NOTES AND CORRESPONDENCE

A Note on the Mt. Saint Helens Volcanic Eruption

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16 June 1980 and 1 November 1980

ABSTRACT

The violent eruption of the Mt. Saint Helens volcano on 18 May 1980 was examined using GOES-EAST satellite imagery. The University of Wisconsin McIDAS system was used to display the imagery and derive a number of plume measurements—including the plume's area, temperature, speed and an estimate of plume height. A thickening of the surrounding cirrus shield was observed (believed to be associated with gravity wave activity) as well as two distinct phases of volcanic activity that occurred during the eruption. A comparison of the Mt. Saint Helens eruption to the 1979 Soufriere eruptions revealed that the Mt. Saint Helens volcanic eruption produced a much larger plume, indicative of a more violent eruption. It is also shown that the height of the plume could not be reliably extracted from the infrared data due to the low tropopause in the vicinity of the volcano.

1. Introduction

The Mt. Saint Helens volcano erupted in an explosive and spectacular fashion at approximately 1538 GMT (0838 PDT) 18 May 1980. The eruption produced a force estimated equal to 10–50 megatons of TNT (Greathouse, 1980), the equivalent of 25 000 atomic bombs of the size released over the city of Hiroshima during World War II. The violent volcanic eruption dramatically changed the character of the surface near the volcano and the ash fallout from the plume affected a large percentage of the area's population. While the effects of the volcano have been well documented by the mass media, the location of the Mt. Saint Helens volcano provided a unique opportunity to view the volcanic eruption from the GOES-West satellite. A sequence of satellite images is presented in this paper, depicting both the eruption and some interesting associated meteorological phenomena.

2. Initial eruption

The McIDAS (Man computer Interactive Data Acquisition System) at the University of Wisconsin has the ability to receive and process the GOES East and West digital data directly, as well as store raw data in a cassette archive system (Chatters and Suomi, 1975). Archived images from 1345 to 0445 GMT of 18–19 May with an interval of every 30 min were extracted for analysis. The first four satellite pictures presented (Figs. 1a–1d) are visible images for 1515, 1545, 1615 and 1645 GMT with a 1 km resolution at the subsatellite point. The image navigation and state boundaries were provided by routine programs within the McIDAS system.

The intense release of energy inferred by the dramatic growth of the ash cloud is readily evident from the images. The 1515 GMT image (Fig. 1a) was included to show the prevailing cloud conditions before the eruption. A mostly thin broken cirrus overcast covered the entire area of the image. The cirrus was situated to the west of a weak ridge located over the Washington-Idaho border at 1200 GMT 18 May. The next three images depict the nature of the explosion in detail. At 1545 GMT (Fig. 1b) (approximately 10 min after the explosion), the ash cloud bears a striking resemblance to an overshooting top of a thunderstorm. The outline of the volcanic ash cloud, which was very distinct, was calculated to have an area of 3.9×10^3 km^2. The growth of the ash cloud was spectacular, as it grew well above the cirrus cloud cover estimated at ~7.6 km (25 000 ft) by the National Weather Service. A shadow was observed through the cirrus clouds to the west of the volcanic cloud. The next two images (1615 and 1645 GMT, Figs. 1c and 1d) depict the volcanic cloud to be rapidly expanding and forming a plume downstream. Table 1 lists the aerial extent of the volcanic cloud as determined from the visible images. The area of the plume by 1645 GMT is 1/10 the size of the state of Washington.

