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FREQUENCY AND REGIONAL EXTENT OF ASH ERUPTIONS FROM ALASKAN VOLCANOES

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Historic records indicate Alaskan eruptions large enough to disrupt air traffic have had an average recurrence interval of about 5-10 years during the last century. These small eruptions typically each last a few hours, and disperse about 0.1-0.2 km^3 of ash in a plume several hundred kilometers long. Mt. St. Augustine and Mt. Redoubt have erupted most often and so constitute the greatest hazards to air traffic.

The frequency and style of tephra eruptions from Alaska volcanoes has changed through time. Some prehistoric eruptions were hundreds of times larger than the 1989-1990 Mt. Redoubt event. The 1912 Katmai eruption put an estimated 25 km^3 of ash into the atmosphere during a sustained eruption lasting almost 3 days, while prehistoric ashfalls have reconstructed volumes of 50-100 km^3 and produced significant fallout more than 1,500-2,000 km from the source volcanoes over areas of 10^5-10^6 km^2. If a large Alaskan volcanic eruption occurred today it would put huge volumes of ash into the air and might blanket most of Alaska and northwest Canada or large regions of the northern Pacific Ocean for a week or more.

ANALYSIS OF SATELLITE IMAGES OF REDOUBT VOLCANO PLUMES

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The discharge of ash and the resulting danger to air transportation was one of the primary hazards associated with the 1989-1990 eruption of Redoubt Volcano. Satellite images are a valuable source of information for the analysis of the plume, especially if the data is available in a timely manner. Advanced Very High Resolution Radiometry (AVHRR) images were acquired and analyzed, and the results provided to the Alaska Volcano Observatory (AVO). AVO used this information to access the plume and ash trajectory and distribution. During the first few weeks of the eruption, six hours elapsed after a satellite pass before images were provided to the AVO. However, six hours was considered unacceptable due to the dynamics of volcanic processes. Thus, a procedure was developed to provide satellite images within 1.0 to 1.5 hours after a satellite pass.

Since the start of the eruption, approximately 50 AVHRR and Landsat digital data tapes have been collected for retrospective studies. AVHRR images recorded in late December reveal plumes that emanate from Redoubt and trail off to the east across Cook Inlet and over Prince William Sound and the Gulf of Alaska. Images recorded after December show plumes that were circular with a diameter of a few tens of kilometers. The plumes, as recorded by the satellites, were cold (-20 to -60^{O}C) because they cool and expand upon rising, and come to equilibrium with the surrounding atmosphere. By relating the plume temperature recorded on the images to the temperature/altitude structure of the atmosphere as measured by soundings, the altitude of the plumes were accessed. An atlas of the satellite images is being compiled.

ALASKA AIRLINES OPERATING PROCEDURES DURING THE 1989-1990 REDOUBT ERUPTIONS

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The eruption of Mt. Redoubt, 1989-90, and the subsequent incident with a B747 encountering the initial ash cloud, sent a shock wave through the aviation community. A B747 ingesting sufficient quantities of ash to cause all four engines to stop operating in flight forced the airlines serving Anchorage to react by suspending operations. Alaska Airlines was among that group.

Anchorage is too important to Alaska Airlines to just wait for an "All Clear" Signal before resuming service, so we needed a plan of action.

Chief Pilot, Tom Cufley, was to fly on the first airplane from Seattle that would try a landing at Anchorage. On December 16 after the eruption, one of the normally scheduled cargo planes landed at Anchorage International Airport. There was a break in the cloud cover that would allow the flight to descend while maintaining visual contact with the ground. This was to be the foundation of our plan to resume full service. The idea is if ash was not visible in these cloud openings, then there is no danger of encountering ash while descending. I followed on the next flight.

By focusing on where the ash had not fallen, Alaska Airlines was able to resume a full schedule. With the aid of wind direction and velocity information from our arriving airplanes, we were able to accurately determine ash trajectories. On-site coordination allowed for a realistic flight-crew briefing and debriefing. These combined factors made the operation a success.

