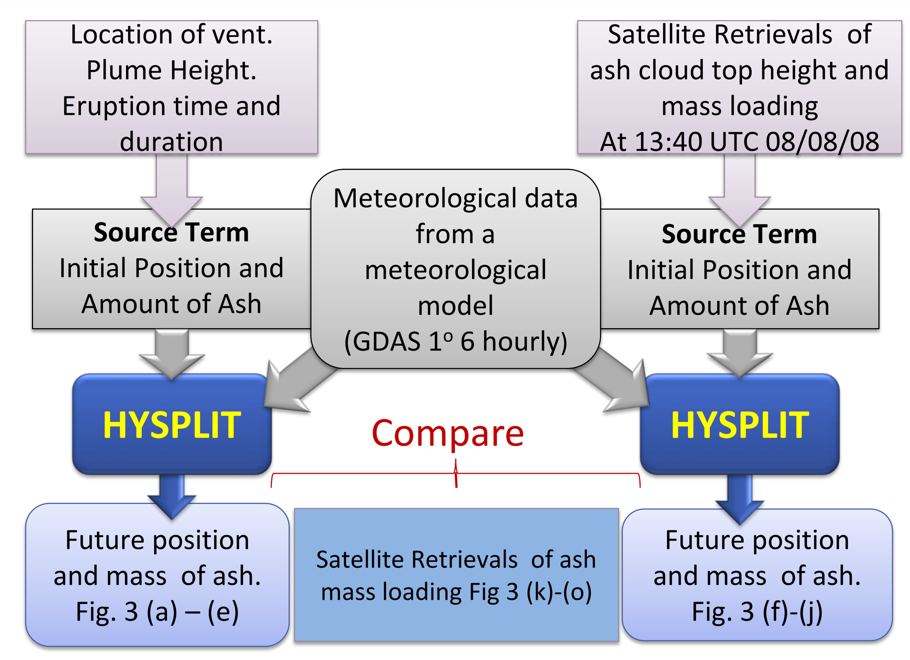


Figure 1 HYSPLIT forecasts of ash mass loading for the 2008 eruption of Kasatochi (Aleutian Islands) are produced using two different methods of estimating the source term. Inputs into HYSPLIT include meteorological data from a meteorological model and a source term which is the initial position and amount of ash. One method is described in Table 1. The second method is described in Fig. 2. Forecasts are produced at 5 times which correspond to the times at which satellite retrievals are available. The critical success index (also called the threat score) is calculated to compare forecast areas with observed areas.

$$CSI = \frac{A}{A+B+C}$$ C A B

Critical Success Index: A measure of how well two areas coincide.

Start Time (UTC)	Duration (hrs.)	Plume Height H	$\dot{M} = \dot{V}\,\rho_{magma}$ ([2]Mastin eqn.)	[3]M_{63}
08/07/2008 22:00	1	14 km	8×10^6 kg/s	0.4
08/08/2008 02:00	1	14 km	8×10^6 kg/s	0.4
08/08/2008 04:30	10	18 km	2×10^7 kg/s	0.4

