Tracking of 1992 Eruption Clouds from Crater Peak Vent of Mount Spurr Volcano, Alaska, Using AVHRR

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CONTENTS

ABSTRACT

The 1992 Crater Peak vent eruptions of Mount Spurr provided a robust test of the new High Resolution Picture Transmission (HRPT) Information Processing System (HIPS), which was installed in Anchorage for real-time tracking of volcanic clouds. One principle objective of the tracking system is to avoid aviation hazards. The system receives Advanced Very High Resolution Radiometer (AVHRR) images from polar-orbiting satellites and processes them using a two-channel technique. The resulting processed imagery reflects the extensive real-time capability now available. The frequency of data collection (about once every few hours) allows for an understanding of the patterns of change in spectral response that occur during the evolution of a volcanic cloud. Volcanic clouds imaged during and shortly after eruption are optically thick and can contain abundant water droplets and (or) ice, and these characteristics cause their spectral signal to closely resemble a meteorological cloud. As the volcanic cloud disperses, the spectral properties of the cloud change, first at the edge and then throughout. These changes produce a volcanic cloud signal that can be distinguished by using a brightness temperature difference determined from thermal bands 4 and 5 of the AVHRR. The usefulness of this technique of tracking clouds for long distances was investigated using archived data. Two clouds were tracked for more than 80 hours and thousands of kilometers, during which the band 4 minus 5 brightness temperature signal decayed. These clouds traveled southward over the continental United States and posed a potential hazard to aircraft. To alleviate this potential hazard, the measurable brightness temperature difference signal needs to be correlated with ash concentration and particle size to determine when drifting volcanic clouds are a threat to aircraft.

INTRODUCTION

Since 1986, three volcanoes (Augustine Volcano, Redoubt Volcano, and Mount Spurr) have erupted in the Cook Inlet area of Alaska. Each of these eruptions has had a significant impact on commercial aviation at Anchorage. The National Weather Service has greatly improved its capability to measure and track ash clouds in order to better advise the aviation community about the location of hazardous ash clouds. Two significant improvements, which were made following the Redoubt activity in 1989–90, were the installation of a High Resolution Picture Transmission (HRPT) Information Processing System (HIPS) workstation for rapid digital-image processing of Advanced Very High Resolution Radiometer (AVHRR) data from polar-orbiting weather satellites, and the leasing of a meteorological C-band radar. Weather satellite data have been used by many investigators to observe ash clouds (Hanstrum and Watson, 1983; Matson, 1984; Sawada, 1987; Prata, 1989; Holasek and Rose, 1991; Schneider and Rose, 1994) but until now, real-time analysis of processed images has been difficult.

The AVHRR data complement the radar observations because the radar can map clouds near the volcano, within minutes of eruption (Rose and others, this volume), while the AVHRR can track the clouds for up to several days. Three eruptions of the Crater Peak vent of Mount Spurr provided a real-time test of the equipment's ability to detect and map significant ash clouds. The results obtained with the new HIPS workstation equipment, and the results obtained on the long-range tracking of the cloud over North America using archived AVHRR data are described herein.

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TWO-CHANNEL AVHRR DETECTION OF VOLCANIC CLOUDS

AVHRR satellite data are received from the NOAA 11 and 12 polar-orbiting satellites at the National Weather Service Forecast Offices in Anchorage, Alaska, through the HIPS system and is linked to meteorologist workstations in forecast offices of the Alaska Region Operations Network. Full passes (4.4-km resolution) over active volcanoes are available as soon as 10 minutes after pass completion, with subsectors (1.1-km resolution) available within 40 minutes. All five spectral bands, from visible to thermal infrared, are received (band 1: 0.58–0.68 µm; band 2: 0.73–1.10 µm; band 3: 3.55–3.93 pm; band 4: 10.3–11.3 pm; and band 5: 11.5–12.5 µm). Satellite coverage extends from the western edge of the Kamchatka Peninsula to east of British Columbia; this coverage encompasses four major air routes near the volcanoes of Alaska and Kamchatka. Because of orbital irregularities and the movement of volcanic clouds, coverage frequency is variable and gaps as long as 8 hours can occur.