Once our flights started to arrive and depart, the demand for tickets increased due to other carriers cancelling flights. Approximately 1,800 Holiday passengers were stranded in Anchorage wanting to fly south while nearly 600 passengers were in Seattle trying to go north. Alaska Airlines had an obligation to fulfill by making sure everyone made it home for the Christmas Holidays.

In addition to the 18 scheduled flights, 26 passenger and 20 cargo flights were added during this period. This caused a strain on our schedule for assigning crews to cover the extra flights, and it took a Herculean effort to free up airplanes from our regular schedule. The extra trips were scheduled mostly during the night and early morning hours when the schedule is lightest.

The operation was also based on the "On Site Go Team." The team was able to evaluate the situation, make decisions from the scene, and be able to interpret the FAA Notices to Airmen (NOTAMS) as they related to the real conditions. The "On Site" concept allows decisions to be made in "Real Time". Remote operations rely on ash and weather forecasts and FAA NOTAMS. Too often, NOTAMS are broadly scoped and cover too wide an area, and, as we witnessed, can be misleading for an operation such as ours at Alaska Airlines.

DESCRIPTION OF THE WIND PROFILES INSTALLED IN HOMER, ALASKA

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As a part of the overall system to detect and predict the motion of volcanic ash clouds, plans are being made to establish a small network of Wind Profilers in Alaska. One Wind Profiler operating at 404.37 MHz has been in operation in Homer, Alaska, since December 1990. The remainder of the network will be installed when a new frequency allocation is approved that will prevent potential interference with the 406.05 MHz band used by Search and Rescue Satellites (SARSAT).

The Wind Profiler in Alaska is almost identical to the ones being installed in the NOAA Wind Profiler Demonstration Network in the midwestern United States. It consists of an equipment shelter and an antenna array. The shelter houses all the active components: transmitter, receiver, beam steering unit, and signal and data processors. Adjacent to the shelter is the antenna, which is a coaxial-collinear phased array measuring 13 meters on a side.

The standard NOAA Wind Profiler which was installed in Alaska required modifications in order to provide accurate data on the speed and direction of the upper winds in the presence of spurious reflections from glacial mountains and nearby sea clutter. These changes were accomplished by additional perimeter clutter fences and new computer processing algorithms to remove the effects of wave motion returns from the clear-air atmospheric echoes.

AIRBORNE LIDAR DETECTION AND IN SITU MEASUREMENTS OF ASH EMISSIONS FROM THE 1990 VOLCANIC ERUPTIONS OF MOUNT REDOUBT

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In January and June 1990 we obtained airborne in situ and remote sensing lidar measurements of volcanic emissions from Mt. Redoubt, Alaska. The lidar provided excellent real-time information on the distribution of the volcanic effluents. The in situ measurements provided information on the size distributions, mass concentrations, and nature of the particles, as well as the concentrations of various trace gases, in the volcanic emissions.

In post analysis, the lidar observations were combined with the in situ measurements to derive the fluxes of particles and gases from the volcano. For the intraeruptive emissions, the derived fluxes were: water vapor, ~160-9440 kg s^{-1}; CO_2, ~30-1710 kg s^{-1}; SO_2, ~1-140 kg s^{-1}; particles (<48 m diameter), ~1-6 kg s^{-1}; SO_4, <0.1-2 kg s^{-1}; HC1, <0.01-2 kg s^{-1}; and NO_x, <0.1-2 kg s^{-1}. During a paroxysmal eruption of Mt. Redoubt on January 8, 1990, the particle (<48 µm diameter)-emission flux averaged ~10^4 kg s^{-1}.

The particle-size distributions for both paroxysmal and intraeruptive emissions showed nucleation (<0.1 µm diameter) and accumulation (~0.1-1.0 µm diameter) modes. On January 8, 1990, the number of concentrations of particles were initially mostly in the accumulation and coarse particle (>1.0 µm diameter) modes; there were comparatively few nucleation-mode particles. After seven hours of aging, the concentrations of particles of all sizes had decreased, but nucleation-mode particles were relatively more prominent. Most of the particle mass in the January 8 eruption was in giant-sized particles, predominantly diameters of ~10 µm and ~30 µm. Most of the particle mass in the intraeruptive emissions was in the accumulation mode, with diameters of ~0.8 µm. The particles in the intraeruptive emissions consisted primarily of mineral elements without any sulfuric acid coating. Very little of the SO_2 (~0.1%) was oxidized to sulfate in the cold, dark conditions of the arctic atmosphere.