Mastin eqn.: $H = 2.00\dot{V}^{0.241}$

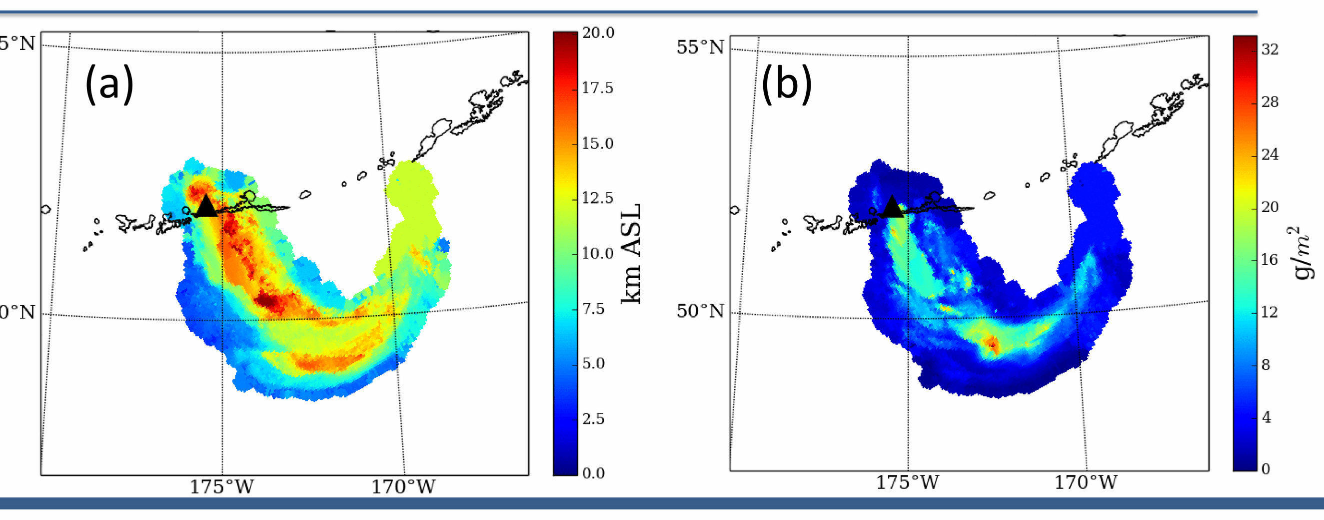
[2]Mastin, L. G., Guffanti, M., Servranckx, R., Webley, P., Barsotti, S., Dean, K., et al. (2009). A multidisciplinary effort to assign realistic source parameters to models of volcanic ash-cloud transport and dispersion during eruptions. *Journal of Volcanology and Geothermal Research, 186*, 10-21.
[3]L.G. Mastin , M. Guffanti, J.W. Ewert, J. Spiegel , *Preliminary Spreadsheet of Eruption Source Parameters for Volcanoes of the World*, U.S. Geological Survey Open-File Report 2009-1133, v. 1.2, 25p. 2009

Table 1: Ash is initialized as a uniform line source which stretches from the summit of the volcano (300 m) to the top of the plume. The duration of the eruption and the plume height are obtained from observation[1]. The amount of ash released per unit time, $\dot{M}$, is determined by an empirical equation relating plume height and volumetric flow rate. This amount is multiplied by an estimate of the fraction of fine ash M_{63} which is obtained from a table published by the USGS. The magnitude of the forecast mass loading is then compared to satellite retrievals and the amount of fine ash released is adjusted to be in better agreement with observation. In this case the rates shown in the table were multiplied by 0.001 to obtain the forecasts shown in Fig. 3 and 4.

