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ALASKA VOLCANO-DEBRIS-MONITORING SYSTEM: NEW TECHNOLOGIES TO SUPPORT FORECASTING VOLCANIC-PLUME MOVEMENT

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ABSTRACT

The eruptions of Redoubt Volcano during 1989–90 revealed a number of deficiencies in National Weather Service (NWS) operations that greatly hampered the forecaster's ability to accurately forecast and issue timely advisories on the movement of airborne volcanic debris. The forecaster lacked knowledge of (1) the physical properties of airborne volcanic debris, (2) the initial location of debris in the atmosphere, both vertically and horizontally, (3) real-time winds near and downstream of the volcano, and (4) rapid access to volcanic-debris-tracking models.

To help resolve these deficiencies, an Alaska volcano debris monitoring system has been designed, acquired, and installed at the NWS offices in Anchorage, Alaska. The system consists of a wind-profiling Doppler radar that provides hourly vertical profiles of winds near the volcano, a satellite downlink and processing system for tracking volcanic plumes using a variety of polar-orbiting satellites, a C-band radar to provide vertical and horizontal extent of the plume at and near the volcano, a new volcanic-debris-tracking model, and an upgrade to the regional computer and communications network for processing, applications, and display of the volcano debris monitoring system database.

INTRODUCTION

Volcanic ash injected into the atmosphere from the 1989–90 Redoubt eruptions became the most common and widespread hazard (Brantley, 1990) from this series of eruptions. The ash caused significant damage to property, especially aircraft, and severely disrupted normal activities in south-central Alaska, where about 60 percent of the State's population lives.

Redoubt Volcano is one of four active volcanoes that lie along the west side of Cook Inlet (fig. 1). These four volcanoes have erupted for a combined total of seven times in the last 80 years. Some of those eruptive episodes have lasted over a 2-year period. The four volcanoes are part of an active chain that extends from upper Cook Inlet, southwest along the Alaska Peninsula, to the western Aleutians. This chain includes a total of 35 volcanoes active during the last century (Simkin and others, 1981).

During the last eruptive episode of Redoubt Volcano, the NWS found that there were a number of deficiencies in information that greatly hampered the forecaster in accurately forecasting and issuing timely advisories on the movement and concentration of volcanic debris injected into the atmosphere. The forecaster had no information on (1) ash particle size and concentration, (2) initial height or horizontal extent of the plume into the atmosphere, (3) real-time vertical profiles of the winds near and downstream of the volcano, and (4) rapid access to volcanic-ash-trajectory models.

The potential for future hazardous eruptions near Cook Inlet led Congress to support a volcano monitoring program for south-central Alaska to minimize the affects on the population and commerce. A major participant in the monitoring program is the NWS. The purpose of this paper is to describe the technologies that have been chosen by NWS for the task of ash detection, monitoring, and tracking in Alaska. The system, called the Alaska volcano debris monitoring system, consists of new remote-sensing instrumentation, development of new predictive models, and an upgrade of the NWS regional computer and communications network for processing, applications, and display of the integrated database from the monitoring system.

REMOTE-SENSING TECHNOLOGIES

The remote sensing instrumentation in the Alaska volcano debris monitoring system consists of a Doppler wind profiler, a non-Doppler weather radar (C-band), and a polar satellite downlink, processing, and display system.