LIGHTNING DETECTION AND LOCATION AS A REMOTE ASH-CLOUD MONITOR AT REDOUBT VOLCANO, ALASKA

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Few of Redoubt volcano's recent eruptions were observed directly because of bad weather and brief winter days. The unseen ash clouds were a substantial hazard to aircraft. In the absence of direct observation, the presence of ash clouds was deduced, with some uncertainty, from seismicity. Lightning, normally rare around Cook Inlet, accompanied nearly all of Redoubt's ash-producing eruptions. Lightning radiates broadband radio waves that allow remote detection and location of lightning and, therefore, ash clouds. As an experiment, the Alaska Volcano Observatory deployed a commercially available lightning detection system (LDS) around Cook Inlet. This LDS is normally used by the Bureau of Land Management's Alaska Fire Service to detect and locate cloud-to-ground lightning in Alaska's interior during summer months. The Cook Inlet LDS became operational on February 14, 1990. Lightning was detected in 11 and located in 9 of the 12 subsequent eruptions. Most cloud-to-ground lightning strikes occurred at or near the volcano. The number of cloud-to-ground discharges produced by a given eruption was directly related to the quantity of ash produced. Discharges that occurred early in an eruption had a negative polarity, while late discharges tended to be positive; this phenomenon suggests that coarse particles carried a negative charge and fine particles carried a positive charge. Intracloud lightning, as determined from eyewitness accounts but not detected by the LDS, was more abundant than cloud-to-ground lightning and tended to persist in the ash clouds even at substantial distances from the volcano. In the February 15, 1990 eruption, intracloud discharges persisted to a distance of at least 120 km from the volcano. A system capable of locating intracloud lightning could potentially track ash clouds as long as discharges persist. Lightning data dispel the ambiguity inherent in using seismic data alone, for the coincidence of seismic lightning signals provides compelling evidence of an ash cloud. Lightning detection also provides a rapid remote measure of eruption magnitude. Alaska Volcano Observatory has now acquired and deployed a cloud-to-ground LDS dedicated to monitoring Cook Inlet volcanoes.

ECONOMIC CONSEQUENCES OF THE 1989-90 MT. REDOUBT ERUPTIONS: ASSESSMENT METHODOLOGY AND ANECDOTAL EMPIRICAL EVIDENCE

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The eruptions of Mt. Redoubt in the late fall and winter of 1989-90 resulted in major disruptions of air transportation, both with respect to people and freight, threatened the physical integrity of the Drift River oil terminal facility, caused the shut-down of Cook Inlet oil production, and in other ways caused the total production of goods and services in Alaska to decrease. The eruptions may also have caused some firms to reconsider south-central Alaska as a site for doing business.

This paper presents a methodology and design for a social accounting framework that structures the classification and regional distribution (or redistribution) of economic impacts attributable to the 1989-90 Mt. Redoubt eruptions. The accounts design attempts to deal with several issues that arise in the assessment of the impacts of natural disasters. These include measurement of increases and decreases in economic activity attributable to the disaster, the distribution of these changes across regions, and the separation of mitigation costs from direct costs of the disaster. The paper illustrates the use of the account structure with some preliminary applications of the methodology to specific episodes associated with the eruptions.

FORECASTING VOLCANIC DEBRIS IN ALASKA

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The Center Weather Service Unit (CWSU) of the National Weather Service has the responsibility to provide forecasts that insure smooth flow of air traffic into and out of Alaska. The Mt. Redoubt eruption presented a number of problems to the region. Numerous explosive episodes caused significant damage to aircraft, severely disrupted air traffic, and resulted in airports closing operations.

