Using Satellite Based Volcanic Ash Products to Improve HYSPLIT Transport and Dispersion Model Predictions

Alice Crawford[1,2] , Barbara Stunder [1], Jaime Kibler[3], Michael J. Pavolonis[4]

[1] NOAA/ARL, College Park, MD, [2] UMD/CICS, College Park, MD, [3]NESDIS/OSPO/SPSD/SAB-Washington VAAC, College Park, MD

[4] NOAA Center for Satellite Applications and Research, Madison, WI

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) on the likely evolution of the ash cloud. The model requires meteorological data and an ash source term (position, time, amount and size of ash) as input. Output consists of mass loading or concentration as a function of time and position. Historically, real time quantitative information about an eruption has been sparse. Even estimations of the plume height and duration of the event, two quantities which significantly impact the future spatial extent of the ash cloud, can have significant uncertainties. Consequently the initialization and thus the output of a transport and dispersion model can have large uncertainties. Recently, satellite based volcanic ash retrieval algorithms have been developed which can identify the spectral signature of ash and then calculate the mass loading, cloud height and effective radius as a function of position for the ash cloud. This type of information can dramatically reduce uncertainty in model output by reducing uncertainty in the source term. It also has the potential to direct model development by providing more opportunities for model evaluation. Here we look at the 2008 eruption of Kasatochi in the Aleutian Islands. We use satellite retrievals provided by NOAA/CIMSS for this eruption which utilized data from the MODIS instrument. We use five retrievals which are spaced 11 to 12 hours apart. The first retrieval occurred near the end of the main eruption. We compare HYSPLIT output produced using different source terms. We use the satellite retrievals both to help construct some of the source terms and for verification. For further verification, data from the CALIOP lidar instrument aboard CALIPSO is used. This case illustrates the potential for improving transport and dispersion model output by using satellite information to construct source terms and for model evaluation.

http://www.arl.noaa.gov/HYSPLIT_info.php

METHOD

SOURCE TERMS

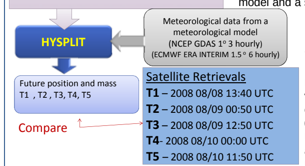
Line - uniform line source above the vent

CYL - uniform cylindrical source centered at vent with radius of 100 km

RT1 – source at location of retrieval at T1

RT2 - source at location of retrieval at T2

RT3 - source at location of retrieval at T3

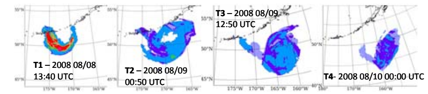


[1] Waythomas , Scott , Prejean , Schneider , Izbekov, Nye , "The 7-8 August 2008 eruption of Kasatochi Volcano, central Aleutian Islands, Alaska" , *J. of Geophysical Research* Vol. 115, B00B06, doi:10.1029/2010JB007437, 2010.

Figure 1 HYSPLIT forecasts of ash mass loading for the 2008 eruption of Kasatochi (Aleutian Islands) are produced using different estimations of the source term. Inputs into HYSPLIT include meteorological data from a meteorological model and a source term which is the initial amount of ash. Forecasts are produced at 5 times which correspond to the times at which satellite retrievals are available.

For sources initiated at the vent (Line and CYL) ash was emitted up to 14 km for 1 h at 08/07 22 UTC and 08/08 02 UTC and up to 18 km for 8 h at 08/08 4 UTC.[1]

RT1, RT2, RT3 sources are described in Figure 2.



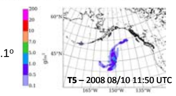


Figure 2: Passive IR satellite retrievals[2] of column mass loading of ash at five time periods. These retrievals as well as the retrievals for top height were regridded onto a 0.05° longitude x 0.1° latitude grid. To create a source term, the total mass released from each grid point was determined by the retrieved mass loading.

Mass was released in a layer from the retrieved top height to 2.5 km below the top height. Retrievals at T1-T3 were used to create source terms for input into HYSPLIT. All retrievals were also used for verification. The minimum mass loading detectable by satellite is dependent on many factors but is approximately 0.1 g/m[2] in good conditions.

[2]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.

HORIZONTAL EXTENT OF ASH

		Observed Yes	Observed No
Critical Success Index	$CSI = \frac{A}{A+B+C}$		
Probability of Detection	$POD = \frac{A}{A+C}$	Modeled Yes: A	B
False Alarm Ratio	$FAR = \frac{B}{A+B}$	Modeled No: C	D

CSI – overall measurement of spatial overlap
POD and FAR both low - modeled cloud too small
POD and FAR both high – modeled cloud too large
POD low and FAR high – modeled cloud offset
POD high and FAR low – good spatial overlap

Figure 3: The cumulative distribution function (CDF) of the mass loading produced by the cylindrical source at all five time periods. In this example the mass loading of the modeled cloud spans 5-6 orders of magnitude. For HYSPLIT runs initiated at the vent, the model is configured to emit one unit mass /h and the output is given in unit mass/m^2. A threshold must be chosen in order to compare the spatial overlap of the modeled and observed clouds. Four thresholds are chosen as shown. The unit mass can be converted to grams by estimating that the threshold is equal to 0.1 g/m^2. The light blue shaded area indicates a range of thresholds which might be chosen by applying an empirical equation with a plume height of 14-18 km and a mass fraction of fine ash of 10%. This type of graph illustrates the effect of changing the threshold. The different thresholds are equivalent to different mass eruption rates (MER) or to different ash reduction levels available operationally or on the web in the VAFTAD format.