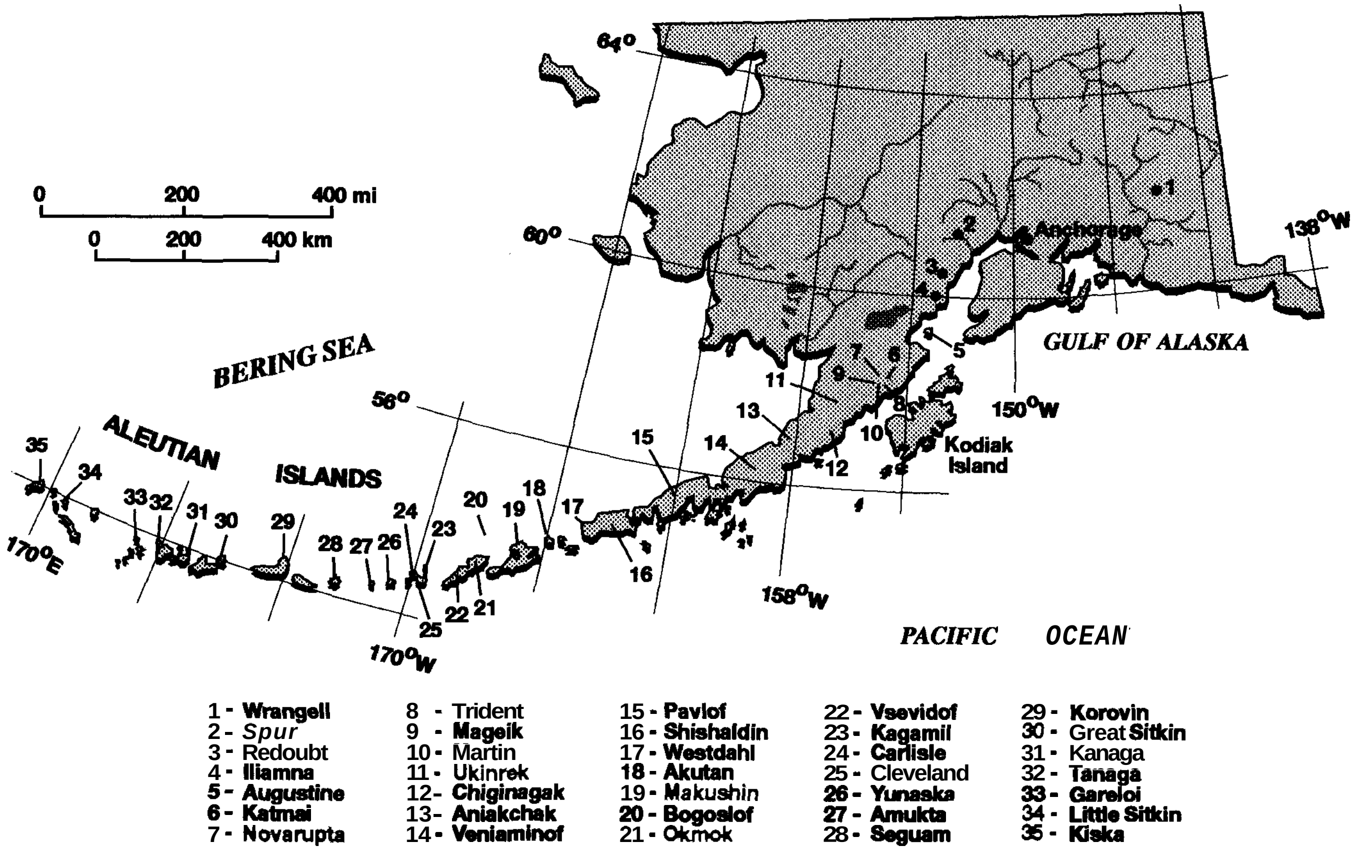

Figure 1. Volcanoes along Cook Inlet, Alaska, that have shown activity in the last century, including Mt. Spurr (2), Redoubt Volcano (3), Iliamna Volcano (4), and Augustine Volcano (5). Source: Alaska Volcano Observatory.

WIND PROFILER

A wind-profiling Doppler radar observes the weak back-scatter from turbulent inhomogeneities in the atmospheric radio refractive index. The–ultra high frequency (UHF) system (405 MHz) is suited for high-resolution, clear-air wind observations from 1 km to 16 km producing data every 6 minutes that is arranged into hourly, vertically averaged wind profiles (Balsley and Gage, 1982). Many studies have been made of the precision of profiler wind measurements. Thomas and Williams (1990) report that, in a comparison of profiler and rawinsonde (balloon) winds, the standard deviation was close to 3 m/s, with an inherent accuracy for the profiler of less than 1 m/s.