The major forecast problem centers around a lack of information concerning plume characteristics: (1) lack of ash particle size and concentration; (2) no current ash location; and (3) lack of real-time winds near and downwind of the volcano. The forecaster is forced, for safety sake, to include a large hazardous zone around the estimated trajectory of the ash for aircraft to avoid. This can cause unnecessary delays to travel around the zone when most of it is ash free.

To assist the aviation community in their need for information on ash distribution, the CWSU generated an ash-trajectory plot with 4 hour movement of the ash plume. This plot was updated as new information became available. The biggest source of information was from pilot reports. This plot was distributed to over 90 users.

VOLCANIC AIR-AIRCRAFT INCIDENTS IN ALASKA IN THE YEARS PRIOR TO THE DECEMBER 15, 1989 747 REDOUBT ENCOUNTER

Juergen Kienle, *University of Alaska Fairbanks, Alaska*

Commercial and military aircraft have encountered volcanic ash in the Cook Inlet basin on three other occasions besides the most recent events near Redoubt Volcano in 1989/90. Over the past 36 years, aircraft have met volcanic ash plumes on four occasions, three times in the past 13 years alone, resulting in a variety of technical problems. No crashes or deaths resulted from these encounters so far.

Mt. Spurr 1953: A short one-day eruption of Mt. Spurr, 120 km west of Anchorage, caused heavy ash falls that lasted for three hours from noon until 3 p.m. Maximum plume heights were about 21 km (70,000 ft.) and extensive lightning was observed by L. Metzner. Twenty-six aircraft of the Air Force's 5039th Air Transport Squadron were evacuated to Laird and

MOUNT REDOUBT: TRACING VOLCANIC ASH PLUMES FROM SPACE

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Volcanic ash and debris are extremely hazardous to aircraft, with several craft experiencing near-catastrophic inflight damage as a result of flying through the debris. To respond to these potentially catastrophic events, the Federal Aviation Administration (FAA) and National Oceanic and Atmospheric Administration (NOAA) have established a cooperative Volcano Hazards Alert Program. The program encompasses all volcanic debris reaching at least 5 km altitude within U.S. airspace or international airspace designated as a U.S. Flight Information Region (FIR).

Upon detection or notification of an explosive volcanic eruption, NOAA's National Environmental Satellite, Data, & Information Service (NESDIS) has the responsibility to coordinate information (i.e., satellite-imagery analyses, trajectory forecasts, pilot report summaries, etc.) directly to primary FAA and NOAA facilities responsible for flight safety and warnings, including: NWS Meteorological Watch Offices, NWS National Aviation Weather Advisory Unit, National Meteorological Center, and FAA Central Flow Control Facility. These primary facilities have the responsibility of issuing "significant meteorological warnings" (SIGMET) to all aviation interests.

Mount Redoubt in Alaska began a series of explosive volcanic eruptions on 14 December 1989. Since the initial event, geostationary and polar-orbiting environmental satellites have been used to track ash and volcanic debris from over twenty eruptions of Redoubt. During the 15 February 1990 eruption, a pyroclastic surge resulting in a serious mudflow along the Drift River was detected in "real time" using AVHRR HRPT data, and timely warnings were issued to the hydrologist in Anchorage, Alaska. Multispectral imaging from polar spacecraft offers enhanced potential for monitoring ash plumes, even when debris is not apparent using single-channel visible or infrared data.

This paper briefly reviews the history of volcanic ash tracking in NESDIS (dating back to Mount St. Helens in 1980), the recent history of Mount Redoubt, and analysis techniques being planned and implemented.

THE 1989-90 ERUPTION OF REDOUBT VOLCANO: CHRONOLOGY, CHARACTER AND EFFECTS

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Redoubt volcano, a remote 10,200-foot-high stratovolcano 110 miles southwest of Anchorage, began its third major eruption this century on December 14, 1989. An initial eruptive phase (December 14-19) consisted of numerous and repeated vent-clearing explosive events that generated ash-rich eruption columns rising to over 40,000 feet. Airborne ash generated by these events was carried by prevailing winds east and north toward the populous parts of the Cook Inlet region shutting down air traffic for 3 days. On December 15, a 747 jet passenger airliner lost all 4 engines after encountering an ash cloud 80 miles north of Anchorage; the engines wee later restarted and the aircraft landed safely. The second phase of the eruption, consisting of episodic lava dome emplacement (similar to Mount St. Helens) and destruction, began on December 22: 13 such lava domes were emplaced over the next 120 days. Each was destroyed by brief (<20 minute) explosive events that produced ash clouds which also effected air traffic but for a much shorter time than in the initial phase.