An interesting feature to note on the 1615 and 1645

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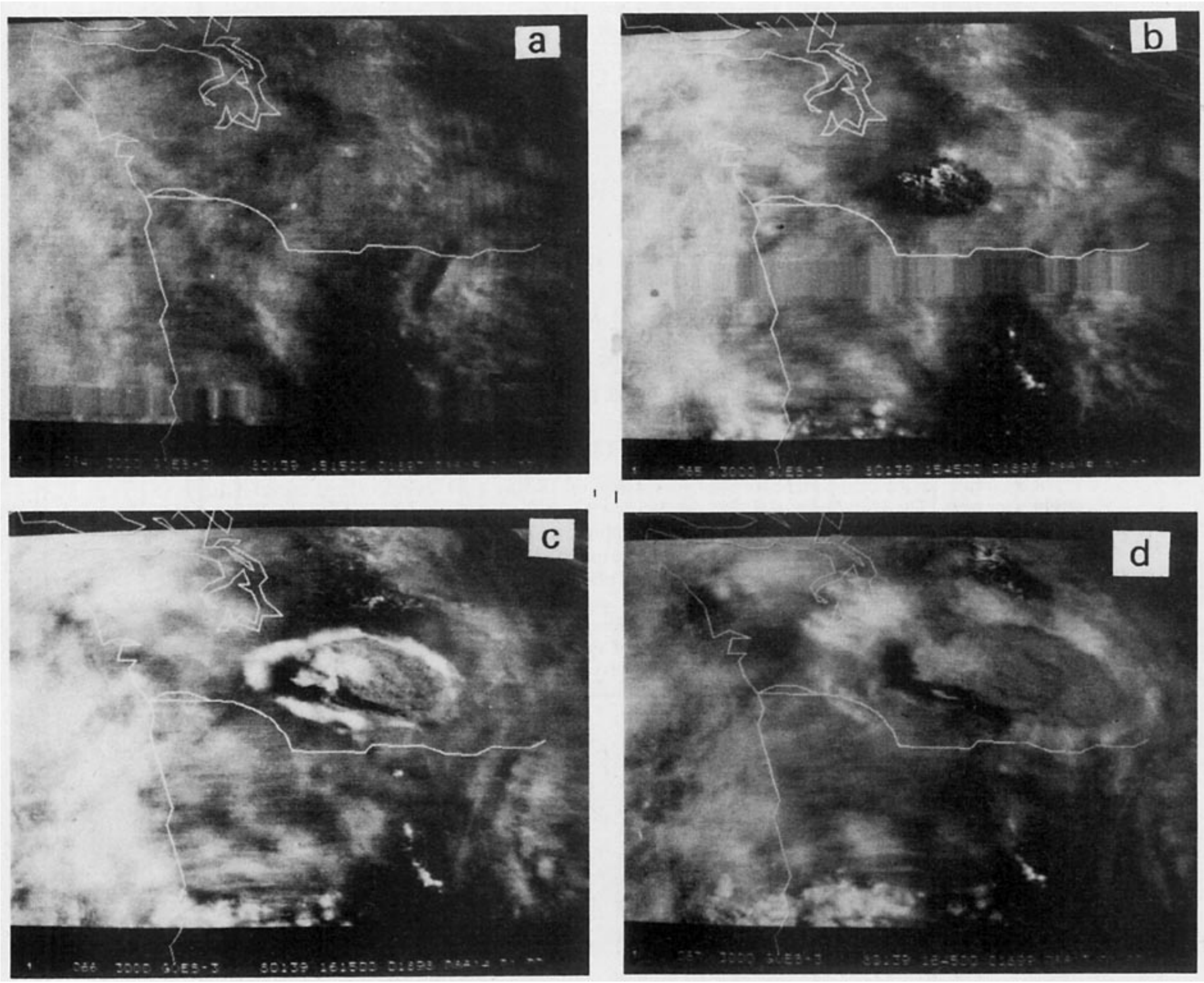


FIG. 1. GOES visible images (1 km resolution) 18 May 1980 (a) 1515 GMT, (b) 1545 GMT, (c) 1615 GMT, (d) 1645 GMT.

GMT images is an area of white that moves rapidly away from the ash cloud. The white area was determined to be the cirrus cloud cover becoming thicker and is believed to be associated with gravity wave activity moving rapidly away from the volcano. Surface observations and infrared satellite images (not included) verify that the cirrus deck did thicken during this period. The area expansion and the speed of the gravity wave activity are listed in Tables 1 and 2. The disparity in velocity calculated for different directions from the volcano is due to the large scale flow which was reported to be from 260° at ~20 m s^{-1} from 7.6–9 km at Salem, Oregon, for 1200 GMT. The surface observations were examined to determine if any surface pressure anomalies were recorded. Three stations in the state of Washington (Olympia, Stampede Pass and Spokane) reported only unsteady pressures. The fact that the surface observations failed to report significant activity, despite the phenomenon clearly appearing on the satellite images, may be due in large part to the mountainous region in which the stations are located.

An examination of the entire sequence of visible images revealed that the Mt. Saint Helens eruption was not one large single event but a major explosion followed by a less intense but more continuous period of activity. The images presented in Fig. 2 show that by 1915 and 1945 GMT a new and more distinct plume marks the beginning of a second period of volcanic eruptions from the volcano. As noted from SEAN (1980), a pilot reported an abrupt color change of the eruption from dark gray to pale gray at 1917 GMT. The color change indicated that the volcanic ash was originating from deeper sections of the volcano. This level of activity appeared to last ~6–7 h.