We used band 4 minus band 5 brightness temperature difference images to detect volcanic clouds, and to distinguish them from meteorological clouds. Thermal data from bands 4 and 5 were converted from raw sensor counts to radiance, using the technique of Lauritson and others (1988). A slight nonlinearity in bands 4 and 5 was corrected using a quadratic function of radiance. The radiance values were converted into brightness temperature values, using the inverse Planck function, and band 4 minus 5 brightness temperature images were created. Volcanic clouds are known to have negative band 4 minus 5 brightness temperature differences (Prata, 1989; Schneider and Rose, 1994), whereas meteorological clouds generally have positive brightness temperature differences (Yamanouchi and others, 1987). For volcanic clouds, the magnitude of the negative brightness temperature difference depends on many characteristics. These characteristics include the optical thickness of the cloud; amounts of water, volcanic ash, and sulfuric acid in the cloud; mean size and size distribution of particles in the cloud; and temperature contrast between the cloud and the underlying surface (meteorological clouds, land, or water) (Prata, 1989; Wen and Rose, 1994).

The volcanic cloud signal detected by the brightness temperature difference method has well-defined edges, which allow us to define the area of the cloud. Cross sections through volcanic clouds show a clearly defined edge at a brightness temperature difference value of -0.5°C (fig. 1). The ability to detect cloud edges is important in reducing aircraft hazards, because it is a snapshot of cloud position that can be quickly reported. It also serves as a periodic check on the trajectory models for the ash cloud.

Table 1. List of AVHRR images used for this study showing date and time of satellite coverage, hours since start of eruption, and satellite used.

Time (UT)	Hours since start of eruption	Satellite
	August 19,1992	
01:26	1.5	NOAA-11
03:38	3.6	NOAA-11
05:10	5.2	NOAA-12
13:38	13.6	NOAA-11
17:20	17.3	NOAA-12
18:57	18.9	NOAA-12
23:30	23.1	NOAA-11
	August 20, 1992	
13:23	37.4	NOAA-11
23:15	47.3	NOAA-11
	August 21, 1992	
23:00	71.0	NOAA-11
	August 22, 1992	
11:21	83.4	NOAA-11
	September 17,1992	
12:40	3.7	NOAA-11
17:00	8.0	NOAA-11
22:44	13.7	NOAA-11
	September 18,1992	
11:00	26.0	NOAA-11
20:45	35.7	NOAA-11
	September 19,1992	
09:00	49.0	NOAA-11
18:53	57.9	NOAA-11
	September 20,1992	
07:00	70.0	NOAA-11
17:04	80.1	NOAA-11

OBSERVATIONS OF THE CRATER PEAK VOLCANIC CLOUDS

Eleven images of the volcanic cloud resulting from the August 18, 1992, eruption of Crater Peak and nine images of the volcanic cloud from the September 16–17, 1992, eruption were analyzed for this study (table 1). The evolution of the volcanic cloud signal can be seen in figure 2, a series of images collected by the HIPS system of the August 18 volcanic cloud. The earliest image, collected about 90 minutes after the start of the eruption (fig. 2*A*), shows a cold, circular volcanic cloud in band 4 and high thermal contrast between the volcanic cloud and the lower, warmer meteorological clouds. The band 4 minus band 5 brightness temperature difference algorithm does not work well on this image (fig. 2B). The second image in this series was collected 2 hours later and shows a

