1-1 Stratosphere-Troposphere Observations; Approach from Atmospheric Remote-sensing to Social Safety

Predicting and Validating the Motion of an Ash Cloud during the 2006 Eruption of Mount Augustine Volcano, Alaska, USA.

Richard L. COLLINS, Javier FOCHESATTO, Kenneth SASSEN, Peter W. WEBLEY, David E. ATKINSON, Kenneson G. DEAN, Catherine F. CAHILL, and MIZUTANI Kohei

On 11 January 2006, Mount Augustine volcano in southern Alaska began erupting after 20-year repose. The Anchorage Forecast Office of the National Weather Service (NWS) issued an advisory on 28 January for Kodiak City. On 31 January, Alaska Airlines cancelled all flights to and from Anchorage after multiple advisories from the NWS for Anchorage and the surrounding region. The Alaska Volcano Observatory (AVO) had reported the onset of the continuous eruption. AVO monitors the approximately 100 active volcanoes in the Northern Pacific. Ash clouds from these volcanoes can cause serious damage to an aircraft and pose a serious threat to the local communities, and to transcontinental air traffic throughout the Arctic and sub-Arctic region. Within AVO, a dispersion model has been developed to track the dispersion of volcanic ash clouds. The model, Puff, was used operational by AVO during the Augustine eruptive period. Here, we examine the dispersion of a volcanic ash (or aerosol) cloud from Mount Augustine across Alaska from 29 January through the 2 February 2006. We present the synoptic meteorology, the Puff predictions, and measurements from aerosol samplers, laser radar (or lidar) systems, and satellites. Aerosol samplers revealed the presence of volcanic aerosols at the surface at sites where Puff predicted the ash clouds movement. Remote sensing satellite data showed the development of the ash cloud in close proximity to the volcano consistent with the Puff predictions. Two lidars showed the presence of volcanic aerosol with consistent characteristics aloft over Alaska and were capable of detecting the aerosol, even in the presence of scattered clouds and where the ash cloud is too thin/disperse to be detected by remote sensing satellite data. The lidar measurements revealed the different trajectories of ash consistent with the Puff predictions. Dispersion models provide a forecast of volcanic ash cloud movement that might be undetectable by any other means but are still a significant hazard. Validation is the key to assessing the accuracy of any predictions. The study highlights the use of multiple and complementary observations used in detecting the trajectory ash cloud, both at the surface and aloft in the atmosphere.

Keywords
Aviation hazards, Volcanic aerosols, Lidar, Remote sensing

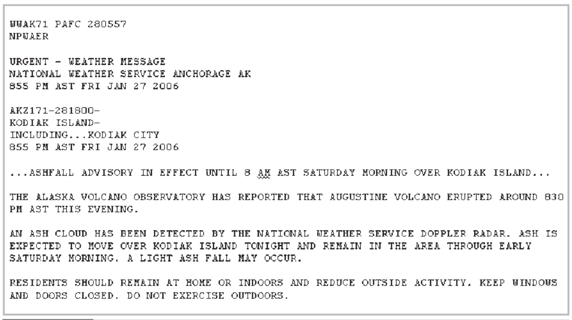
1 Introduction

On 11 January 2006 Mount Augustine (59.36°N, 153.435°W) volcano in southern Alaska began erupting after a 20-year repose (Power et al, 2006). There were 13 explosive eruptions in 20 days with a period of continuous activity from 28 January until 2 February. This period began at 0537 28 January UTC (2037 27 January Alaskan Standard Time, AKST) with four strong explosions that generated ash plumes to heights of 9 km above sea level. Figure 1 shows the ash plume over the volcano on the afternoon of 30 January. The Anchorage Forecast Office of the National Weather Service (NWS) issued an advisory at 0555 28 January UTC (2055 27 January AKST) warning residents of Kodiak City to remain indoors and avoid exposure to the ash (Fig. 2). At 0506 31 January UTC (2006 30 January AKST) Alaska Airlines cancelled all flights to and from Anchorage (Fig. 3) after the Anchorage Forecast Office had issued a series of advisories for Kodiak Island, Kenai Peninsula, Western Prince William Sound and Anchorage.

The NWS advisory notes that the Alaska Volcano Observatory (AVO) had reported the eruption. AVO was established in 1988 as a joint program of the United States Geological Survey (USGS), Geophysical Institute (GI) at the University of Alaska Fairbanks (UAF), and the State of Alaska Division of Geological and Geophysical Surveys (ADGGS). AVO is charged with monitoring the 100 active volcanoes in the Northern Pacific. The AVO reports are used, including correspondence with the NWS and Federal Aviation Agency (FAA), to alert aircraft to the presence of volcanic ash clouds that could damage the aircraft and pose an aviation hazard. The need for such a monitoring program was highlighted during the December 1989 eruption of Mt. Redoubt volcano (Miller and Chouet, 1994). During this eruption a Boeing 747 aircraft flew into the Redoubt ash cloud. The ash interrupted the operation of all four engines (Steenblik, 1990; Casedevall, 1994). The engines restarted 1–2 minutes before impact, with no loss of life. Damage to the aircraft was estimated at $80 million. Since that time, UAF-GI within AVO has developed an ash dispersion model called "Puff" that allows forecasters to predict the movement of volcanic ash clouds and warn aircraft of potential hazards (Searcy et al., 1998; Dean et al., 2002)

Fig.1 Volcanic eruption cloud from Mount Augustine volcano at 2200 30 January 2006 UTC (1300 AKST)

Photograph courtesy of Game McGimsey (AVO/USGS)



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URGENT - WEATHER MESSAGE
NATIONAL WEATHER SERVICE ANCHORAGE AK
855 PM AST FRI JAN 27 2006

AKZ171-281800-
KODIAK ISLAND-
INCLUDING...KODIAK CITY
855 PM AST FRI JAN 27 2006

...ASHFALL ADVISORY IN EFFECT UNTIL 8 AM AST SATURDAY MORNING OVER KODIAK ISLAND...