3. Infrared images

A sequence of GOES infrared images (IR) is shown in Fig. 3. The resolution is 8 km at the subsatellite

TABLE 1. Area of volcanic plume and gravity wave as measured from visual images.

Time (GMT)	Plume	Gravity wave
1515	0	0
1545	3.9×10^3 km²	—
1615	9.1×10^3 km²	18.7×10^3 km²
1645	17.4×10^3 km²	61.7×10^3 km²
1715	26.0×10^3 km²	not clearly defined
1745	40.9×10^3 km²	—

Velocity of gravity wave determined from 1615 and 1645 GMT images.

North of Volcano	40 m s^{-1}
West of Volcano	22 m s^{-1}
South of Volcano	31 m s^{-1}
East of Volcano	70 m s^{-1}

TABLE 2. Infrared temperatures (°C) of Mt. Saint Helens volcano.

Time (GMT)	Temperature of plume over volcano	Range of average temperatures of the plume downwind from volcano
1515	—	—
1545	−47	−47 to −55
1615	−53	−53 to −55
1645	−53	−55 to −57
1715	−52 to −54	−56 to −58
1745	−51 to −53	−56 to −59
1845–0415*		−56 to −58

* Not all IR pictures during this time period were in acceptable condition; however, temperature did not vary greatly during the sequence.

point. The enhanced dark area represents temperatures colder than ~ −50°C. The sequence is self explanatory, except to note that by 0445 GMT (Fig. 3j), the volcano is no longer injecting ash and steam to the same height it was during the early periods. The volcanic plume is drifting downwind at a speed of ~ 20–25 m s^{-1}. This speed was calculated from the downwind edge of the plume and agrees with the nearby radiosonde reported winds above 8 km. A