Alaska Volcano Observatory, through its seismic monitoring network and field observations, recorded all of the explosive eruptions and predicted several of them. Eruption notification and hazards were communicated to the airline industry through an agency call-down list, daily updates, and a color-coded hazard alert.

Six major explosive eruptions have occurred from Redoubt and neighboring Spurr and Augustine volcanoes in the past 38 years. All three of these Cook Inlet volcanoes are now monitored seismically so that their future eruptions can be reported immediately and in some cases predicted. West of Cook Inlet, the 39 active volcanoes that occur spaced along a 1500-mile-long arc from the Alaska Peninsula through the Aleutian Islands (and average one eruption per year) are not presently monitored. These otherwise remote volcanoes do, however, present a continuing hazard since several great circle air routes parallel or cross this arc.

NOAA'S RESPONSE TO THE MOUNT REDOUBT ERUPTIONS OF DECEMBER 1989

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The National Oceanic and Atmospheric Administration (NOAA) is responsible for monitoring the ejection of volcanic ash into the atmosphere and the subsequent forecast of where the ash is likely to be dispersed. NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) is responsible for the monitoring of an notification of ash eruptive events in real-time. NOAA's National Weather Service's (NWS) responsibility is to provide forecast information on the location and predicted track of volcanic ash. This guidance is provided in real-time through the issuance of Significant Meteorological Messages (SIGMETs) by NWS forecasters. NOAA's responsibility is stated in the memorandum of understanding between the Federal Aviation Administration and NOAA on Volcanic Hazards Alert.

As shown by the KLM event on December 15, the ability to monitor and forecast the volcanic-ash cloud dispersion in the atmosphere was inadequate. NOAA was asked to review the situation and generate a proposal for improving the volcanic-ash monitoring and forecast program. NOAA was able to pull together its various elements and generate a proposal within a few weeks. The Alaska Volcano Project consists of various components: new observing capabilities, new computer and communications equipment, and studies to enhance the numerical modeling systems. The presentation will provide a review on the progress of the Alaska Volcano Project.

USING A PERSONAL COMPUTER TO OBTAIN PREDICTED PLUME TRAJECTORIES DURING THE 1989-1990 ERUPTION OF REDOUBT VOLCANO, ALASKA

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C.I. Bauer, *National Weather Service, Anchorage, AK,* and
J.F. Paskievitch, *U.S. Geological Survey, Anchorage, AK*

The Alaska Volcano Observatory (AVO) and the Anchorage Weather Service Forecast Office (WSFO) daily obtain predicted plume trajectories (PPTs) for Redoubt Volcano, Alaska. Data for the PPTs are produced on a National Oceanic and Atmospheric Administration NAS/9000 computer. It models measured and forecasted winds to predict the path of a weightless-particle release at various pressure altitudes above a specified location. The paths are assumed to indicate the general direction and speed that ash from an eruption at that location will travel.

In response to the Redoubt eruption, we programmed an IBM AT-style computer to dial the NAS/9000 and obtain the PPTs. The program enables AVO and WSFO to easily collect the day's PPTs each morning. Thus, the PPTs are immediately available in the event of an eruption later in the day. The PPTs are plotted on a map of Alaska, showing the predicted location of the ash at three-hour intervals for different altitudes between 5k and 53k feet. The plots are easily telefaxed to interested parties. The program has been modified to enable the user to obtain PPTs for other US volcanoes.