THE ALASKA VOLCANO OBSERVATORY HAS REPORTED THAT AUGUSTINE VOLCANO ERUPTED AROUND 830 PM AST THIS EVENING.

AN ASH CLOUD HAS BEEN DETECTED BY THE NATIONAL WEATHER SERVICE DOPPLER RADAR. ASH IS EXPECTED TO MOVE OVER KODIAK ISLAND TONIGHT AND REMAIN IN THE AREA THROUGH EARLY SATURDAY MORNING. A LIGHT ASH FALL MAY OCCUR.

RESIDENTS SHOULD REMAIN AT HOME OR INDOORS AND REDUCE OUTSIDE ACTIVITY. KEEP WINDOWS AND DOORS CLOSED. DO NOT EXERCISE OUTDOORS.

Fig.2 National Weather Service Ash Advisory: 0555 28 Jaunuary UTC (2055 27 January, 2006. AKST)

Alaska Airlines Cancels Anchorage Flights As Result Of Mt. Augustine Volcanic Ash
1/30/2006 8:06 p.m.

ANCHORAGE, ALASKA – Alaska Airlines announced it has canceled all flights to and from Anchorage, Alaska, tonight and early Tuesday morning. The flights were canceled as a safety precaution related to the pattern of ash at altitude created by the Mt. Augustine volcano.

As of 6 p.m. Alaska time, 36 flights were canceled. The airline is monitoring the pattern of ash at altitude on a continuous basis and anticipates resuming Anchorage flights on Tuesday.

Fig.3 Alaska Airlines announces flight cancellations

http://www.alaskasworld.com/Newsroom/ASNews/ASstories/AS_20060130_200557.asp.

Validation of the Puff model is not trivial; satellites may only see the volcanic ash clouds when they are at their thickest close to their sources, oftentimes the ash clouds drift southward from Alaska over the Pacific Ocean where there are no observatories capable of detecting the cloud, weather conditions can obscure the ash cloud when it becomes embedded in tropospheric clouds (Dean et al., 2004). During the 2006 Mount Augustine eruption, a cloud of volcanic ash circled southern Alaska before heading northward across the interior of Alaska and was detected by a variety of remote sensing instruments near to the volcano and at lidar observatories at Fairbanks and Chatanika. In this study, we examine the dispersion of a volcanic ash cloud from Mount Augustine across Alaska from 29 January through 2 February 2006. We present the synoptic meteorology, the Puff predictions, and measurements from aerosol samplers, laser radar (or lidar) systems, and satellites. A map of Alaska showing the key locations is given in Fig. 4.

2 Movement of ash cloud in neighborhood of Mount Augustine

Mount Augustine volcano had been in a state of continuous eruption from 2330 on 28 January UTC (1430 AKST) with steady ash emission, small pyroclastic flows, and an elevated level of seismicity. The prevailing synoptic situation near the surface during the period of eruption was dominated by a weak but persistent low pressure center positioned over the Kenai Peninsula with an accompanying trough extending to the north/northwest (Fig. 5). During 27 — 31 January, the low and trough were largely stationary with only small fluctuations in strength and position. There was a weak surface flow evident from the east/northeast across the southern-central part of the state including the Kenai Peninsula. At upper levels (250/300 mb), strong steering was absent, with the jet axis taking up a zonal orientation well south of the eruption site. At the beginning of the period, at 500 mb, a closed low (Fig. 6a) was situated over the Kenai Peninsula. This feature moved slowly west-

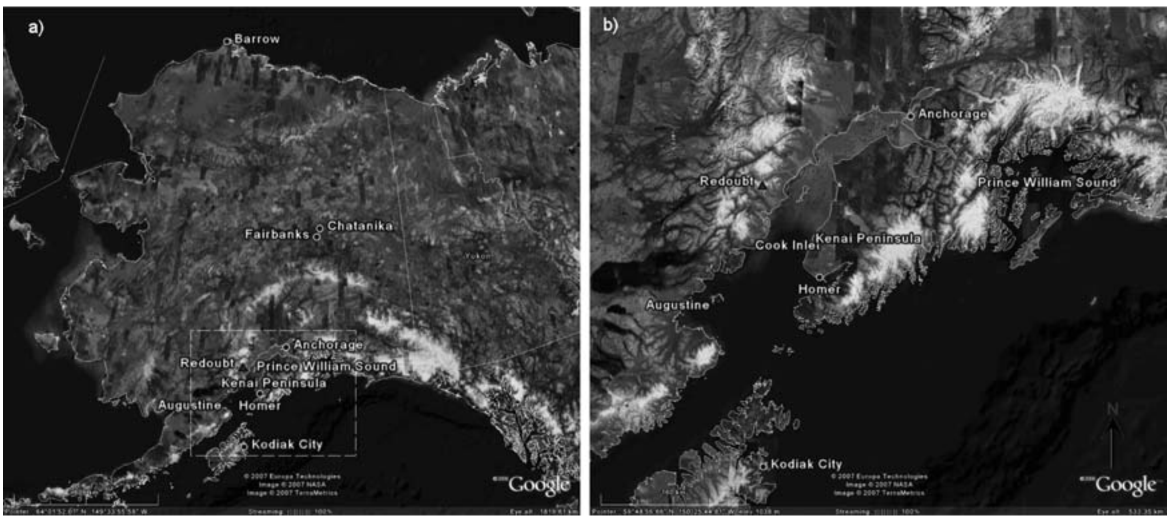

Fig.4 *Map of Alaska showing key locations*

Map background courtesy of Google Earth. (a) State of Alaska and (b) the Cook Inlet region. Places named include: Barrow (71˚18’ N, 156˚47’ W), Fairbanks (64˚51’ N, 147˚43’ W), Chatanika (65˚7’ N, 147˚28’ W), Anchorage (61˚13’ N, 149˚54’ W), Kodiak City (57˚47’ N, 152˚24’ W), Augustine volcano (59˚22’ N, 153˚26’ W), Redoubt volcano (60˚29’ N, 152˚44’ W), Homer (59˚39’ N, 151˚33’ W), Cook Inlet, Prince William Sound and the Kenai Pennisula.

ward over the next several days (Figs. 6b and 6c). Examination of the wind flow pattern suggests that material injected into the 5 km level (approximately 500 mb) would, in the first days, initially move towards the south/southeast and then curve tightly back around to end up west of the volcano. Towards the end of the initial period (30 January, Fig. 6c), the initial trajectory was away from the volcano and was weakly north-northwest. This pattern was also evident at the 3 km (700 mb) level.