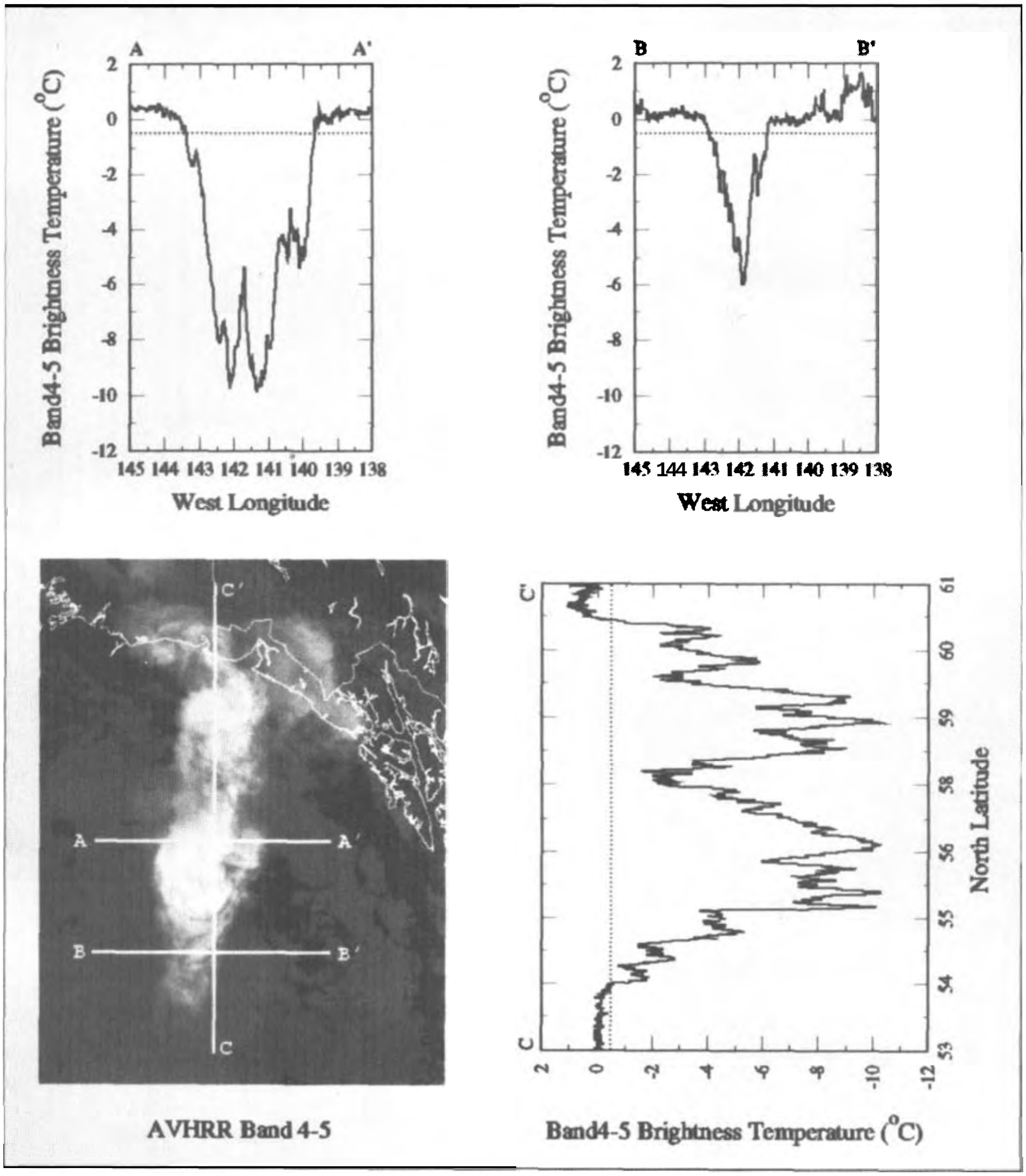

Figure 1. Cross sections through a band 4 minus band 5 image that compare brightness temperature difference of a volcanic cloud to those of meteorological clouds. Interior volcanic cloud shown has negative band 4 minus band 5 brightness temperature differences as large as -14°C, whereas meteorological clouds, land, and open water generally have brightness temperature differences greater than zero. Dotted line at -0.5°C shown for reference.