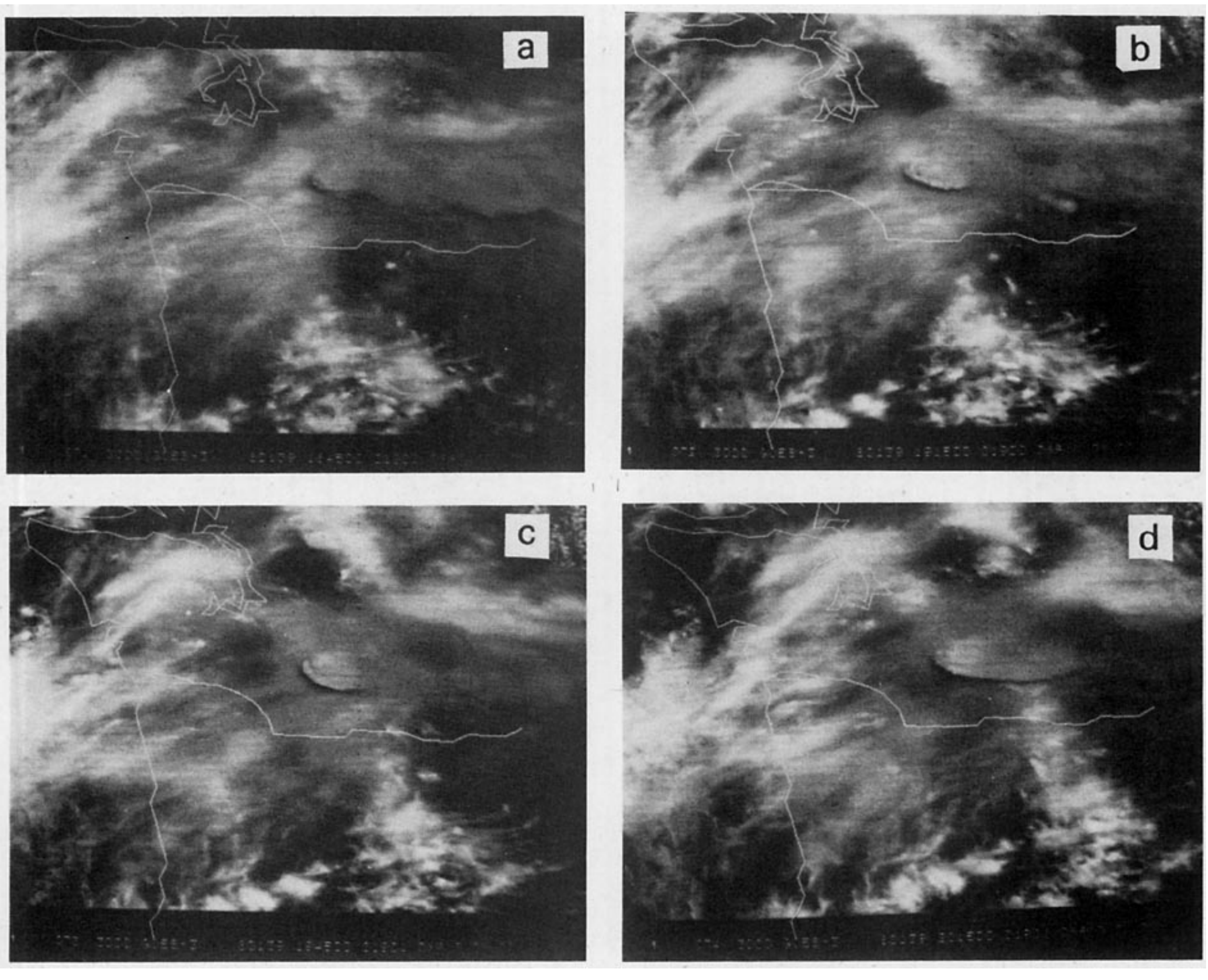


FIG. 2. GOES visible images (1 km resolution) 18 May 1980 (a) 1845 GMT, (b) 1915 GMT, (c) 1945 GMT, (d) 2015 GMT.