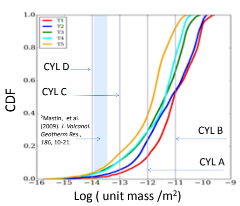


Figure 4: The mass loading CDF of the satellite retrievals at each of the 5 time periods (solid lines). For comparison, CDF's of the modeled clouds which were initiated with the first satellite retrieval (RT1 ECMWF) are shown (dashed lines). A measure of how well the modeled and observed mass loading distributions compare is the absolute value of the maximum difference between the two CDF's (Kolmogorov Smirnov Parameter, KSP). CDF's for values above the threshold of 0.1 g/m2 are used to calculate the KSP. Because this threshold is not exact, there is a fairly large error in the KSP. High values above 0.7 indicate that the distributions have little overlap while values below 0.5 indicate fairly good overlap. Values of KSP are shown in Fig. 5d.

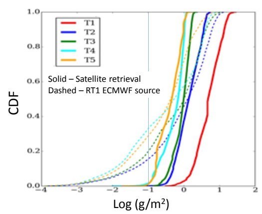
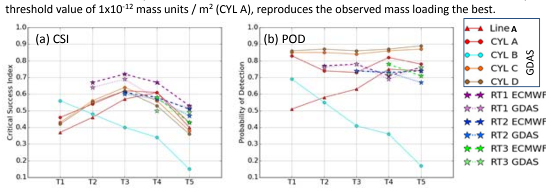
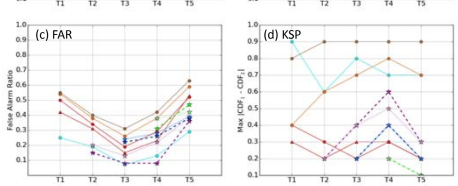


Figure 5: The CSI, POD, FAR and KSP are plotted for different source terms and meteorological data sets for the 5 time periods. The RT1 source consistently produced the highest CSI by having a fairly large POD and one of the lowest FARs. RT2 and RT3 had similar CSI, but there appears to be no advantage to using the later satellite retrieval for initialization in this example. The Line source (same threshold as CYL A) initially produced a plume that was too narrow (low POD and FAR), however the plume spread with time. Although CYL B does well for the first time period, the plume dissipates much too quickly (low FAR and POD). CYL A, C and D had similar CSI's. CYL C and D had both the highest POD's and highest FAR's. CYL B , C and D have a very high KSP, indicating that the mass distribution has little overlap with the observed mass distribution. For the sources initiated at the vent, picking a threshold value of 1x10^{-12} mass units / m^2 (CYL A), reproduces the observed mass loading the best.





Estimation of thickness:
For sources initiated with a satellite retrieval the cloud thickness must be estimated. Here we show results for mass released from the top height to 2.5 km below the top height. We also investigated releasing mass in a 6 km layer centered on the retrieved top height and a thick layer from the top height to a point 2 km above ground level. Using different thicknesses produced comparable results to the ones shown.

VERTICAL STRUCTURE OF ASH

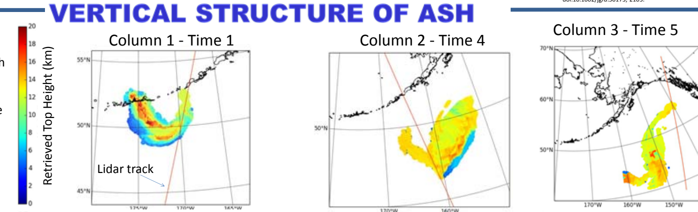
Figure 7: The top row shows plots of the satellite retrieved top height at T1, T4 and T5 which are the time periods where a lidar overpass intersected the cloud. The orange line shows the lidar track.

Row 2-6 show data from the CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization instrument aboard CALIOP. The data was obtained from the NASA Langely Research Center Atmospheric Science Data Center. https://eosweb.larc.nasa.gov

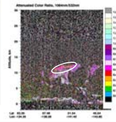
Row 2 shows curtain plots of the 532 nm backscatter of the lidar in shades of blue and gray and the satellite retrieved top heights along the lidar track in red.