To support the Alaska volcano debris monitoring system, the wind profiler was installed in Homer, Alaska, about 100 km from Redoubt Volcano (fig. 2) in December 1990. The Homer site provides hourly vertical profiles of winds near the Cook Inlet volcanoes. Figure 3 shows an example of the wind measurements from the Homer profiler. Other profiler sites are proposed for Talkeetna and Middleton Island, Alaska (fig. 2). These two sites will give hourly vertical wind profiles at locations downwind from the Cook Inlet volcanoes. These sites will also provide winds along two major air-traffic corridors over south-central Alaska that have relatively poor upper-air network coverage (fig. 4).

C-BAND RADAR (5 CENTIMETER)

Ground-based radar observations and calculations can provide significant information on estimating (1) the height of the eruptive column above the volcano, (2) the maximum vertical and horizontal dimensions of the ash cloud downwind, and (3) the location and horizontal velocity of the ash cloud. NWS radar observations of ash clouds from Mount St. Helens demonstrated that weather radar (5 cm) can yield timely information during and following volcanic eruptions (Harris and Rose, 1983). However, there are some constraints.

One- to 10-cm radars sometimes cannot discriminate between ash clouds and meteorological clouds and rain targets (Stone, this volume). Thus, on cloudy, rainy days, ash plumes may go undetected by weather radar if the radar is the only source of detection. In addition, once an ash cloud is in the dispersed stage, particle sizes may be too small to be detectable by radar. Radar must be used in conjunction with other observational measurements to be an effective data source.

In October 1990, a 5-cm C-band radar was located in Kenai, Alaska, approximately 90 km from Redoubt (fig. 2). The radar is mounted on a modified recreational motor home and is portable. The unit can be moved rapidly to optimize observations of the other volcanoes in the Cook Inlet area. Data from the radar site is sent, in real time, by telephone to the forecaster in Anchorage for display on remote monitors.

HIGH RESOLUTION PICTURE TRANSMISSION PROCESSING SYSTEM

NOAA/TIROS (National Oceanic and Atmospheric Administration—television and infrared observing satellite) polar-orbiting satellites have been used in some cases to detect and track ash clouds utilizing a number of instruments on the platform. Advanced very high resolution radiometer (AVHRR) visible and infrared imagery have been used to track volcanic clouds in Alaska (Holasek and Rose, 1991; Schneider and Rose, this volume) and southeast Asia (Prata and others, 1985) using standard methods to track meteorological clouds. Infrared imagery has been used to discriminate volcanic clouds from ordinary water/ice clouds utilizing two signatures in the brightness temperatures (Prata, 1989). The first signature is based on the emission characteristics of silicates in the ash cloud. Silicates have a lower emissivity at 11 µm than at 12 µm where water/ice show peak emissivity. This effect is seen as a negative temperature difference between channels 4 and 5 of the AVHRR instrument. The second signature is a lower emissivity for sulfuric acid