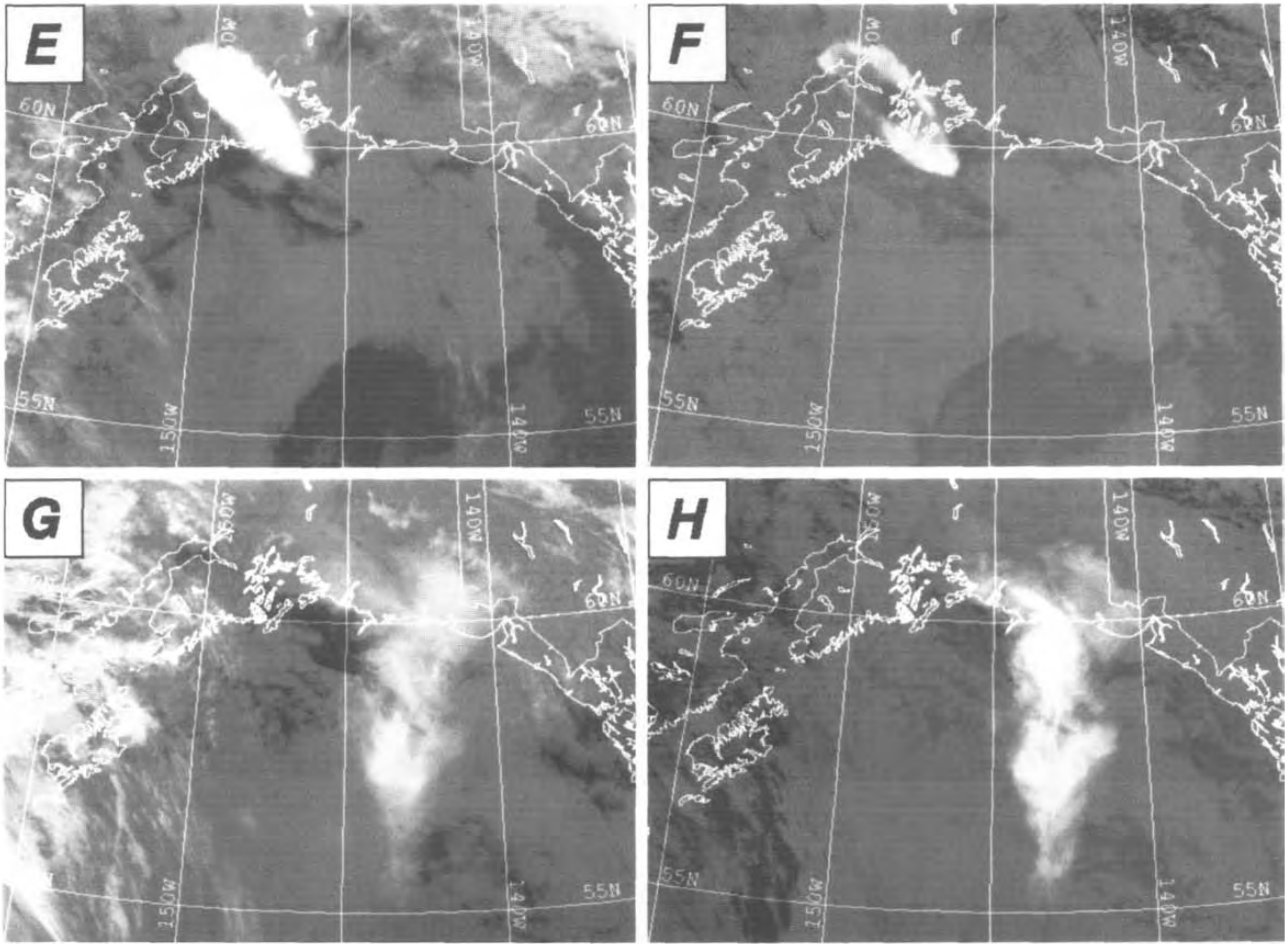

Figure 2. Continued. E, AVHRR band 4 image at 9:10 p.m. ADT (August 19, 05:10 UT). F, Corresponding band 4 minus band 5 brightness temperature image at 9:10 p.m. ADT (August 19, 05:10 UT). *G*, AVHRR band 4 image at 5:38 a.m. ADT on August 19 (13:38 UT). H, Corresponding band 4 minus band 5 brightness temperature image at 5:38 a.m. ADT on August 19 (13:38 UT).