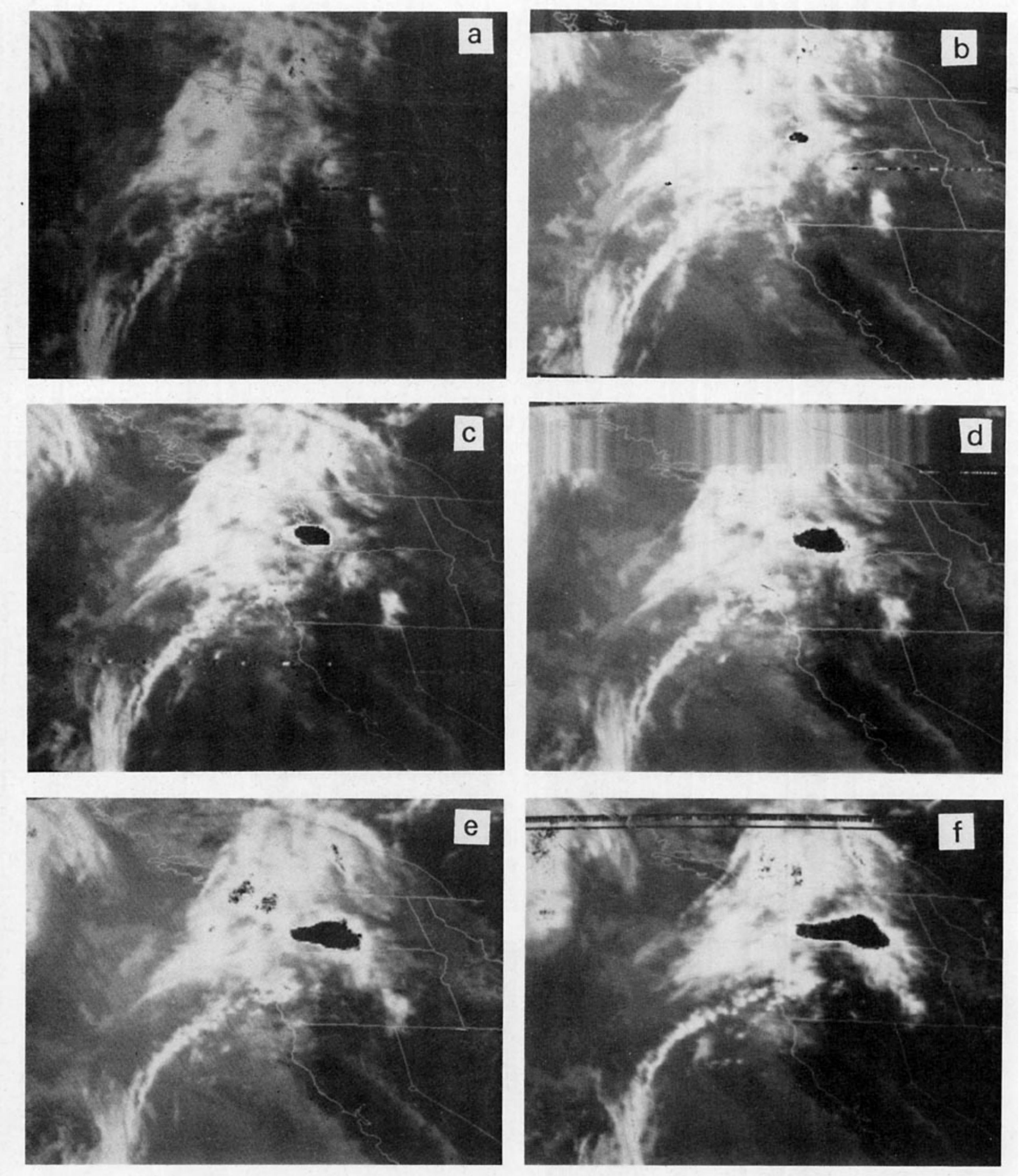


FIG. 3. GOES infrared images (4 km resolution) 18–19 May 1980 (a) 1515 GMT, (b) 1545 GMT, (c) 1615 GMT, (d) 1645 GMT, (e) 1715 GMT, (f) 1815 GMT, (g) 1845 GMT, (h) 2145 GMT, (i) 0145 GMT, (j) 0445 GMT.

listing of the downwind extent of the plume is given in Table 3.

Infrared satellite images have been used previously to study volcanic plumes. Studies of the 1979 eruptions of the Soufriere volcano by Krueger and Oliver (1980) and Krueger (1980) provide some interesting comparisons of these eruptions and the eruption of Mt. Saint Helens. The area of the −50°C or colder plume was calculated from the images and is listed in Table 4. The areas derived from the infrared