GRAIN IMPACTS ON AN AIRCRAFT WINDSCREEN: THE REDOUBT 747 ENCOUNTER

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In December 1989, a Boeing 747-400 aircraft intercepted an ash cloud from an eruption of the Redoubt Volcano. The encounter caused strong abrasion on leading edges and windscreens, and severely impaired engine function. To better understand the nature of the ash cloud, its remote-sensing signature, and the encounter itself, we have obtained an abraded 150 kg polycarbonate-laminate front windscreen of the 747, to analyze quantitative characterizations of the impact pits, in terms of the size-frequency distribution, areal density, and orientation. Ultimately, we would like to relate the impact signature to in-situ ash-cloud volume densities, and thus to its appearance in orbital imaging. In our analyses, we use (a) 747 slip-stream and boundary-layer characteristics, and (b) polycarbonate-laminate blanks, abraded by Redoubt ash at selected mass-flux rates in the laboratory for count calibrations.

Inspection of the windscreen shows the following: (a) Strong abrasion zonation dependent on azimuth from the direction of flight, ranging from complete destruction (opaque frosting) of juvenile windscreen material near the centerline (15% of windscreen area), to the onset of inter-pit juvenile material at about 45 degrees from the centerline, to only occasional elongated pits on the surface parallel to the direction of airflow (opaque frosting occurred within the inferred forward pilot line-of-sight); (b) Strong shadowing effects due to the presence of obstacles in the slipstream path--washer pylons and wiper blades appear to have interrupted the impact trajectory enough to have shielded small areas, even in the zone of head-on impact, suggesting mitigation of frosting by appropriate baffling upward of the area to be protected. This work was partially carried out under the NASA Solid Earth Sciences Program at the Jet Propulsion Laboratory, California Institute of Technology.

IMPACT OF VOLCANIC ASH FROM REDOUBT VOCANO ERUPTION ON GE CF6-80C2 TURBOFAN ENGINES

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The 1989-1990 eruption of Redoubt Volcano, Alaska, and the near tragedy of KLM Flight 867 on 15 December

1989 underscore the threat to aircraft safety from volcanic ash clouds.

Between December 1989 and February 1990, at least 4 commercial jet liners suffered damage from encounters with ash clouds from Redoubt Volcano. The most serious incident occurred on 15 December 1989 when a new Boeing 747-400 aircraft equipped with GE CF6-80C2 engines encountered an ash cloud as the aircraft descended from the north for a scheduled landing in Anchorage. An eruption of Redoubt at 10:15 am (AST) produced an ash-rich eruption column which climbed to approximately 40,000 feet altitude. Wind speeds at the time were 100 knots in a northeasterly direction. At approximately 11:46 am (AST), KLM Flight 867 entered the volcanic ash cloud at approximately 25,000 feet altitude, 150 nautical miles northeast of Redoubt. Immediately upon entry into the cloud, the aircrew increased power and attempted to climb out of the ash cloud, gaining nearly 3,000 feet additional altitude before all 4 engines stalled. The aircraft descended approximately 13,000 feet during the next 8 minutes before the pilots restarted the four engines and resumed flight to Anchorage. While there were no injuries to passengers, the damage to engines, avionics, and aircraft structure from this encounter was significant. Similar engine thrust loss and engine and aircraft damage was experienced by two Boeing 747 aircraft during 1982 volcanic eruptions of Galunggung Volcano in Indonesia. Other encounters between jet aircraft and ash clouds from Mount Redoubt on 15 and 16 December 1989 and 21 February 1990 did not result in engine thrust loss.

The primary cause of engine thrust loss in the volcanic ash ingestion events in Indonesia in 1982 and at Redoubt was the accumulation of melted and resolidified ash on the stage 1 turbine nozzle guide vanes. These deposits reduced the effective flow area causing an increase in the compressor operating line and compressor surge. Compressor airfoil erosion contributed to the loss of surge margin. Turbofan engines tested operating at high combustor discharge temperatures, and exposed to high concentrations of sand/dust with low melting point, exhibit symptoms and conditions similar to those of engines exposed to volcanic ash. Operation at low-thrust level while in an ash cloud significantly reduces the rate of engine performance degradation.

these two recent eruptive events. Seismic monitoring, direct observations of eruptions, ash-fallout information, radiosonde measurements, and ground weather observations provide ground truth, which helps us evaluate the satellite data. In addition, our work has included spectral reflectance studies of ash samples in the laboratory.