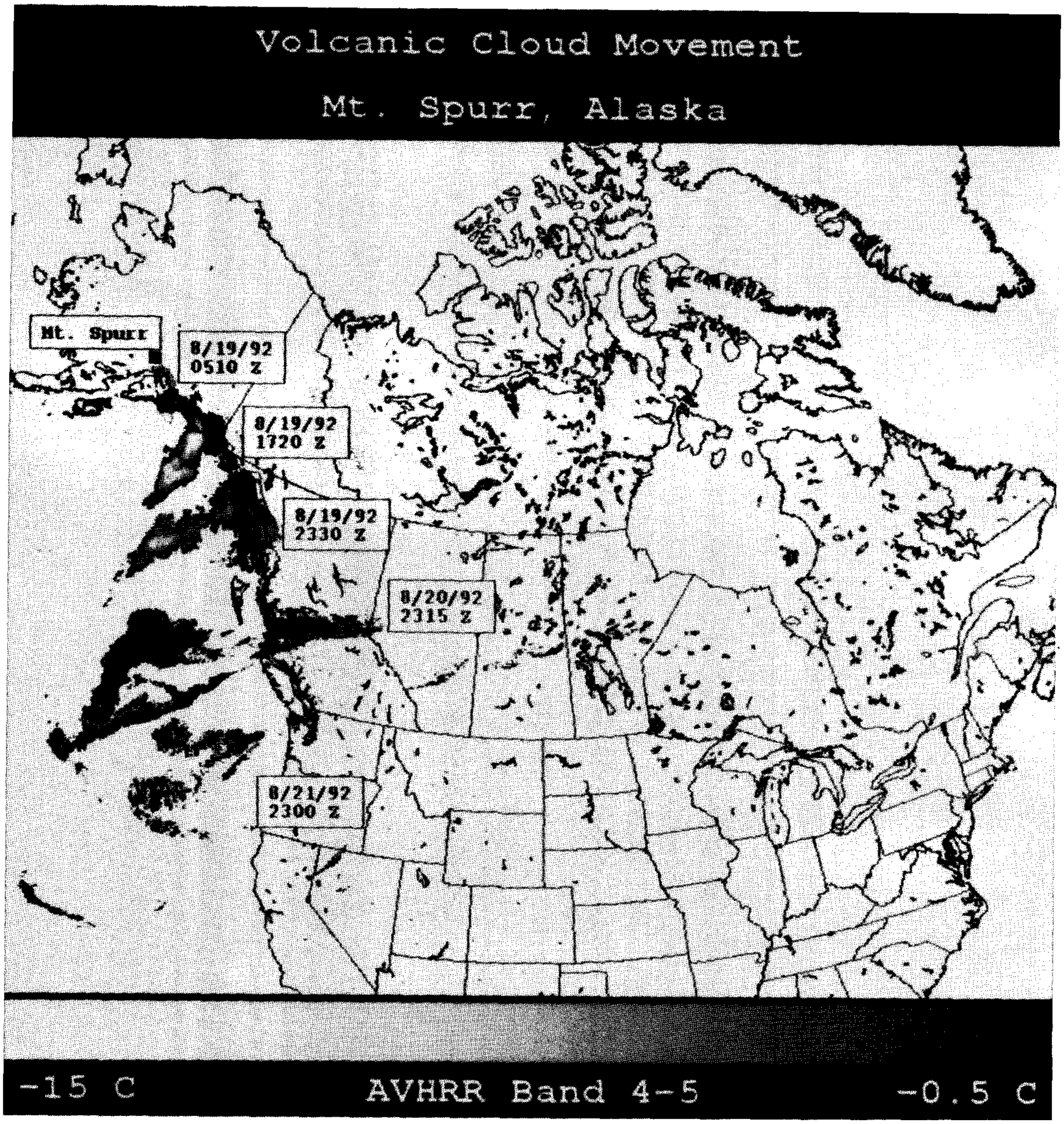

Figure 3. Composite of five band 4 minus band 5 images, showing the long-distance transport of the August 18, 1992, volcanic cloud from the Crater Peak vent of Mount Spurr, Alaska. This cloud was detected in 11 images, but for clarity, only five images are shown. Alaska daylight time equals Z (same as UT) - 8 hours.

larger cloud in the band 4 image (fig. *2C)* and a fringing response from the band 4 minus band 5 process (fig. 2*D*). The third image (fig. *2E)* was collected *90* minutes later. By this time the eruption had ended, and the fringe of negative band 4 minus band 5 values had grown and encircled the entire volcanic cloud (fig. *2F).* The fourth image was collected 8 hours later. The volcanic cloud is difficult to distinguish from the meteorological clouds in the band 4 image (fig. 2*G*), but it is easily distinguished on the band 4 minus 5 image (fig. *2H)* in which the entire cloud shows negative brightness temperature difference values.

The utility of the band 4 minus band 5 operation to track clouds for days following an eruption was tested using two archived AVHRR data sets. **A** composite of five images of the August volcanic cloud is shown in figure **3,** and a composite of nine images of the September volcanic cloud is shown in figure 4. In these images, only the pixels with negative band 4 minus band 5 brightness temperature values are shown. Because many factors affect the magnitude of the negative brightness temperature difference, the regions of the cloud with the greatest t mperature difference do not necessarily have the highest concentration of particles.