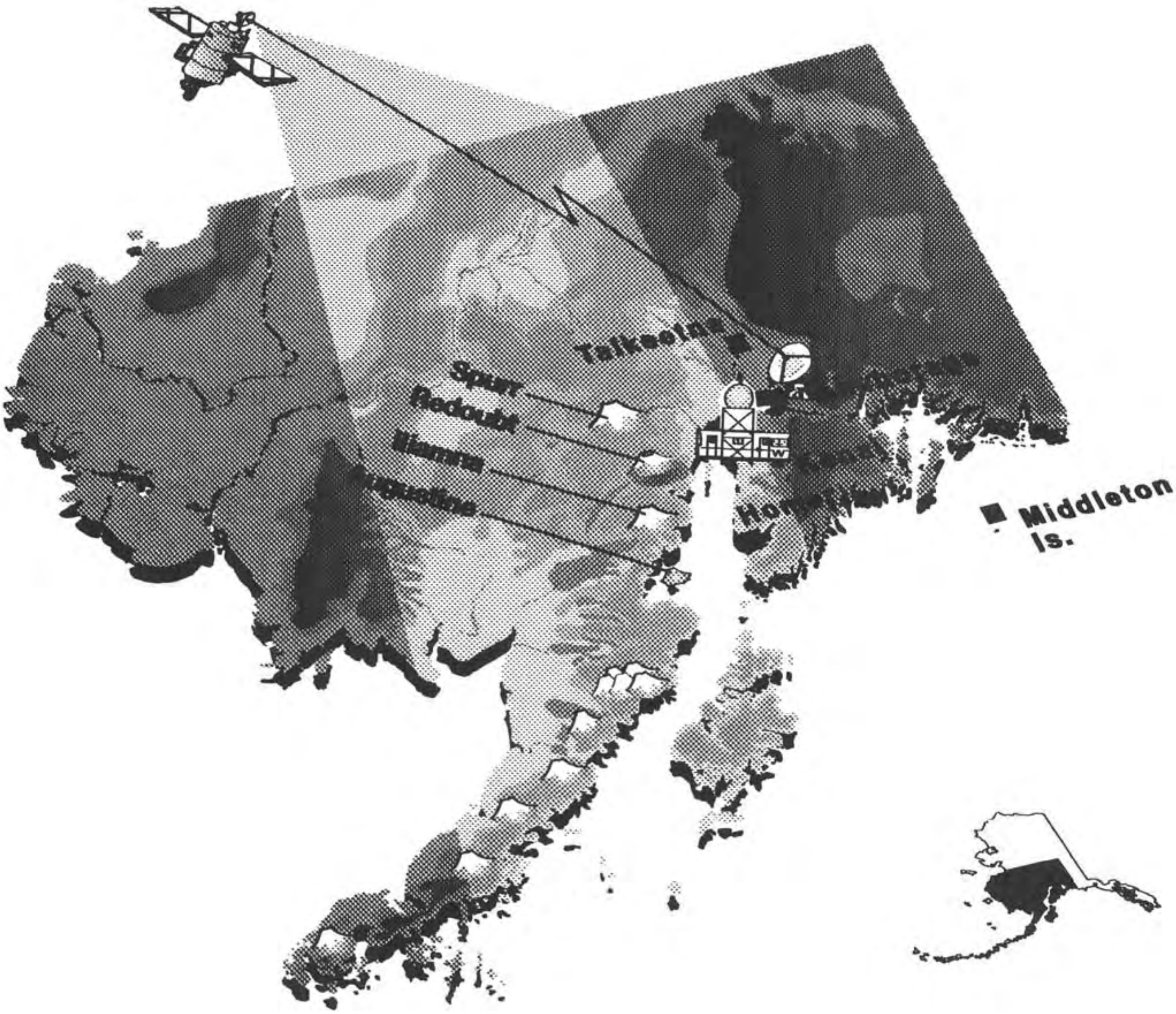

Figure 2. Location of remote-sensing instrumentation of the Alaska volcano debris monitoring system in relation to the four volcanoes along Cook Inlet.