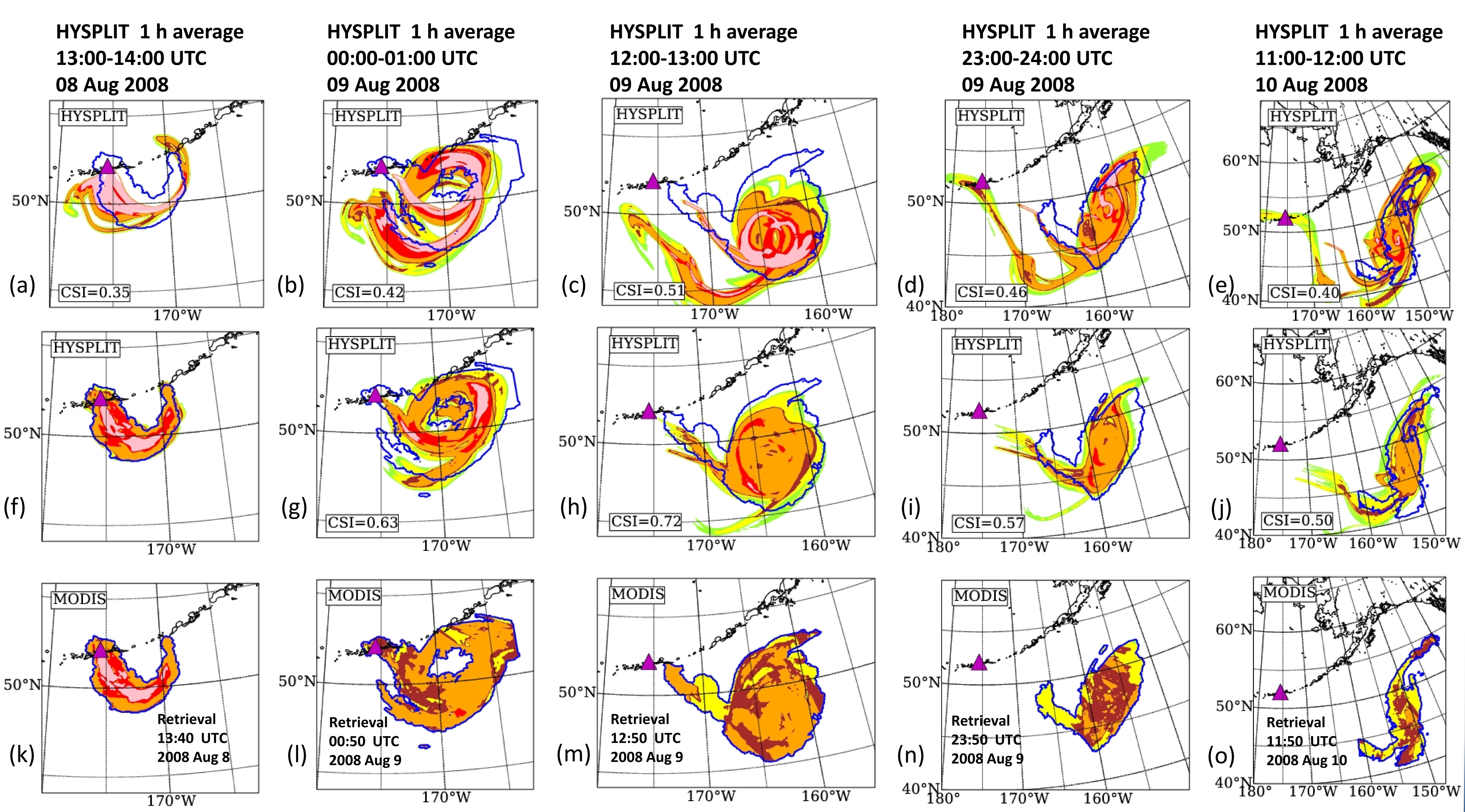
[1] Waythomas , Scott , Prejean , Schneider , Izbekov, Nye , "The 7-8 August 2008 eruption of Kasatochi Volcano, central Aleutian Islands, Alaska" , *J. of Geophysical Research* Vol. 115, B00B06, doi:10.1029/2010JB007437, 2010.

Figure 2 Satellite retrieval of (a) ash cloud top height and (b) ash mass loading at 13:40 UTC on August 08 2008. The retrieval at this time was used to create a source term for input into HYSPLIT. The ash was initialized in a layer 2 km deep centered at the retrieved top height at each location. The amount of ash at each location was determined by the retrieved mass loading. The data was obtained from the MODIS instrument. Satellite ash retrievals were provided by Michael Pavolonis and are available at ftp://ftp.ssec.wisc.edu/pub/geocat/noaa_ash_retv/kasatochi.)

Pavolonis, Hiedinger, Sieglaff, "Automated Retrievals of Volcanic Ash and Dust Cloud Properties From Upwelling Infrared Measurements.", *J. of Geophysical Research: Atmospheres*, VOL. 118, 1436-1458, doi:10.1002/jgrd.50173, 2103.