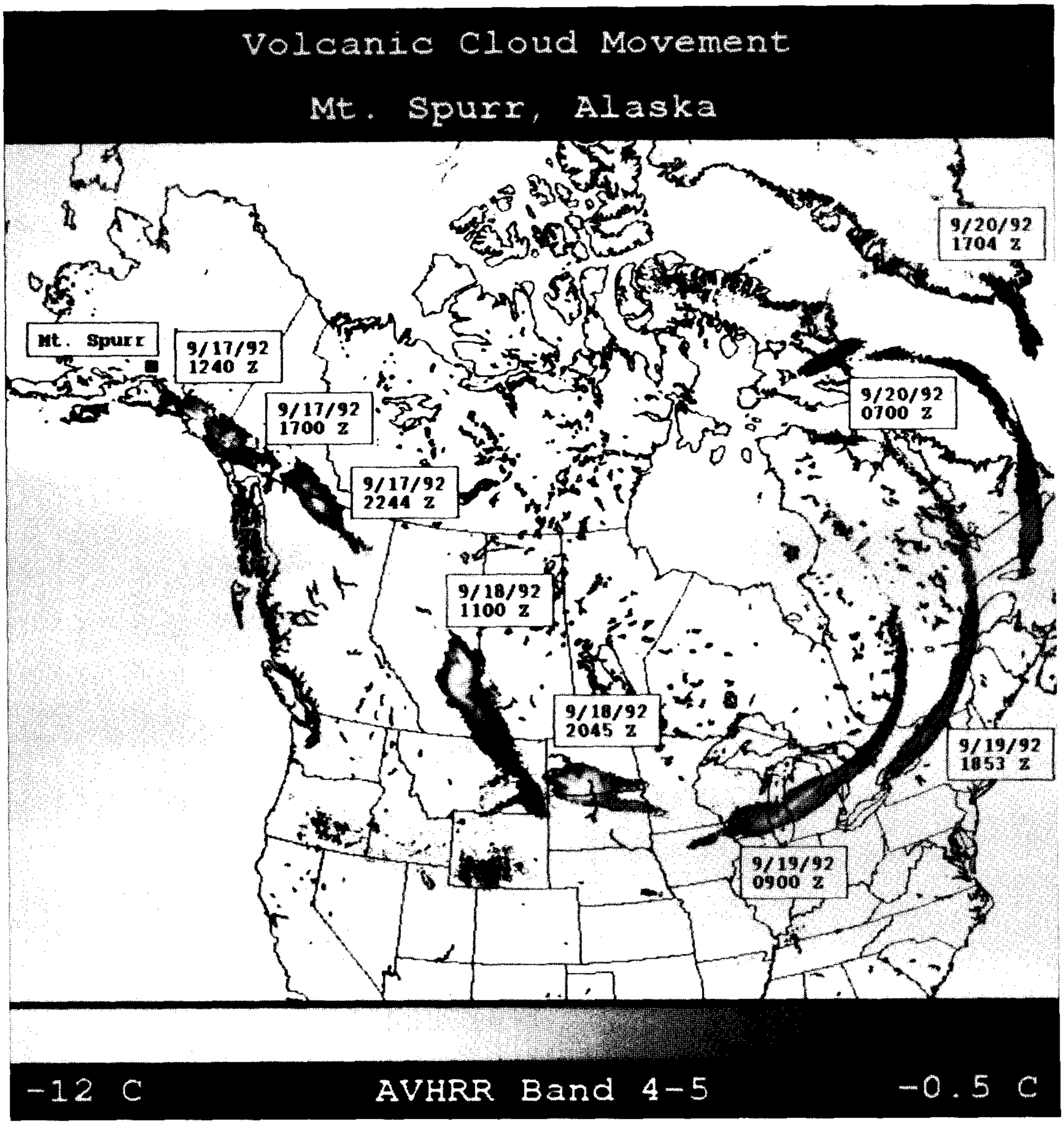

Figure 4. Composite of nine band 4 minus band 5 images, showing the long-distance transport of the September 16-17, 1992, volcanic cloud from the Crater Peak vent of Mount Spurr, Alaska. Alaska daylight time equals Z (same as UT) - 8 hours.