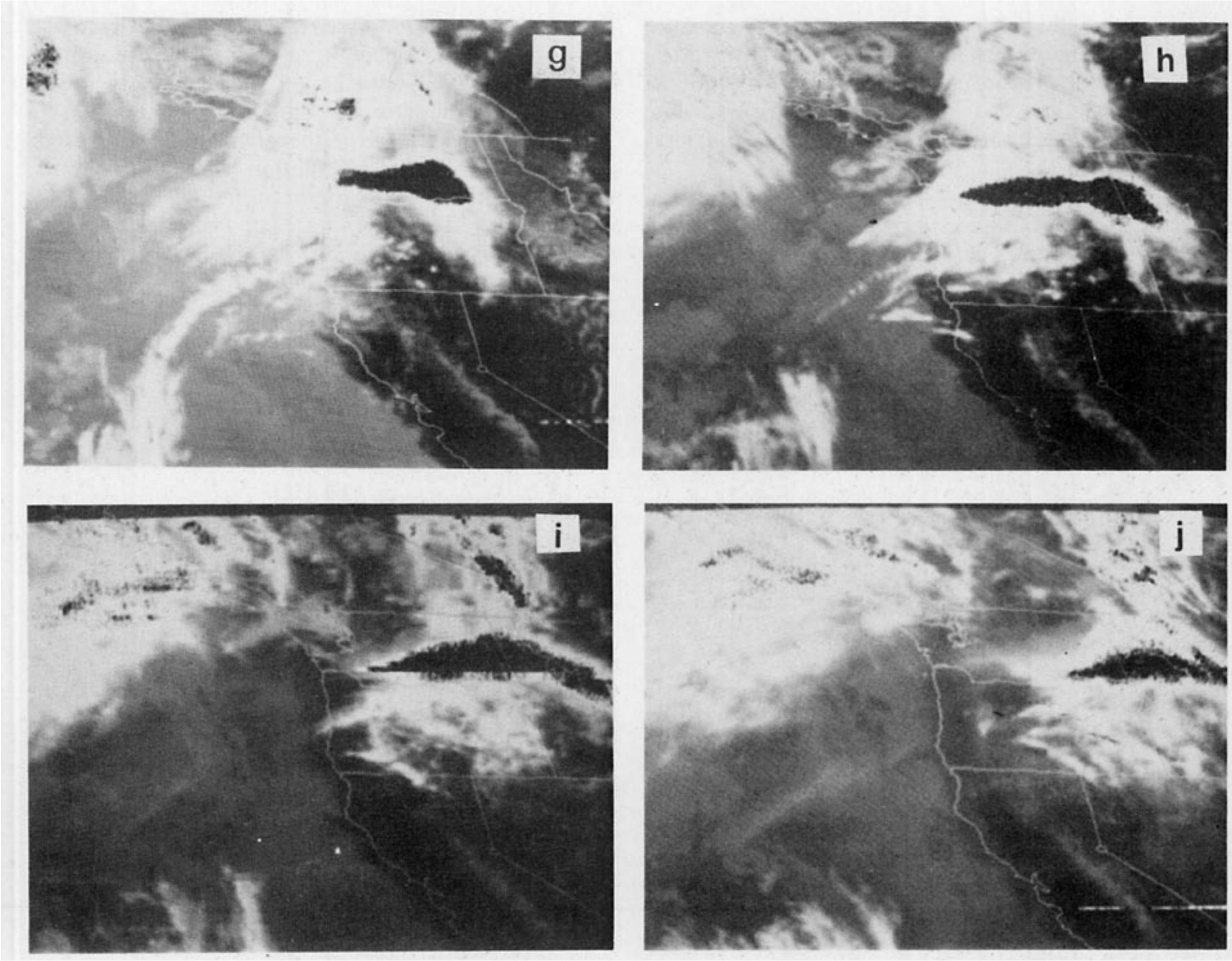


Fig. 3. (*Continued*)

images are considerably smaller than the area calculated from the visual images for the same time period. The reason for this lies in the fact that the −50°C lower boundary excludes much of the area near the edges of the plume where the plume is not thick enough to block upwelling infrared radiation from lower levels. A comparison with the Soufriere volcano data (Krueger, 1980), although by no means

Table 3. Downwind extent (km) of the volcanic plume as outlined by the −50°C or colder enhancement except for first five images. Times are GMT.

1515	0	Area calculations made from visible images
1545	70	
1615	112	
1645	169	
1715	220	
1745	280	
1815	322	
1845	386	
1915	425	
1945	468	
2015	510	
2045	539	
2115	559	
2145	600	
2215	635	
2245	671	
2315	719	Eastern edge of plume moves off image

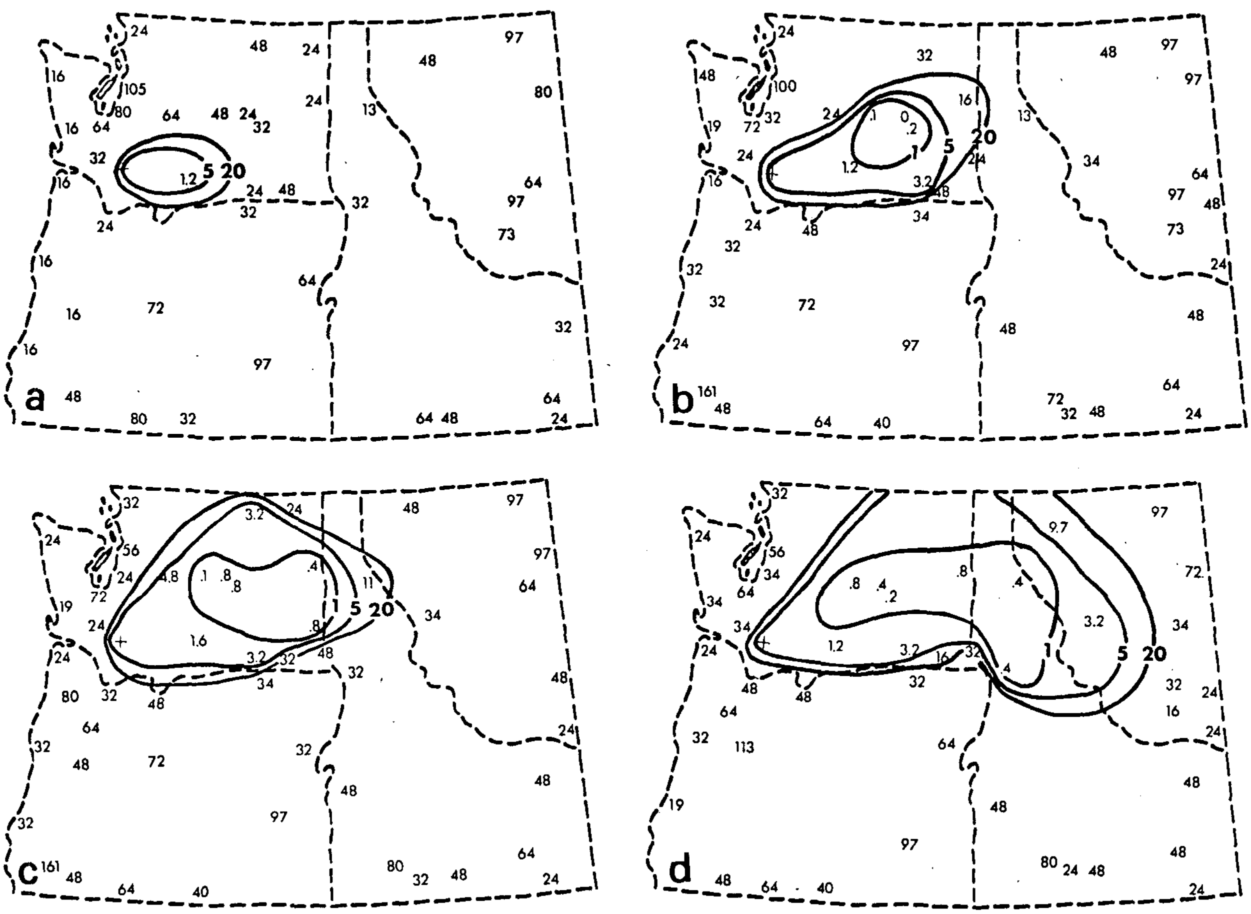
Table 4. Area ($\times 10^3$ km^2) of volcanic plume with an infrared temperature colder than −50°C (for comparison, the area of the State of Washington is ~176.5 × 10^3 km^2). Times are GMT.