RESULTS AND DISCUSSION



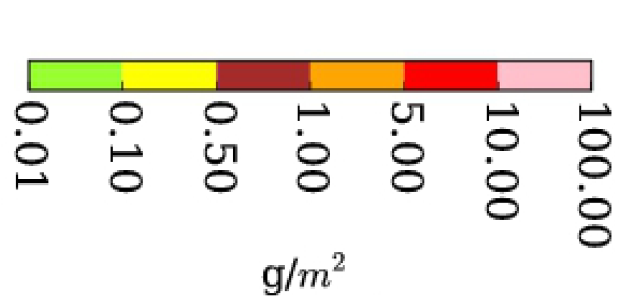
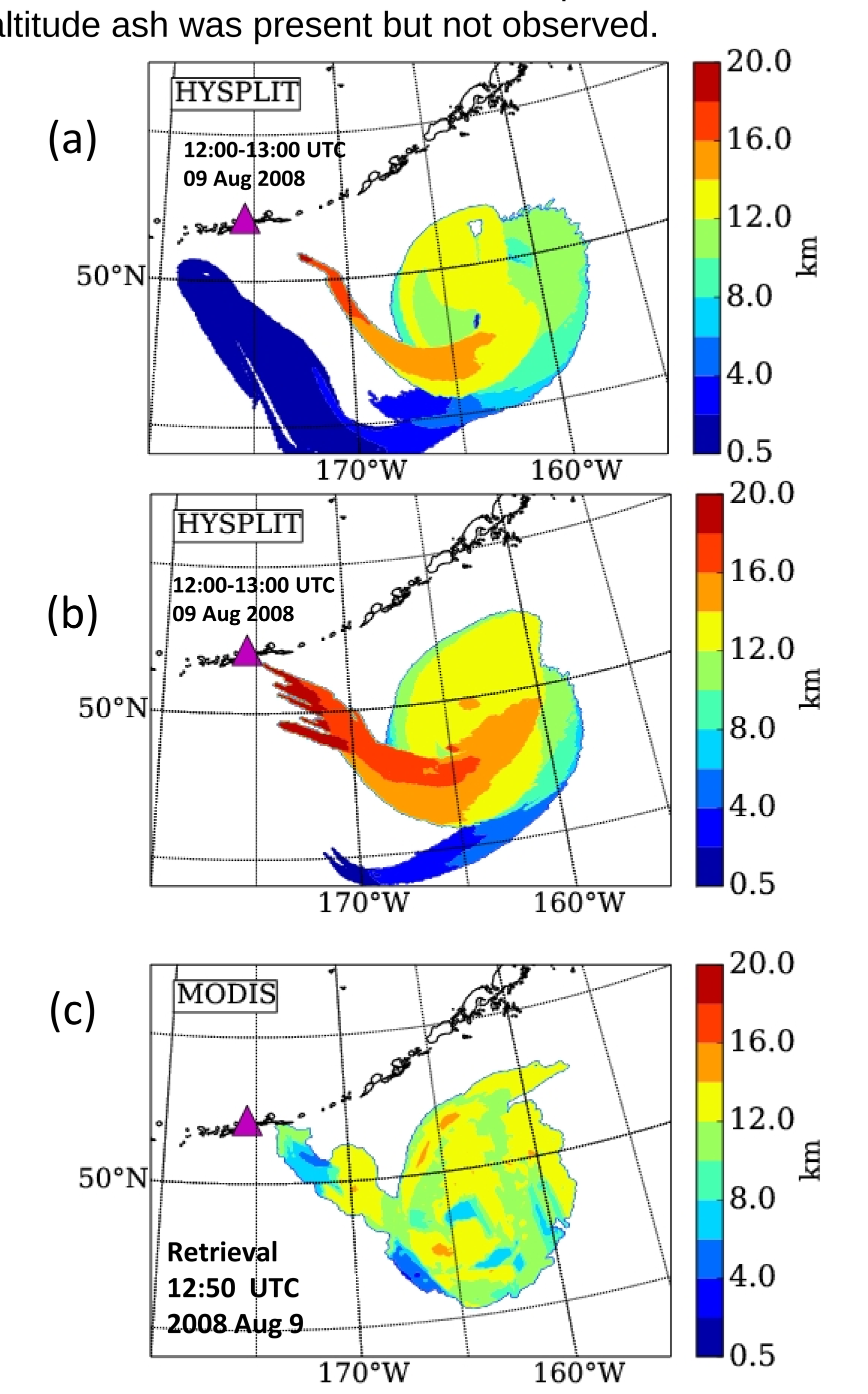