In response to the Mount Augustine volcano eruption, AVO rated the level of concern code as ‘red’ (eruption is underway with significant emission of ash into the atmosphere and highly hazardous eruption underway or imminent) and UAF-GI within AVO initiated an ongoing running of the Puff model to predict the location of the ash cloud and warn of possible aircraft hazards. Puff was run for the continuous phase of the eruption in late January 2006 using an initial 5 km ash plume and forecast wind fields from the North American Mesoscale Model (NAM 216) for Puff initialization. To make the best use of the forecast data, the model was run for an initial 24-hour period (2320 28 January UTC, 1420 AKST) and then restarted for another 24 hour, continuing until 2 February. Each new prediction used the most recent forecast wind fields. As expected from the meteorological analyses, the Puff prediction showed that the ash would initially circle the volcano before heading northward across Alaska. The initial Puff predicted ash cloud trajectory is southeast towards Kodiak Island (Fig. 7a). This prediction assisted in the release of the NWS ash advisory in conjunction with correspondence between AVO operations, the Anchorage Volcanic Ash Advisory Center (VAAC), NWS Aviation Weather Unit and NWS Weather Forecast Office. The trajectory had a subsequent gradual backing in direction around to the northeast and across the Kenai Peninsula by the following day (Fig. 7b). By the third day, this has given way to a direct northeasterly trajectory, up Cook Inlet towards Anchorage (Fig. 7c). Model predicted ash concentrations were greatest near Mount Augustine with progressively lower concentrations over the mainland.

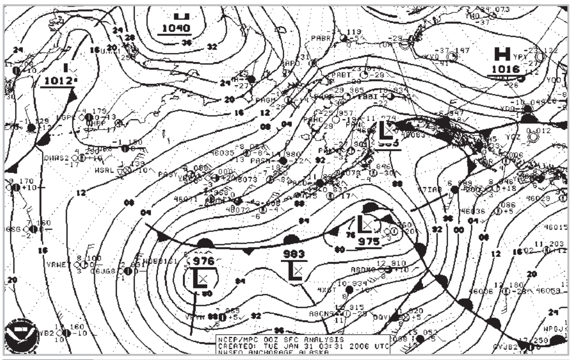

Fig.5 *Typical surface conditions during the period of eruption, 31 January 2006*

Atmospheric flow during this time was weak out of the southeast/northeast over much of Alaska.

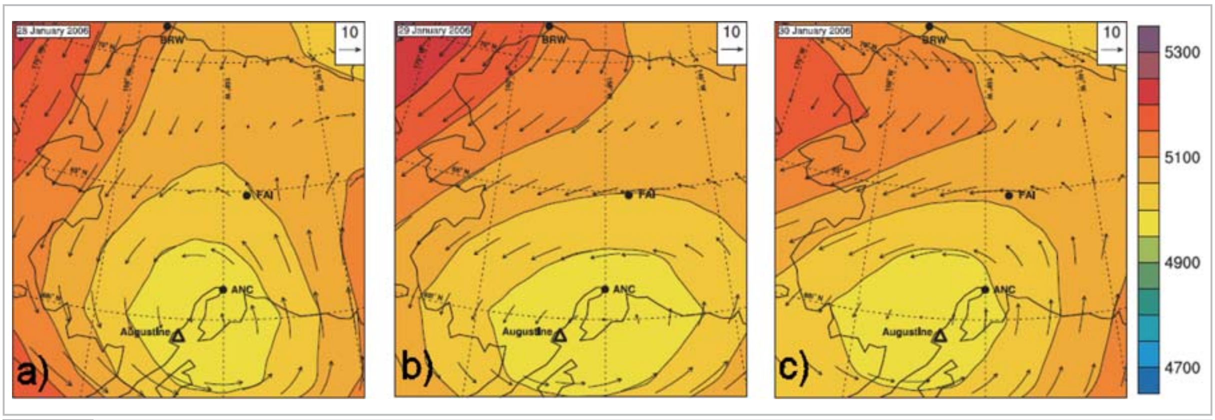

Fig.6 *500 mb heights and 500 mb wind vectors*

10 ms^{-1} (~20 kts) calibration in upper right corner. Altitudes are given in m ASL. (a) 28 January, (b) 29 January and (c) 30 January 2006.