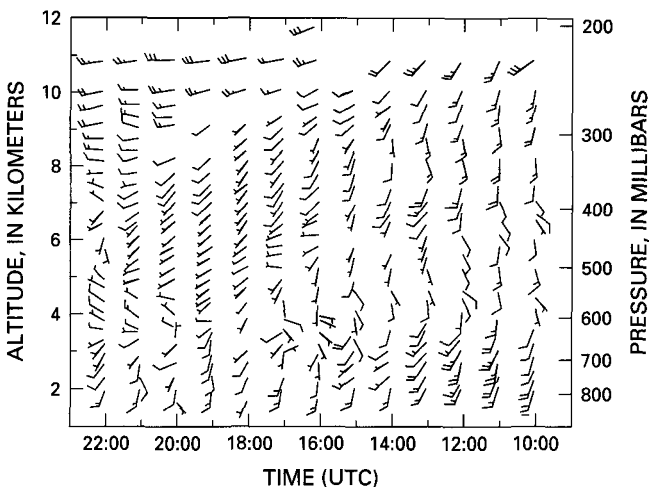

Figure 3. Hourly vertical profiles of wind from the Homer, Alaska, profiler for April 2, 1991. Orientation of "arrow" shaft indicates wind direction and has a precision of ±10°. "Flag" length indicates wind speed: a "half-flag" has a value of 5 knots; a "full-flag" has a value of 10 knots. UTC, Coordinated Universal Time.

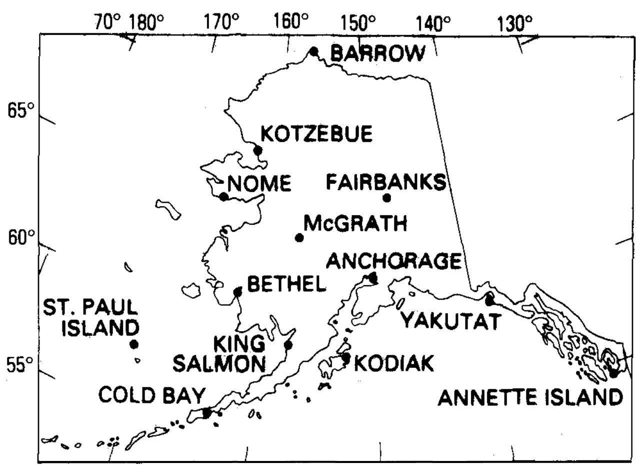

Figure 4. Location of the upper-air (rawinsonde balloon release) network in Alaska.

droplets or acid-coated particles (11 µm) when compared to water/ice particles (12 µm).

The high spatial resolution of the NOAA/TIROS polar-orbiting satellites (1 km), their great spectral range, and frequent coverage make these satellites a significant monitoring and tracking tool over Alaska. At low latitudes, the polar orbit limits the view of the same point to only four times per day for two satellites. Because the orbits of the satellites are near polar and sun synchronous, their orbital paths tend to converge at the poles, and, in the higher latitudes, coverage can be up to 18 passes per day from the same two polar satellites.

There are other operational instruments on-board the NOAA/TIROS polar-orbiting satellites that have potential to support the monitoring and tracking of volcanic plumes. The TIROS observational vertical sounder (TOVS) on the polar-orbiting satellites should be able to provide considerable information on volcanic clouds and conditions around them. TOVS consists of a high-resolution infrared radiation sounder (HIRS) that contains 20 infrared channels and a passive microwave sounding unit (MSU). TOVS also provides vertical profiles of temperature, moisture, and geostrophic wind down to the surface in areas of no clouds. This data can be used to estimate the maximum height and trajectory of ash clouds.

A high-resolution image-processing system (HIPS) was installed in Anchorage, Alaska, in June 1991 (fig. 2). The system includes a tracking antenna located at the international airport, an ingest/synchronization computer, a main processor, and four workstations at the three Alaska forecast offices (Anchorage, Juneau, and Fairbanks) and the Center Weather Service Unit in Anchorage. Eighteen polar-orbiting passes over Alaska can be processed to produce at least 12 satellite-image products per pass; these are distributed via the Alaska region operational communications network (ARO-NET). The HIPS system was also designed to ingest data from other polar-orbiting satellites, including those of the defense meteorological satellite program (DMSP), to increase coverage so that an image is available over any given point in Alaska every 1.5–2 hours. The aerial coverage for HIPS is within a 1,500-km radius from Anchorage.