1545	2.34	From visible image
1615	10.6	
1645	18.8	
1715	25.8	
1745	Scan lines missing	
1815	42.3	
1845	51.1	
1915	60.5	
1945	65.8	
2015	71.4	
2045	78.4	
2115	84.7	
2145	89.2	
2215	91.1	
2245	Scan lines missing	
2315	101.0	Eastern edge of plume moves off satellite image.

exact, shows that the Mt. Saint Helens volcano yielded a much larger plume in area than Soufriere. If the plume size is an indication of the strength of the eruption, then the Mt. Saint Helens volcanic eruption was much more violent than the Soufriere eruption.

A series of visibility maps were plotted from the surface observations to compare the satellite view of the plume with the ash fallout (Fig. 4). As expected, the two were found to agree quite well in both movement and speed, since there was little directional shear of the wind with height evident from radiosonde observations made prior to the eruption.

The last information gathered from the infrared satellite images was a calculation of the plume temperature over and downstream from the volcano. The temperatures listed in Table 2 are averages taken at various intervals throughout the thickest part of the



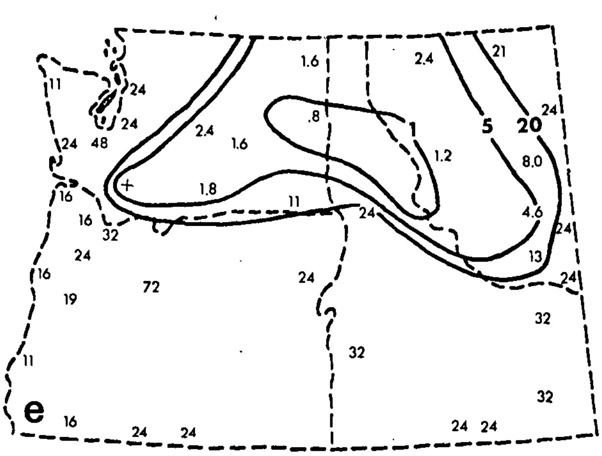


FIG. 4. Visibilities plotted from surface observations (km) (a) 1800 GMT, (b) 2100 GMT, (c) 0000 GMT, (d) 0300 GMT, (e) 0600 GMT.

volcanic plume. The assumption made here, as in other papers, is that the upper portion or plume surface temperature is at or very close to that of the environment. If conventional radiosonde data are available, then an estimate of the height can be made. This technique was employed by Krueger and Oliver (1980) and Krueger (1980) for the Soufriere eruptions. However, an estimate of the height of the plume is difficult for the Mt. Saint Helens volcano because of the low tropopause. Radiosonde data were analyzed for three stations in the Northwest and a sounding typical of the three, Salem, Oregon, is shown in Fig. 5. The tropopause was found to have a temperature of −63°C at ~12 km. However, the lower stratosphere had a fairly isothermal profile with the temperatures ranging from −58°C at 12.5 km to −56°C at 16 km. The temperatures of the plume were calculated to be approximately −55 to −58°C for the infrared sequence previously presented. The radar reports from Portland, Oregon, at 1600 GMT indicate tops in excess of 15.2 km and at 1700 GMT to 13.7 km. This would indicate along with the infrared satellite data, that the top of the plume had penetrated well into the stratosphere. The height measurements derived from the Soufriere volcano were simpler to determine since the tropopause was very high (17 km) and very cold (−80°C), and most of the Soufriere ash plumes never reached the tropopause.