At the date of writing, study of the Augustine images is completed (Holasek and Rose, Bull. Volcanol., in press), while the more extensive Redoubt images are still being intensely studied. Highlights of the conclusions so far: (1) Volcanic eruption clouds are detectable in a variety of weather conditions, both night and day, and over land or water. (2) The multiple infrared channels of the AVHRR sensor are essential in algorithms used for the discrimination of eruption clouds. (3) A single algorithm that can detect all eruption clouds has not been developed. Potential uses of the satellite data include monitoring and tracking eruption clouds, as well as contouring particle burden within the clouds.

UTILITY OF AVHRR SENSOR FOR REMOTE SENSING OF ALASKAN ERUPTION CLOUDS

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The 1989-90 eruption of Redoubt Volcano and the 1986 eruption of Augustine Volcano have provided an opportunity to test and refine the use of the advanced very high resolution radiometer (AVHRR), a multispectral sensor which is aboard two polar-orbiting NOAA weather satellites. Each satellite furnishes twice daily coverage of Alaska at a spatial resolution of 1.1 km, allowing a synoptic view of volcanic eruption clouds. A comprehensive collection of seventy images, representing a wide variety of eruptive and environmental conditions, have been studied during

A MESOSCALE DATA ASSIMILATION SYSTEM ADAPTED FOR TRAJECTORY CALCULATIONS OVER ALASKA

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Soon after a volcanic eruption, it is relatively easy to locate the plume from satellite imagery, at least if the sky is clear. Later, however, as the plume disperses and thins, remote detection becomes more difficult. A series of analyses, feeding wind data to a trajectory model at frequent intervals, is one answer to the need for accurate tracking of the plume.

NOAA's Forecast Systems Laboratory has developed a Mesoscale Analysis and Prediction System (MAPS) for assimilating surface and tropospheric data over the contiguous United States every three hours. Designed to serve aviation and local nowcasting, MAPS is scheduled for implementation at the National Meteorological Center (NMC) within one year. It relies heavily on automated aircraft reports available by the hundreds every hour. It uses isentropic coordinates in the free atmosphere and terrain-following coordinates near the ground. Isentropic coordinates are well-suited for trajectory calculations because air remains on these surfaces in adiabatic flow.

MAPS has been adapted for use over Alaska. The previous definition of topography has been modified to allow for rougher terrain. A major obstacle must be overcome before the full potential of MAPS can be realized: automated aircraft reports over all of Alaska must be collected in real time so that the tropospheric and lower stratospheric wind field can be adequately defined every few hours.

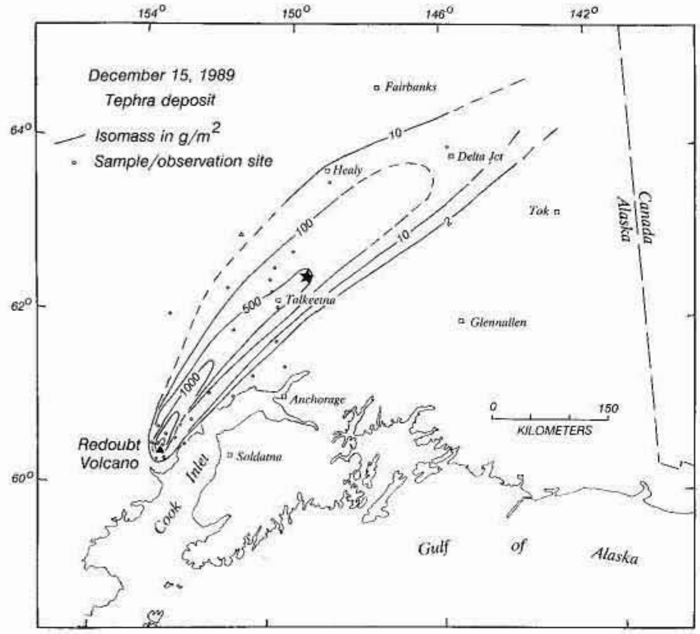
MASS, DISTRIBUTION, GRAIN SIZE, AND ORIGIN OF 1989-1990 TEPHRA-FALL DEPOSITS OF REDOUBT VOLCANO, ALASKA