The detected area of the August cloud increased during the first 47 hours at a rate of 13,000 km^2/hr and reached a maximum area of about 600,000 km^2. The detected area of the September cloud increased at an average rate of 12,000 km^2/hr during the first 26 hours and reached a maximum area of 310,000 km^2 (fig. 5A). The leading edge of the August cloud moved about 3,000 km in 83 hours for an average velocity of 36 km/hr, and the leading edge of the September cloud moved about 4,400 km in 36 hours for an average velocity of 120 km/hr (fig. 5B). For both clouds, the magnitude of the negative band 4 minus band 5 brightness temperature difference first increased and then decreased during the cloud evolution (fig. 5*C*).

DISCUSSION

The sequence of images of the Crater Peak volcanic clouds defined the evolution of the spectral properties of volcanic clouds better than any previous observations. Volcanic cloud optical thickness is a critical parameter in distinguishing volcanic clouds. Opaque volcanic clouds (optical thickness = ∞) have positive band 4 minus band 5 brightness temperature values, and transparent volcanic clouds have negative band 4 minus band 5 brightness temperature values (Prata, 1989). The transition from the opaque stage to the transparent stage is seen in images of the August 18, 1992, cloud (fig. 2).

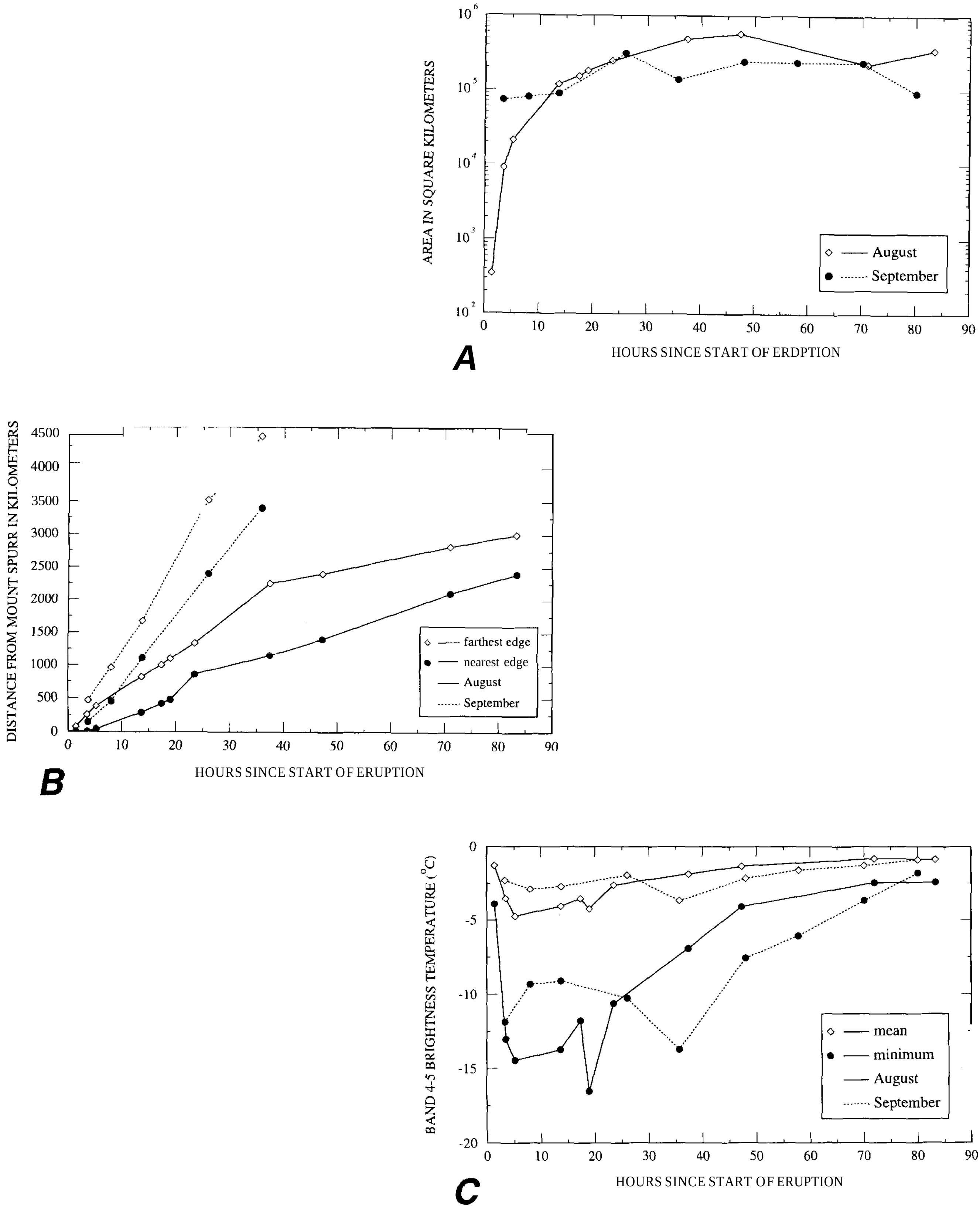

Figure 5. Changes, which occurred during transport, in the August 18 and September 16–17 volcanic clouds from the 1992 eruptions of Crater Peak vent, Mount Spurr, Alaska. ***A***, Volcanic cloud area. B, Distance cloud was transported from the volcano. C, Brightness temperature differences calculated from bands 4 and 5 of AVHRR. Mean temperature of entire cloud and minimum value of each cloud are shown. See text for definition of AVHRR.

Initially, the volcanic cloud is infused with water vapor from entrainment of moist lower tropospheric air. The formation of water droplets and ice crystals produce an opaque cloud (fig. 2*A*), which is spectrally similar to meteorological clouds in the band 4 minus 5 image (fig. 2*B*). As the cloud ages, it disperses along its perimeter to produce a transparent fringe. The transparent portion of the cloud has negative band 4 minus band 5 brightness temperature values, which are depicted as bright white regions, while the opaque core has positive values, which are depicted as dark gray regions (fig. 2*D*). The fringe of negative values grows and the core of positive values shrinks as dispersion proceeds (fig. 2*F*). This continues until the entire cloud is transparent and has negative band 4 minus band 5 values (fig. 2*H*). As the opaque area of the cloud decreases, the magnitude of the brightness temperature difference increases and then decreases as the cloud becomes more transparent over time (fig. 5*C*).