The 1545 GMT image provided an opportunity to use two different techniques to estimate plume height. Before the ash cloud reaches the tropopause, the infrared data should provide a good height estimate of the plume, if the plume surface is at the environment's temperature. The infrared image for 1545 GMT yielded an average temperature of −47°C, indicating the plume had reached nearly 10 km in 10 min (assuming that ~3 min elapsed from the start of the image to when the area of the volcano was scanned). From this, the movement of the plume upward was calculated to be 12 m s^{-1}. An estimate of the height of the plume at 1545 GMT from the shadow that appeared on the visible images was also attempted. The plume height from this technique was determined to be ~16 km, with a calculated vertical velocity of 22 m s^{-1}. The discrepancy between plume height estimates may be due to the assumption that the plume is at

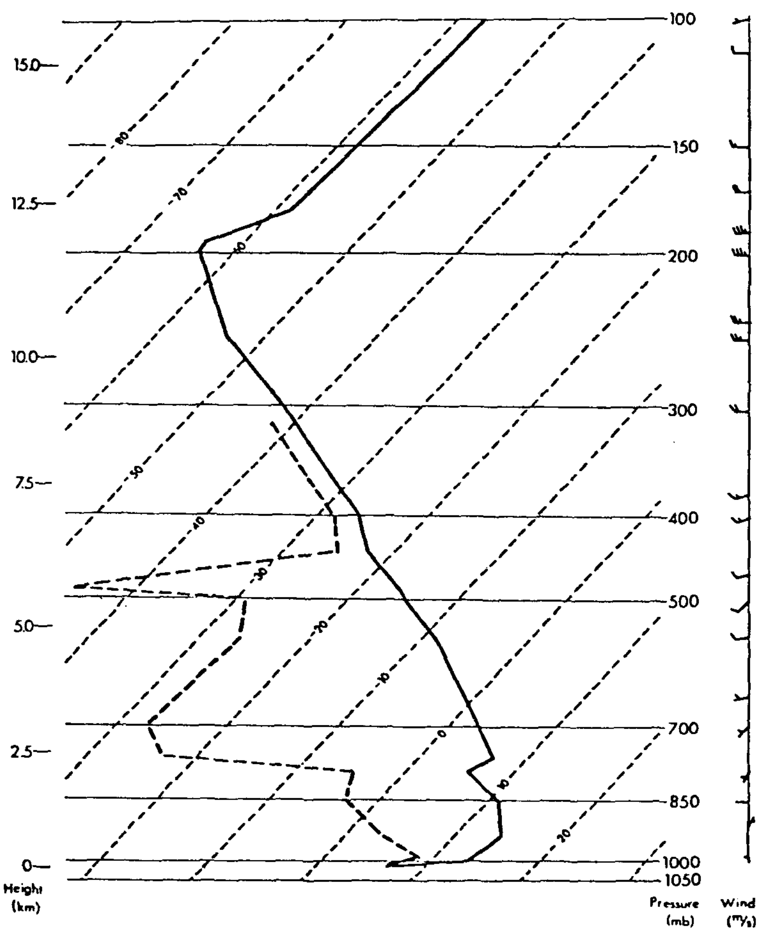


FIG. 5. Sounding from Salem, Oregon, 1200 GMT 18 May 1980.

thermal equilibrium at this time. As pointed out by Settle (1976), during the early stage of a violent eruption, the plume upward velocity is largely determined by the exit velocity of the material. There also are two other factors which could contribute to the low infrared height estimate. The spatial resolution of the sensor may not be small enough to adequately describe the highest area of the plume and the sensor response may be too slow to capture the rapidly evolving plume. If this is the case, then the shadow method of determining the plume height should provide a better estimate.

4. Summary

The GOES-West satellite provided a unique view of the eruption of the Mt. Saint Helens volcano. The eruption was found not to be a single event but composed of one large violent explosion followed by a second smaller but more continuous period of activity. The area of the plume indicates that the eruption was much larger than the Soufriere eruptions; however, the height of the plume could not be reliably extracted from the infrared data because of the low tropopause in the area.

Acknowledgments. We would like to thank Russ Schneider for his help in plotting the conventional data, to Dr. Carlyle Wash, Dr. David Suchman, Edward J. Hopkins and John Stremikis for their help in reviewing the manuscript and to the staff of Space Science and Engineering who helped make this note timely and precise. Partial support for this study was from NSF Grant SED-7919005.

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