William E. Scott, *U.S. Geological Survey, Vancouver, WA,* and Robert G. McGimsey, *U.S. Geological Survey, Anchorage, AK*

Twenty-one significant tephra falls occurred at Redoubt Volcano between 14 December 1989 and 26 April 1990. Although modest in size compared to such recent eruptions at Mount St. Helens 1980 and Galunggung 1982, these events inferfered with and imperiled air travel and disrupted life and commerce in south-central Alaska. Tephra plumes rose to estimated altitudes of 7 to more than 12 km; most drifted to the northeast, east, or southeast. Individual tephra-fall deposits extend maximum distances of 50 to more than 600 km from the volcano with mass concentrations ranging from 1 g/m^2 to 1.5 X 10^5 g/m^2. Mass estimates of individual deposits range from 6 X 10^7 to 4 X 10^{10} kg summing to a total dense-rock volume of about 4 X $10^7 m^3$.

The tephra fall of 15 December produced pumice- and crystal-rich deposits that were coarse grained near the volcano, whereas all subsequent events produced mostly ash-size deposits of lithic fragments and crystals (plagioclase, hornblende, pyroxene, and Fe-Ti oxides). Of the 19 events that produced lithic-crystal tephras, 17 involved at least partial dome destruction. This association, coupled with visual evidence from 4 events and lack of large ballistic fragments near the vent, suggests that much of the lithic-crystal tephra originated in ash clouds elutriated from pyroclastic flows formed by dome collapse.

Most 1989-1990 Redoubt tephra deposits other than proximal deposits of mid-December are composed of ash size material with mean grain sizes between 30 and 125 microns. Beyond 20 km from the volcano, little material is coarser than 500 microns; sorting is poor to very poor. Mean grain size decreases and sorting improves with transport distance. Grain size of many samples is polymodal; modes common to numerous samples occur at 63-125, 16-32, 8-16, and 500-1000 microns. These modes may be controlled by initial crystal-size distribution in the andesite of the dome.



Volcanic ash deposits from the December 15, 1989 eruption of Mount Redoubt were detectable for more than 300 miles northeast of the volcano. The axis of the deposits passed through the town of Talkeetna. Methods used to construct this map are described in the paper by W. Scott and W. McGimsey (this volume). The star (*) indicates the position of the Boeing 747-400 airplane of KLM flight 867, enroute from Fairbanks to Anchorage, when it encountered the ash cloud. Map courtesy of William E. Scott.

DEVELOPMENT OF A PREDICTION SCHEME FOR THE VOLCANIC ASH FALL FROM REDOUBT VOLCANO

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A volcanic plume prediction model has been developed for Alaska volcanoes including Redoubt Volcano. This is a 3-dimensional Lagrangian-diffusion model with gravity fallout of volcanic plume particles. The near real-time and forecasted upper-air data are provided by the NMC global model product through the Unidata program.

The model has been tested with Redoubt Volcano eruption records and compared with the NOAA AVHRR satellite data analyses. The 3-dimensional distributions of the plume dispersal are displayed on the computer screen as functions of time after the eruption. The simulation results agree reasonably well with the AVHRR satellite data analyses.

The model predictions have been demonstrated routinely at the Alaska Volcano Observatory (AVO) for daily hypothetical eruptions. These demonstrations show that the model is capable, within 6 minutes after any eruption report, to display traveling plume locations and dispersal for the following several hours. The prediction will be especially useful during dense-cloud situations when the visual monitoring is difficult, a common condition in winter at the Gulf of Alaska.

The model products are immediately available for aviation purposes through computer networking and FAX transmission supervised by the AVO. Because the model is operational at the AVO, it can offer the timely predictions important to aviation and public safety.