Satellite data are displayed on workstations, and interactive software allows for complete digital manipulation of the imagery and sounding data, including animation, graphic overlay, cartographic projections, multispectral classification, windowing, and full color enhancement.

COMPUTER, COMMUNICATIONS, DATA INTEGRATION, AND MODELS

COMPUTER AND COMMUNICATIONS NETWORK

To insure the optimization of the NWS Alaska computers and communications to handle the large volume of data from the volcano monitoring system and the gridded data sets from various prediction models, the next-generation Alaska region operational computer and communications network (ARO-NET) was developed and made operational in October 1991 (fig. 5). Computer standards such as UNIX (OSF/1 compliance), X-Windows (Motif), and IEEE 802.3 Ethernet with TCP/IP network protocol have been selected to minimize the difficulties inherent in a heterogeneous computer environment. This allows a number of different kinds of computers to be used as workstations and coupled with an advanced wide- and local-area network

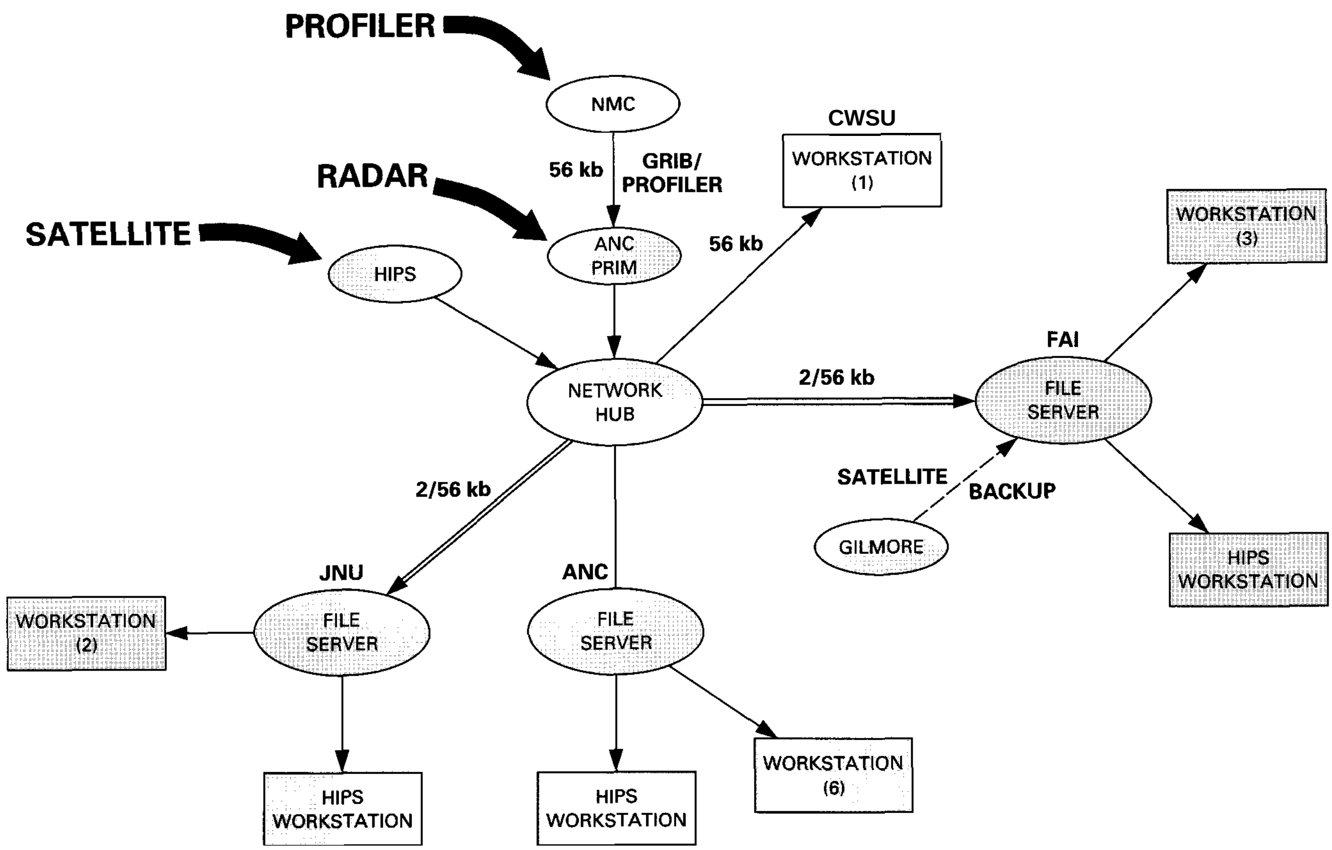

Figure 5. Schematic of Alaska region operational computer and communications network (ARO-NET). JNU, Juneau; FAI, Fairbanks; ANC, Anchorage; NMC, National Meteorological Center; CWSU, Central Weather Service Unit; HIPS, high-resolution image-processing system; GRIB, gridded binary format.

to integrate data from a combination of sources. New RISC (reduced instruction set chip) computers are used as application and file servers on the network, and high-speed digital communications lines (56 kb) have been incorporated to handle the increased volume of data.

INTEGRATED DATABASE

The data from the Alaska volcano debris monitoring system, integrated with other conventional data sources in Alaska, provides the forecaster with a powerful tool to assist in producing effective and timely forecasts. Comparing the integrated database to digital predictive-model output fields and adjusting the model when necessary will provide the forecaster with capabilities never available in field offices in the past. As an example, during eruptive events, forecasters will have available forecaster-selected, multilevel winds valid at 3-hour intervals from the time of initial eruption out to 12 hours, and thereafter every 6 hours out to 72 hours. These constant-height winds will come from gridded, digital-model output and can be displayed as streamlines (wind paths). The forecaster will place observed winds from the profilers, satellites, rawinsonde balloon releases, and other observations over the streamlines. This overlay capability will assist the forecaster to initialize, verify, or adjust the predicted model winds.