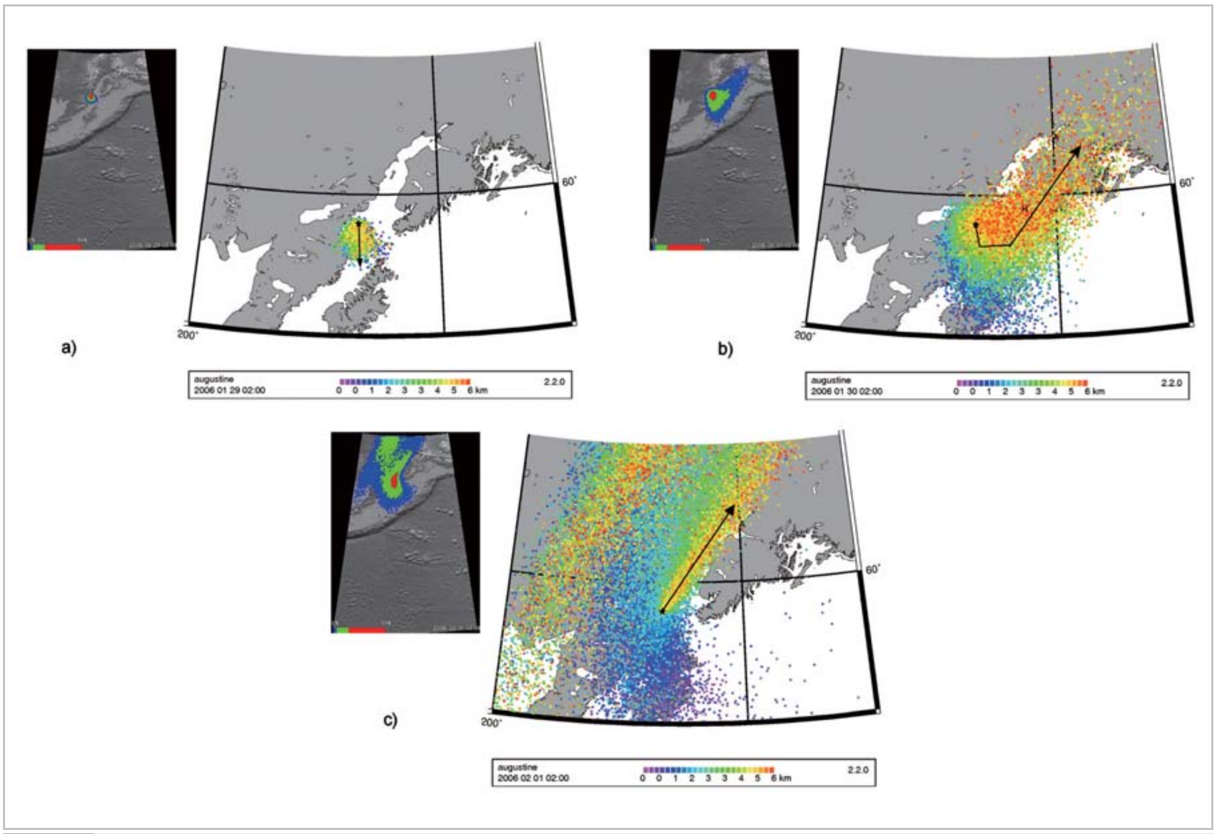

Fig.7 *Puff model predictions of volcanic ash cloud, as airborne ash concentrations and airborne ash color coded by altitude, on (a) 0200 29 January UTC (1700 28 January AKST), (b) 0200 30 January UTC (1700 29 January AKST) and (c) 0200 1 February UTC (1700 31 January AKST). Within each part of the figure, ash concentration is in top left and airborne ash color coded by altitude in on the right*

The ash fall in the Cook Inlet area was recorded on the ground by an eight stage DRUM aerosol impactor at Homer (Raabe et al., 1988; Cahill and Wakabayashi, 1993; Cahill, 2003). The samples were analyzed and indicated the presence of ash at the surface in the town. These aerosol samples show evidence of higher iron to calcium ratios than associated with ambient (i.e., non-volcanic) aerosols. Satellite observations provided measurement of the distribution of the ash cloud in the Cook Inlet area. The detection and tracking of ash clouds from satellite remote sensing uses the 'split window' differencing technique (Prata, 1989). The presence of semi-transparent volcanic ash clouds produces a negative $T_4 - T_5$ brightness temperature difference whereas the clean atmosphere or that containing meteorological clouds generally produces positive differences (Prata, 1989; Wen and Rose, 1994). Figure 8 shows the daily composites of the detected volcanic ash at Mount Augustine and the Cook Inlet region from 28 — 31 January. The ash cloud movement is initially from a southerly or south-easterly direction on 28 January, moving to a more southerly direction by the 29 January and this backs into an easterly direction by 30 January and finally, a north-easterly direction by 31 January. These observations support the Puff-based predictions for this time frame with the ash cloud swirling around Mount Augustine volcano immediately after the eruption. As the cloud spread further from the volcano, the airborne ash concentrations decreased due to fall out, and eventually the volcanic ash concentrations receded to levels below the detection limits of the remote sensing data. The satellite could not track the cloud beyond the area around Cook Inlet.

The Puff model forecasts on 30 January showed that the ash cloud would spread northward over Alaska, reaching Fairbanks after

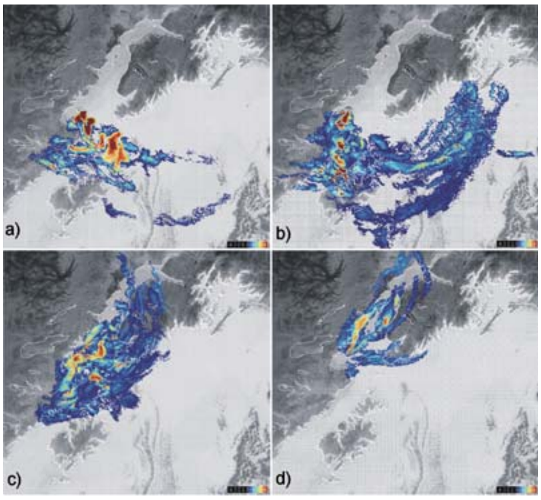

Fig.8 Moderate Resolution infrared spectrometer (MODIS) and advanced very high-resolution radiometer data (AVHRR) ash detection daily composite for: (a) 28 January, (b) 29 January, (c) 30 January and (d) 31 January 2006