Figure 3 Contour plots of mass loading (g/m[2]) of volcanic ash produced by the 2008 eruption of Kasatochi in the Aleutian Islands. Top row (a-e): HYPSPLIT forecast with ash initialized from a uniform line source above the volcano summit. See Table 1 for details. Middle row (f-j): HYSPLIT forecast with ash initialized from the MODIS satellite retrieval at 13:40 UTC on 08/08/2008. See Fig. 2. Bottom row (k-o): MODIS satellite retrieval of ash mass loading. The blue outline in each figure shows the outline of the satellite ash retrieval. HYSPLIT forecasts are 1 hour averages of ash mass loading. MODIS retrievals represent data collected over a period of minutes. The CSI calculated to compare the forecast with the observation is given in a box in the lower left of each forecast. No CSI was calculated for (f) since the observed values were used to initialize the model at this time and thus the forecast and the observation are essentially the same.

Figure 4 Contour plots of top height of ash cloud. (a) (b) (c) correspond to Fig. 3 (c) (h) and (m) but show contours of ash height rather than mass loading. The long tail of ash seen in Fig. 3 (c), (d) and (e) which does not correspond to any observed ash is at a low altitude (< 2 km). Mass is expected to be distributed more heavily toward the top of the eruption column. If we use a distribution in which most of the mass is released above 2 or 4 km then this tail is diminished and the CSI improves somewhat. Although note that some of this tail is outside of the satellites view and thus was not used in the computation of the CSI. The satellite is not able to observe ash which lies below clouds so it is also possible that some low altitude ash was present but not observed.



SUMMARY

Satellite observations were key to obtaining a quantitative forecast. Although the location of the forecast ash in Fig. 3 (a)-(e) would have remained unchanged, the magnitude of the forecast mass loading would have been three orders of magnitude higher if we had to rely on empirical relationships between plume height and mass eruption rate and estimates of fine ash fraction. When volumetric flow rate is plotted against plume height for historical eruptions there is a large amount of scatter in the data. This is expected. To a large extent the amount of thermal energy, and thus the mass of hot material, released by the eruption determines the plume height. However plume heights will also be affected by other factors such as wind speed, presence of water vapor, and density stratification of the atmosphere, just to name a few. Physical processes which cause fine ash to aggregate and fall out sooner than the model predicts can also contribute to over-prediction of the ash mass loading. While it may be possible to adjust the mass eruption rate on the basis of other observations, such as wind speed and humidity, the use of satellite retrievals to help determine the source term would seem to be immediately applicable to a wide range of eruption types and meteorological conditions.

ONGOING WORK

- Apply the same methodology to other eruptions.
- Use satellite retrievals of ash effective radius to refine the source term.
- For ongoing eruptions explore how information from satellite retrievals and meteorological forecasts may be used to generate a predicted source term. For instance a high wind speed may reduce the plume height for relatively weak eruptions. If satellite retrievals indicate that an ongoing eruption has a fairly steady mass eruption rate then it may be possible to predict the future plume height by using a meteorological forecast of the wind speed. Since plume height is the main predictor of the spatial location of future ash, this could lead to significant improvements in forecast accuracy.

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