Because the band 4 minus band 5 algorithm only discriminates transparent volcanic clouds, the magnitude of the brightness temperature difference and the area of the detected cloud are influenced by the temperature of the surface underlying the volcanic cloud. The detected area of the volcanic cloud becomes discontinuous, and the magnitude of the brightness temperature difference decreases when it overlies cold meteorological clouds (see fig. 3, 8/21/92 at 23:00 UT). However, the magnitude of the temperature difference increases when a cloud overlies a warm land surface (see fig. 4, 9/18/92 at 20:45 UT). The brightness temperature difference continues to decrease until the particle concentrations are so low that the cloud is undetectable by this technique. Because several factors affect the discrimination of volcanic clouds, the minimum detectable particle concentration cannot be directly related to brightness temperature difference values.

The signal detected with the band 4 minus band 5 brightness temperature difference needs to be linked to aircraft hazard, possibly through a radiative transfer model, which can quantify the brightness temperature difference values and estimate particle size and burden (Wen and Rose, 1994). Validation of radiative transfer models could be accomplished by direct sampling of a cloud throughout its evolution.

CONCLUSIONS

AVHRR data were successfully analyzed to detect and track the position of volcanic clouds during the Crater Peak eruptions of 1992, using a new capability of the National Weather Service in Anchorage. By detecting the volcanic clouds for longer periods of time, AVHRR complements the C-band radar system employed by the NWS to image the volcanic clouds near the volcano in their first 30 minutes. Analyses of archived AVHRR data show that the volcanic clouds can be detected and tracked for several days following their eruption and throughout several thousands of kilometers of transport.

An algorithm based on a brightness temperature difference from the thermal infrared bands 4 and 5 of the AVHRR was used. A detailed sequence of images from the August eruption defined the evolution of the spectral properties of volcanic clouds better than any previous observations. The brightness temperature difference signal changes as the cloud evolves. It is more enhanced in the first few hours after the cloud forms and becomes transparent, and then it slowly decays to background values over the next few days. Because the magnitude of the brightness temperature difference is also affected by the temperature of the surface beneath the volcanic cloud, regions with the greatest temperature difference do not necessarily have the highest particle concentration.

Two of the Crater Peak clouds dispersed in the direction of the continental United States, raising the issue of whether Alaskan eruptions could pose hazards to principal domestic air routes in North America. Because the volcanic clouds were readily detectable when they crossed the continental United States, real-time processing of AVHRR data could have provided information to air traffic control outside Alaska. We need to calibrate the temperature difference signal to understand when volcanic clouds may be hazardous.

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