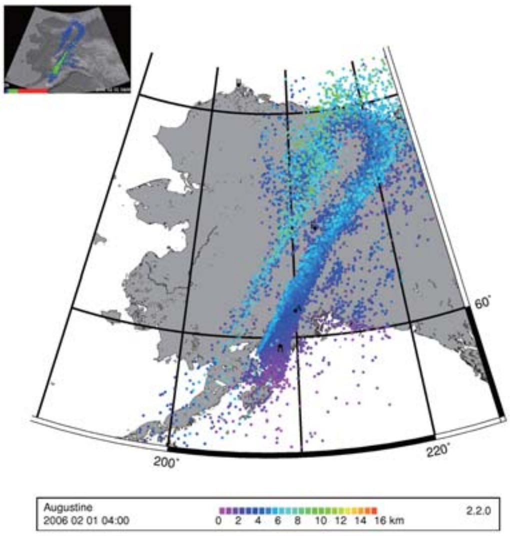

Fig.9 Puff prediction of location of volcanic ash across Alaska for 0400 UTC February 1 2006 (2000 AKST January 31) as airborne ash concentrations (top left) and airborne ash color coded by altitude (right)

about 24 hours (~1900 31 January UTC, 1000 AKST), and continuing northward to the Arctic Ocean (0400 1 February UTC, 1900 31 January AKST). The Puff forecast of the ash cloud is shown in Fig. 9. Based on this prediction, AVO-UAF personnel contacted lidar researchers within UAF and requested them to attempt observations as conditions permitted on January 31 and February 1 2006.

3 Movement of ash cloud across Alaska

From 31 January to 2 February, the 500 mb closed low (Fig. 10) began to deepen and by 1 February, it joined a larger center developing in the northwest, becoming the end point of a trough. This set up a steady flow from the southwest, moving at approximately 20 — 25 knots (10 — 13 ms^{-1}) (Fig. 6). Skew-Temperature plots from Fairbanks upper air station (PAFA) emphasize the nature of this flow over the interior at the 700 mb and 500 mb levels (Fig. 11). The nature and persistence of this flow pattern, evident both in the reanalysis data as well as the observational analysis, would place aerosol entrained at the 500 mb level over Augustine in the vicinity of Barrow approximately 24 — 36 hours later, consistent with the prediction by the Puff model.

The first lidar observations were made after sunset on 0300 — 0500 1 February UTC (1800 — 2000 31 January AKST). A Multi-Wavelength Lidar (MWL) is operated at the Poker Flat Research Range (PFRR), Chatanika (location in Fig. 4) about 50 km north-east of Fairbanks (Aoki et al. 2006). The National Institute for Information and Communications Technology (NICT) and UAF-GI operate the MWL as part of the Alaska Project. The MWL transmits two polarized beams and employs a ten-channel receiver that detects total, parallel and perpendicular polarized, and Raman echoes (For a comprehensive review of current lidar science and engineering see recent reviews edited by Fujii and Fukuchi (2005) and Weitkamp (2005)). The sky was cloudy with broken clouds passing overhead. The integrated lidar echo signal is shown in Fig. 12a. The lidar signal profiles are normalized to unity between 7 and 8 km and plotted as signal in relative units. The echo shows enhancements due to Mie scattering from clouds and aerosol up to 6.2 km. The signal

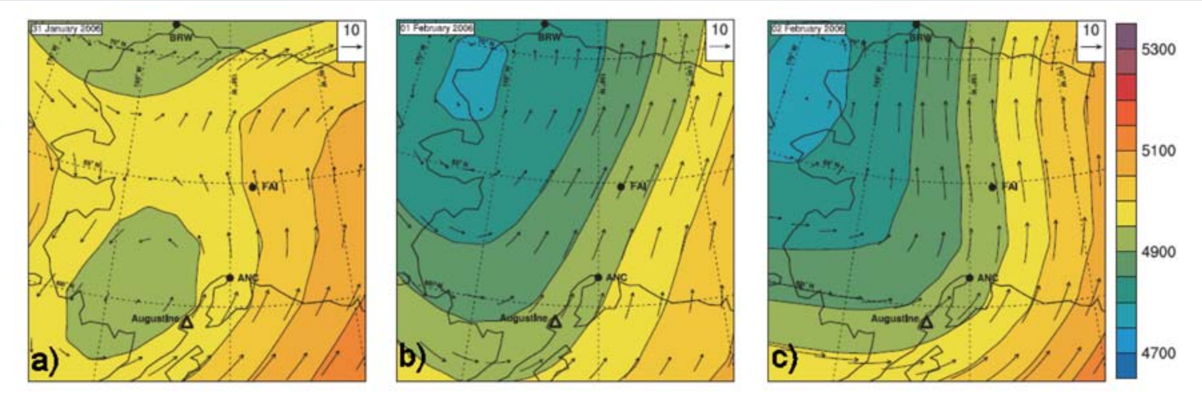

Fig.10 *500 mb heights and 500 mb wind vectors*

10 ms^{-1} (~20 kts) calibration in upper right corner. Altitudes are given in m ASL. (a) 31 January, (b) 1 February and (c) 2 February 2006