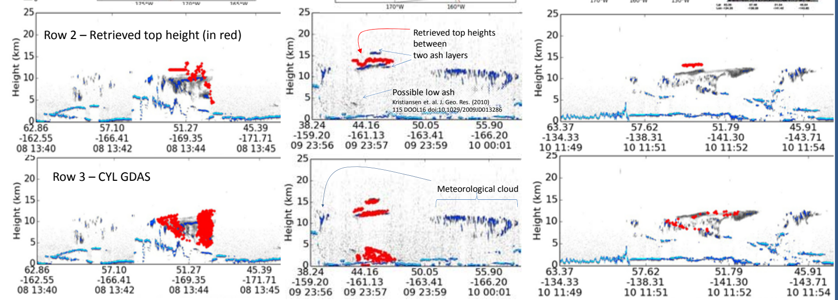
Rows 3-6 show the same curtain plots of the 532 nm backscatter from the lidar as row 2. The position of HYSPLIT computational particles close to the lidar track are plotted in red.

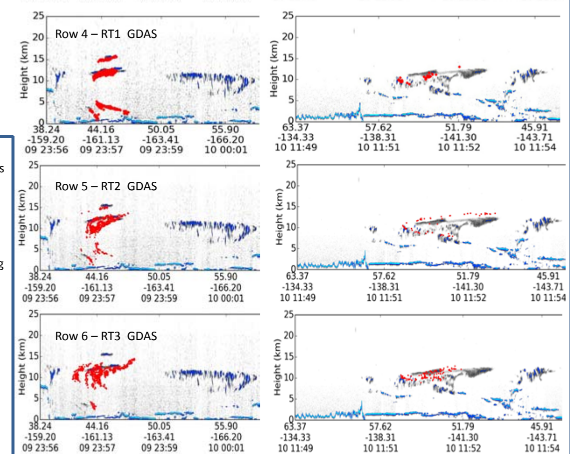
Row 2 - Retrieved top heights
Row 3 – Cylindrical source
Row 4 - RT1 GDAS source
Row 5 – RT2 GDAS source
Row 6 – RT3 GDAS source

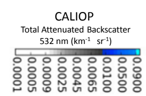


At T5 it is not as clear which lidar features are ash and which are meteorological cloud. The lidar track cuts through the very edge of the ash cloud and there is meteorological cloud nearby. The color ratio browse image indicates that the circled area is the most likely to contain ash.[3]





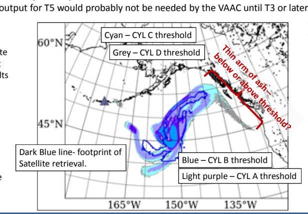




[3]Winker, D. M., Z. Liu , A. Omar , J. Tackett, D. Fairlie (2012), CALIOP observations of the transport of ash from the Eyjafjallajökull volcano in April 2010. *J. Geophys. Res.*, 117, D00U15, doi:10.1029/2011JD016499.

Figure 6: The statistics do not always tell the whole story. This figure shows model output for the cylindrical source at T5. CYL D (as well as CYL C to some extent) shows a thin arm of ash extending along the coastline. This arm is below threshold for CYL A. This arm could significantly affect the long term forecast put out by the VAAC. At times T2-T4, it would be difficult to make a case for choosing between the CYL A, C and D thresholds based on the CSI or agreement in modeled area. Consequently, at these times there would be a large uncertainty in the forecast output for T5. Having information about the mass loading would reduce the uncertainty by making a strong case for choosing the CYL A threshold which clearly produces output which agrees with the observed mass loading better than the CYL B, C, D thresholds.

At T1, the CYL B threshold might be chosen based on the CSI. However if mass loading information is available then the very high KSP values for CYL B and lower values for CYL A and C at this time might lead to a better estimation of the uncertainty in the T5 forecast. (Note T1 and T5 are 46 hours apart and currently VAACs produce +6, +12, and +18 h forecasts and in some cases +24 h forecasts. So model output for T5 would probably not be needed by the VAAC until T3 or later.)



The role of the meteorology:
The ash from the volcano was swept up by a low pressure system. The presence of this strong synoptic scale feature almost certainly makes the modeled cloud at T2-T5 less sensitive to initial conditions and is probably why we see the CSI is lower at T1 than at subsequent times (T2-T4). At T1 the cloud shape is influenced by the eruption dynamics and smaller scale winds which may not be modeled as well.

HYSPLIT output is able to capture the vertical structure of the ash cloud well. The output using the RT2 and RT3 sources do not agree as well with the lidar data at T4 as the output using the RT1 source. Lidar data, retrieved top heights, and model output all suggest that the ash cloud evolves into a complex three dimensional structure with patches and layers. The RT1 source may have an advantage over the RT2 and RT3 sources in that the early cloud has a simpler structure and is better represented by a single layer.

SUMMARY

Using a source term located at the observed position of the ash cloud produces better or comparable results to using a source term located at the vent. The mass loading retrieval can reduce uncertainty in the forecast modeled ash cloud by providing better information on which portions of the modeled cloud would be too diffuse to be detected. A cylindrical source may represent the early plume better than a line source for large eruptions.

Some of this research was in response to requirements and funding by the Federal Aviation Administration (FAA). The views expressed are those of the authors and do not necessarily represent the official policy or position of the FAA

Contact information *Address*: 5830 University Research Court, Rm. 4208, College Park, MD 20740 *Email*: Alice.Crawford@noaa.gov *Tel*: 301-683-1380