ASH DISPERSION MODEL

The air resources laboratory of NOAA is developing a four-dimensional dispersion model for airborne volcanic debris (Heffter and others, 1990; Stunder and Heffter, this volume). This model will utilize wind data from the technologies described above as well as inputs from NOAA's forecast systems laboratory mesoscale analysis and prediction system (MAPS) and National Meteorological Center (NMC) boundary-layer forecast meteorological fields. Designed to serve aviation and local forecasting, MAPS over Alaska will define the tropospheric and lower stratospheric wind fields every few hours after eruption. Over the longer term, NMC forecast winds will be utilized. In addition, satellite imagery will provide information on the location and horizontal extent of the ash cloud. The C-band radar will supply initial vertical height and direction of the ash plume at the volcano. The dispersion model will forecast concentrations and deposition of volcanic debris for forecast periods from eruption to up to 48 hours. The model should be ready for operational use in late 1992.

SUMMARY

The 1989–90 eruptions of Redoubt Volcano have resulted in the establishment of a volcano debris monitoring system to improve the accuracy and timeliness of NWS forecast warnings and advisories to the public during eruptions of Alaskan volcanoes. The long history of frequent eruptions from volcanoes along Cook Inlet clearly indicates that future eruptions are inevitable.

It is anticipated that improved forecast products will have their greatest impact on aviation safety in the Cook Inlet region. Because ash is not possible to detect during flight with present onboard sensors, effective and timely warnings will allow aircraft to avoid ash clouds.

These more accurate forecast products will be in both alphanumeric and graphic form. New products will include a graphical advisory, four-dimensional trajectories, and descriptive statements to the public and emergency-management agencies.

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