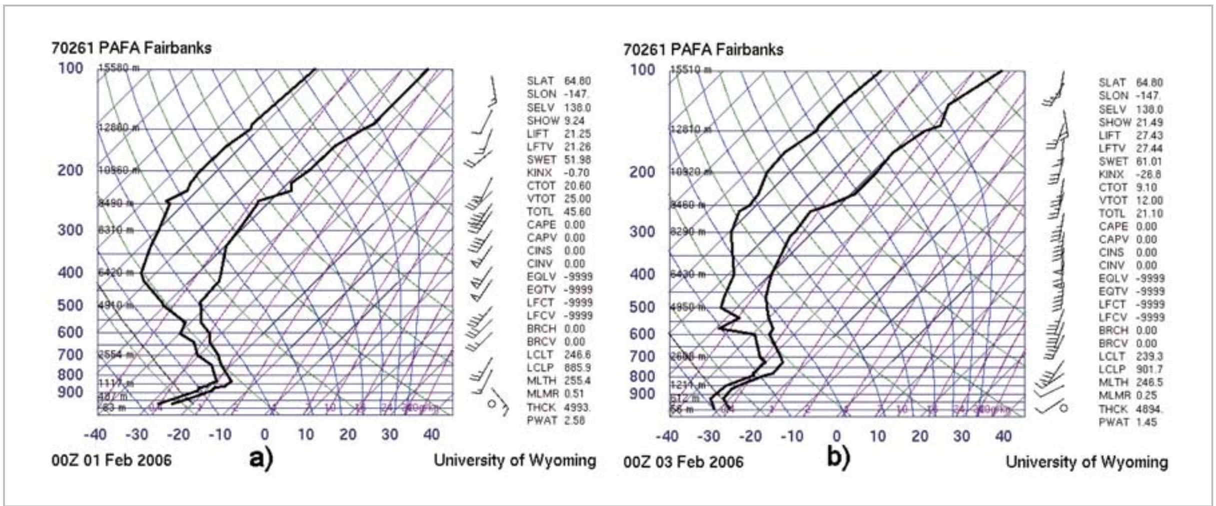

Fig.11 *(a) Skew-T plot for Fairbanks, 0000 1 February 2006 UTC (1500 31 January 2006 AKST). Note strong southwest flow at 700 mb and 500 mb (b) Skew-T plot, 0000 3 February UTC (1500 2 February 2006 AKST) for Fairbanks*

Data courtesy of Univeristy of Wyoming http://weather.uwyo.edu/upperair/sounding.html

below 1.2 km (0.8 km above the ground) is contaminated by overlap of the laser transmitter and telescope receiver. The expected Rayleigh scatter signal from an aerosol free atmosphere is also plotted. Strong enhancements (over 10 times the estimated Rayleigh scatter signal) are observed up to 5 km and weak enhancements (twice the estimated Rayleigh scatter signal) are observed above 5 km. The corresponding aerosol depolarization ratio is plotted as a function of altitude in Fig. 12b. Larger depolarization ratios are observed below 5 km and smaller depolarization ratios are observed above. The corresponding water vapor profile is plotted as a function of altitude in Fig. 12c. Water vapor is detected up to 4.4 km. Fig. 12 shows the integrated signals over the entire 97-minute observing period. A three-stage DRUM aerosol impactor was located in Fairbanks, Alaska, collecting aerosols between 0400 1 February UTC (1900 31 January AKST) and 0400 2 February UTC (1900 1 February AKST) 2006. The aerosol detector at Fairbanks detected ash with iron to calcium ratios similar to those measured at Homer throughout the February 1–2 period.

Examination of the lidar signals over that time period indicates that the echoes above 4.4 km remain relatively constant in altitude,

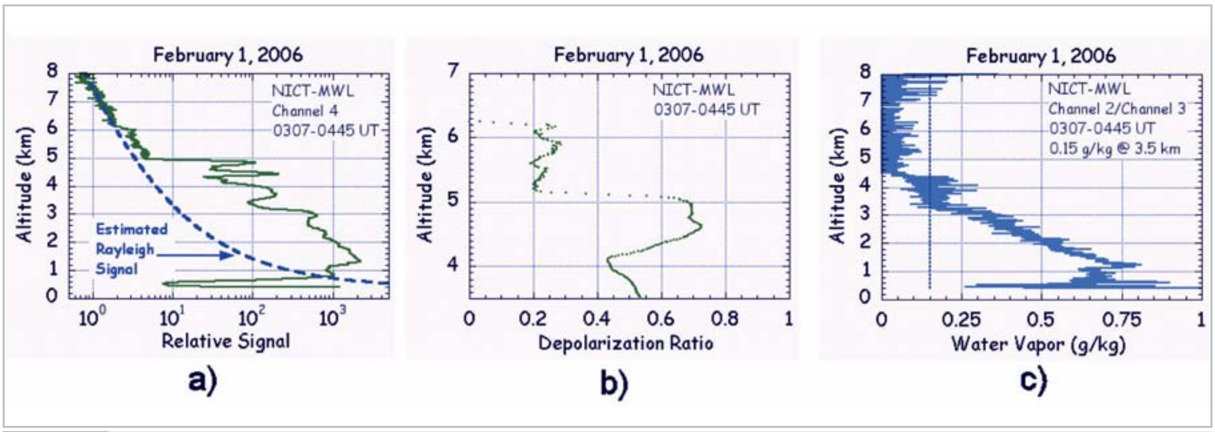

Fig.12 *(a) Relative Lidar echo signal plotted as a function of altitude at Chatanika (green solid). Signal is normalized to unity over 7–8 km ASL. The expected Rayleigh scattered signal is plotted for comparison (blue dash). (b) Depolarization ratio plotted as a function of altitude (green solid). Parallel and perpendicular polarization signal profiles were smoothed with 0.25 km running average, (c) Ratio of water Raman signal to nitrogen Raman signal (blue solid). Signal is normalized to 1.5 g/kg (blue dash) at 3.5 km*

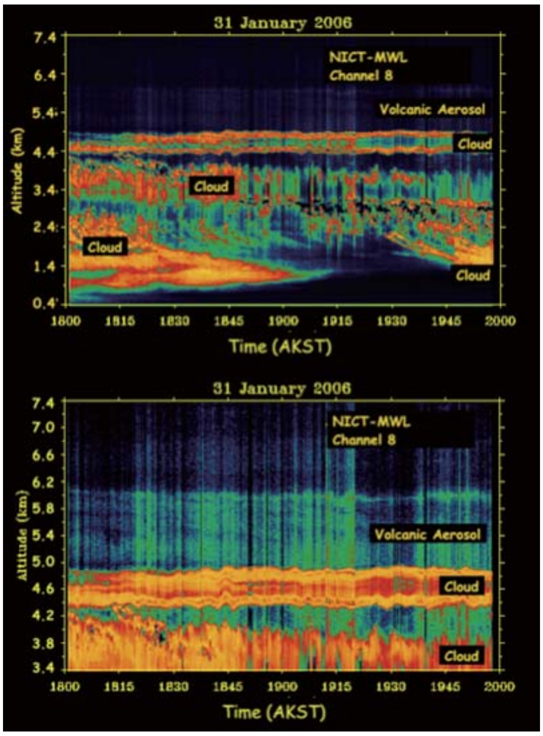

Fig.13 *False color plot of lidar signal as a function of altitude and time (0307–0445 1 February UTC, 1806–1945 31 January AKST)*

The color scale ranges from black (minimum) to yellow (maximum). Upper panel shows signal from ground (at altitude 0.4 km) to 7.4 km. The strong lidar echoes are associated with clouds passing overhead. The evolution of clouds is clearly visible. Lower panel shows signal from 3.4 km to 7.4 km. The color scale has been altered to highlight the volcanic aerosol above a cirrus cloud layer.

while the echoes below 4.4 km progress downward during the observing period (Fig. 13). We interpret the data as follows: precipitating cloud particles (large backscatter, large depolarization and wet) lie below 4.4 km, a layer of cirrus clouds (large backscatter in narrow layers, higher depolarization, and dry) lies between 4.4 and 5.0 km, and volcanic ash (low backscatter, lower depolarization, and drier) lies between 5.0 and 6.0 km. The volcanic ash is undoubtedly present at lower altitudes but masked by the presence of the clouds. The ash may also be contributing to the nucleation of clouds. The local radiosonde measured temperatures of −25°C at 2.5 km falling to −41°C at 4.1 km and −50°C at 7.6 km which would support cirrus cloud formation between 4 and 5 km. Similar observations, where desert dust and cirrus clouds are present, have also been reported by lidar observations at Fairbanks (Sassen, 2005; Sassen et al., 2007). The Puff prediction for this period (0400 1 February UTC, 1900 31 January AKST) is shown in Fig. 14. The model predicts the presence of ash over Chatanika up to altitudes of 6 km. The lidar and sampler measurements confirm the model prediction.

The southerly flow pattern northward across Alaska persisted and was dominant during a second period of lidar observations (2200 2 February UTC, 1300 AKST). The

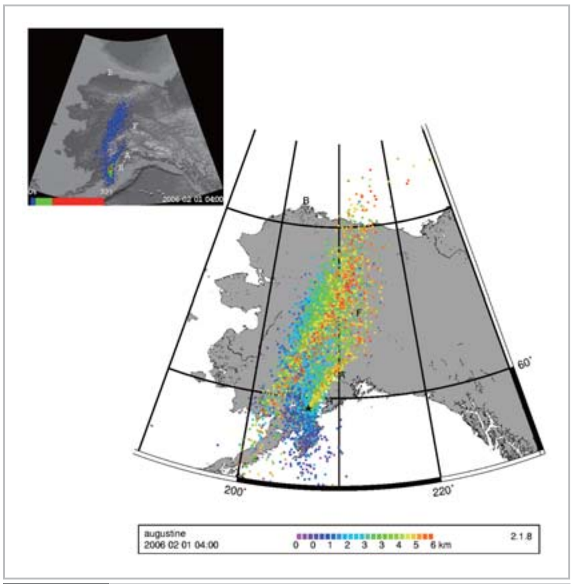

Fig. 14 *Puff prediction of volcanic ash location on 0400 1 February UTC (1900 31 January AKST) as airborne ash concentrations (top left) and airborne ash color coded by altitude (right)*

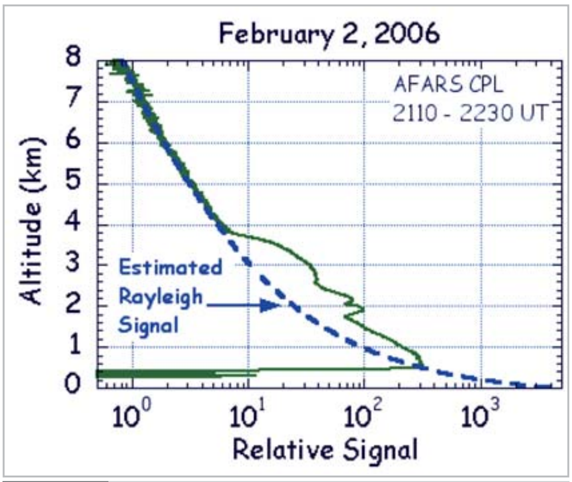

Fig. 15 *Relative Lidar echo signal plotted as a function of altitude at Fairbanks (green solid). Signal is normalized to unity over 7–8 km altitude. The expected Rayleigh scattered signal is plotted for comparison (blue dash)*

Cloud Polarization Lidar (CPL) at the Arctic Facility for Atmospheric Research (AFARS) is operated at Fairbanks, location shown in Fig. 4 (Sassen, 2000; Sassen, 2005). The CPL at Fairbanks transmits a polarized beam at a single-wavelength and employs a dual-channel receiver that detects the parallel and perpendicular polarized echoes. The CPL at Fairbanks was operated under clear sky conditions from 2110 — 2230 on 2 February UTC (1210 — 1330 AKST). The integrated lidar echo signal is shown in Fig. 15. Enhanced scattering is observed in the 1.8 to 3.8 km altitude region, but there is no evidence of aerosol layers above this altitude. The CPL aerosol measurements have also yielded measurements of the depolarization ratio that are similar in value to those measured by the MWL on the previous day in the aerosol layer over Chatanika. The Puff prediction for this period (2200 2 February UTC) is shown in Fig. 16. The prediction suggests that from February 1 to February 2 the trajectory of the ash cloud has more curved over the interior of Alaska. The model predicts the presence of ash over Fairbanks up to altitudes of 4 km, with ash at higher altitudes passing to the east of Fairbanks. The lidar measurements confirm the model prediction with ash detected over Fairbanks up to (but not above) an altitude of 4 km.

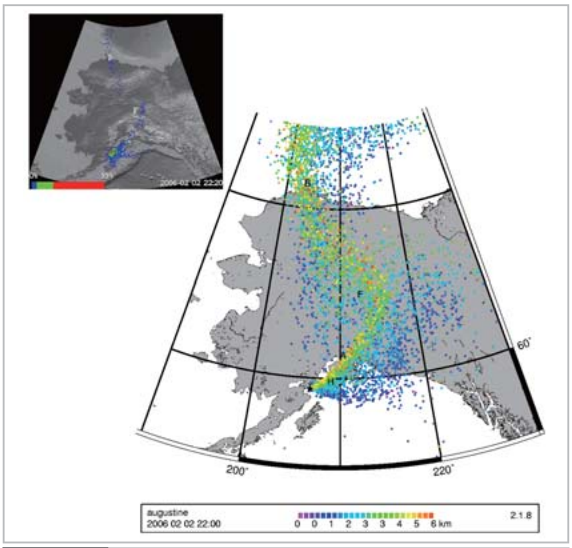

Fig. 16 *Puff prediction of volcanic ash location on 2200 2 February UTC (1300 2 February AST) 2006 as airborne ash concentrations (top left) and airborne ash color coded by altitude (right)*

4 Summary and conclusions

The 2006 eruption of the Mount Augustine volcano provided a unique opportunity to validate the ash cloud dispersion models that have been developed, and are used operationally, to assist in warning aircraft of aviation hazards associated with these clouds. Serendipitously, during 28 January — 2 February, a volcanic ash cloud from Mount Augustine traveled over two operating lidars and two aerosol samplers in Alaska. The clouds were also detected by remote sensing satellite during this period. The AVO Remote Sensing group at UAF-GI provided Puff model predictions of the ash cloud trajectory. We have shown these predictions were validated by a variety of remote sensing and sampling measurements.

We present a summary of the observations and associated predictions in Table 1. We note that the lidar measurements at Chatanika and Fairbanks were collected in response to the 29 January forecast by the Puff model. In summary, the salient predictions of the Puff model are as follows;

(1) The ash cloud initially circled the volcano and remained in the Cook Inlet Area.
(2) The ash cloud then drifted northward over Alaska, with ash from the ground-level up to 6 km.
(3) The trajectory of the ash cloud evolved with the upper level ash (> 4 km) moving separately from the lower-level ash (< 4 km) over the interior of Alaska.

The salient observations are as follows;

(1) Aerosol samplers revealed the presence of aerosols at the surface, that had characteristics (elevated iron/calcium ratios) of volcanic aerosols, at sites where Puff predicted the ash clouds would track over.
(2) Remote sensing satellite data showed the evolution of the ash cloud in the neighborhood of Mount Augustine volcano.
(3) Lidars showed the presence of volcanic aerosol with consistent characteristics aloft over Alaska. The lidars signals were capable of detecting the aerosol, even in the presence of scattered clouds, where the cloud is too thin/disperse to be detected by remote sensing satellite data. The lidar measurements revealed the different trajectories of lower and upper level ash consistent with the Puff predictions.

Here, we have had the opportunity to confirm that the Puff model accurately forecast the path of a volcano ash cloud from Mount Augustine volcano in southern Alaska across the Alaska Range to Fairbanks in central Alaska (~400 miles, 650 km). Dispersion models provide a forecast of volcanic ash cloud movement that might be undetectable by any other

Table 1 *Key measurements and Puff model predictions of Mount Augustine Ash Cloud over Alaska, 28 January – 2 February 2006*

Measurement	Timing	Measured Signal	Puff Timing	Prediction
Sampler at Homer	30 January	Ash at surface with high iron to calcium ratio.	0200 30 January	Movement of ash cloud over Homer
Satellite	29 January – 1 February	IR signature of ash cloud over southern Alaska	0200 29 January – 0200 1 February	Movement of ash in Mt Augustine neighborhood
Lidar at Chatanika	0307 – 0445 1 February 2006	Echo profile up to 6 km	0400 1 February 2006	Ash over Chatanika up to 6 km
Sampler at Fairbanks	1-2 February	Ash at surface with high iron to calcium ratio.	0400 February 1 - 2200 February 2.	Movement of ash cloud over Fairbanks region
Lidar at Fairbanks	2110 – 2230 2 February 2006	Echo profile up to 4km	2200 2 February 2006.	Ash over Fairbanks up to 4 km

All times in UTC (= AKST + 9 hour)

means but are still a significant volcano-based hazard to aviation. Validation of the predictions from Puff is key to assessing the accuracy of any future predictions. The study highlights the use of multiple and complementary observations used in detecting the trajectory ash cloud, both at the surface and aloft in the atmosphere.

Acknowledgments

The authors wish to thank AVO, and especially the AVO-GI remote sensing group, for their time during the eruption for monitoring all the volcanoes and analyzing the Mount Augustine eruption data. The authors thank Game McGimsey of AVO-USGS for the use of the photograph of the Mount Augustine volcano ash cloud. The MWL is operated as part of the NICT Alaska Project. The CPL and sampler measurements were supported by NASA and NSF. AVO is a three-part program supported by the USGS, UAF-GI and ADGGS.

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Richard L.. COLLINS *Ph. D.*

Associate Professor, University of Alaska Fairbanks

Aeronomy and Laser Remote Sensing

Javier FOCHESATTO, *Ph. D.*

Associate Professor, University of Alaska Fairbanks

Aeronomy and Laser Remote Sensing

Kenneth SASSEN, *Ph. D.*

Professor, University of Alaska Fairbanks

Cloud Physics and Remote Sensing

Peter W. WEBLEY, *Ph. D.*

Post Doctoral Research Fellow, University of Alaska Fairbanks, Arctic Region Supercomputing Center

Remote Sensing and Volcanology

David E. ATKINSON, *Ph. D.*

Assistant Professor, University of Alaska Fairbanks

Synoptic Meteorology

Kenneson G. DEAN, *M. S.*

Professor, University of Alaska Fairbanks

Remote Sensing and Volcanology

Catherine F. CAHILL, *Ph. D.*

Associate Professor, University of Alaska Fairbanks

Aerosol Chemistry and Physics

MIZUTANI Kohei, *Ph. D.*

Research Manager, Environment Sensing and Network Group, Applied Electromagnetic Research Center

Laser Remote Sensing