GMS-4 Observations of Volcanic Eruption Clouds from Mt. Pinatubo, Philippines

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Abstract

Visible and infrared imageries of the gigantic volcanic eruption clouds (VECs) from Mt. Pinatubo, Philippines were taken on June 15, 1991 from 0540 - 0940 UT (Universal Time) at one hour intervals by the geostationary meteorological satellite. These imageries were studied and indicated the following features. A giant disc-shaped VEC showing a "wave" textures appeared in the 0640 UT visible image and covered an area 300 km in diameter. The cloud's surface temperature was more than 10 °C greater than the tropopause temperature (≈−83 °C). In addition, a small hot spot with a maximum temperature of −27 °C was located at the center of the cloud, thereby indicating the cloud was injected into the stratosphere. This cloud radially expanded against an easterly wind of 20 m/sec, spread out to an area 400 km in diameter, and showed an increase in its surface temperature at 0740 UT. Furthermore, a higher temperature area with several hot spots (≈−30 °C) appeared in the surrounding the volcano, thus indicating that the volcano's activity continued. At 0840 UT the surface temperature surrounding the volcano decreased, and the area having a surface temperature higher than −60 °C further expanded up to 100 km upwind. This suggests that a radial flux of injected hot material occurred after 0740 UT.

1. Introduction

Volcanic eruption clouds (VECs) have recently gained much attention due to their significant influence on global climate and aviation safety. Many volcanoes are remotely located and not easily accessible, thereby making it difficult to monitor VECs. As a result, satellite remote sensing is an extremely useful tool to monitor volcanic activities.

The first Japanese geostationary meteorological satellite (GMS) was launched in 1977, with this and additional satellites subsequently providing low-resolution multispectral imageries at 3 hr intervals. Funada and Arai (1983) used GMS photographs to study the movement of volcanic ashes from Mt. El Chichon, while Sawada (1987) used GMS multispectral imageries to analytically study the development and dispersal of eruption clouds from 23 volcanoes.

In March 1987 hourly imagery became possible, however, few analyses have been performed on VECs using this data.

This century's largest volcanic eruption occurred in the Philippines on Mt. Pinatubo (15°07'N, 120°20'E, altitude: 1745 m, June 15, 1991), being accompanied by gigantic VECs which were observed at 1 hr intervals using the multispectral imageries from GMS-4.

The present study reports the results of an investigation on the development of VECs using GMS-4 hourly imageries obtained from 0540 - 0840 UT (Universal Time) on June 15, 1991.

2. VEC Visible Imagery Features

Figures 1 - 4 show a series of VEC visible (VIS) imagery photographs taken at 1 hr intervals from 0540 - 0840 UT on June 15, 1991.

The VECs in Fig. 1 (0540 UT) are characterized by a visible gray area (A) and disc-shaped clouds which appear in the center of LUZON

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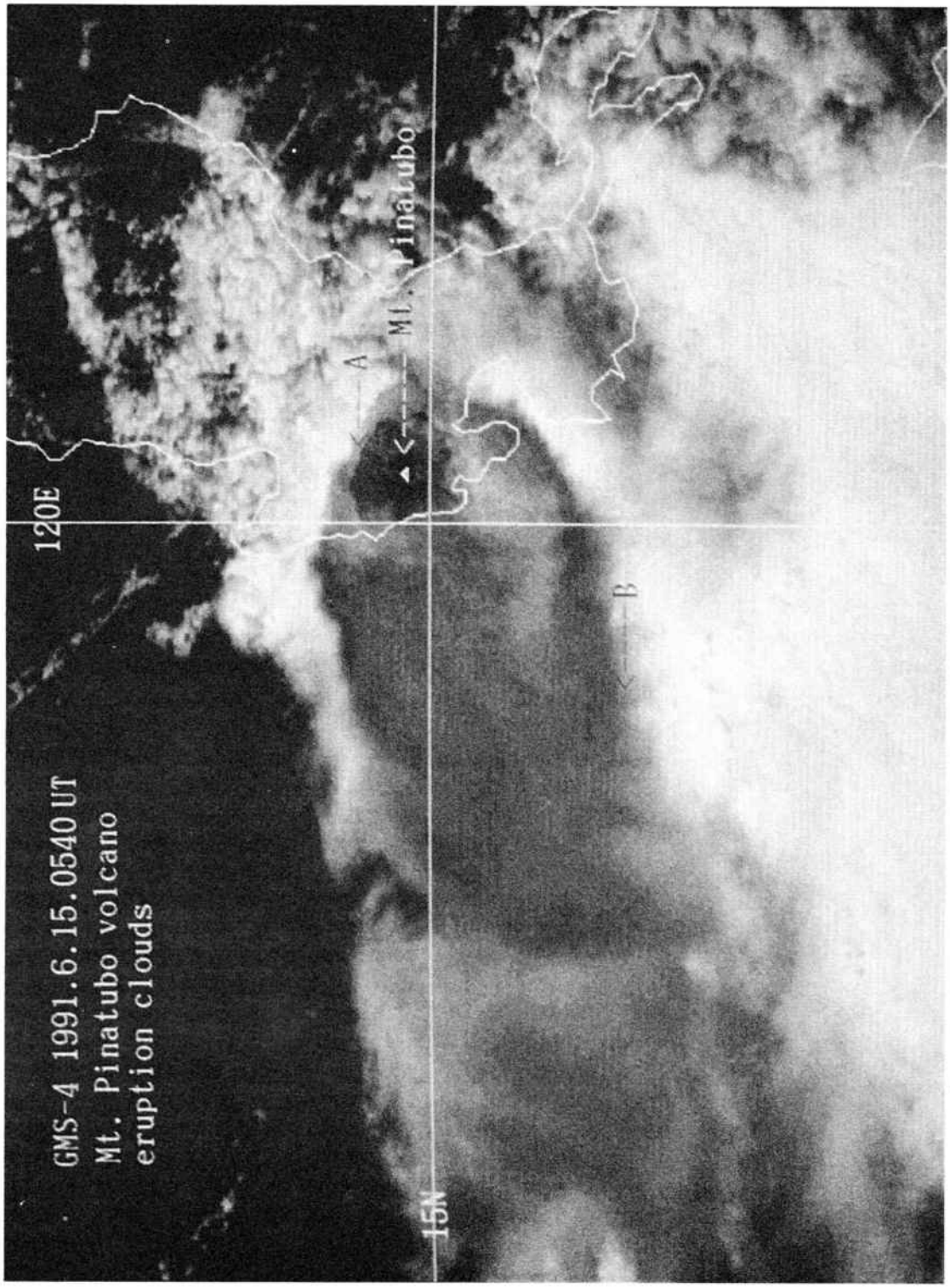

Figure 1 Visible imagery at 0540 UT June 15, 1991. **A** and **B** respectively indicate a disc-shaped volcanic eruption cloud and dispersed volcanic clouds.

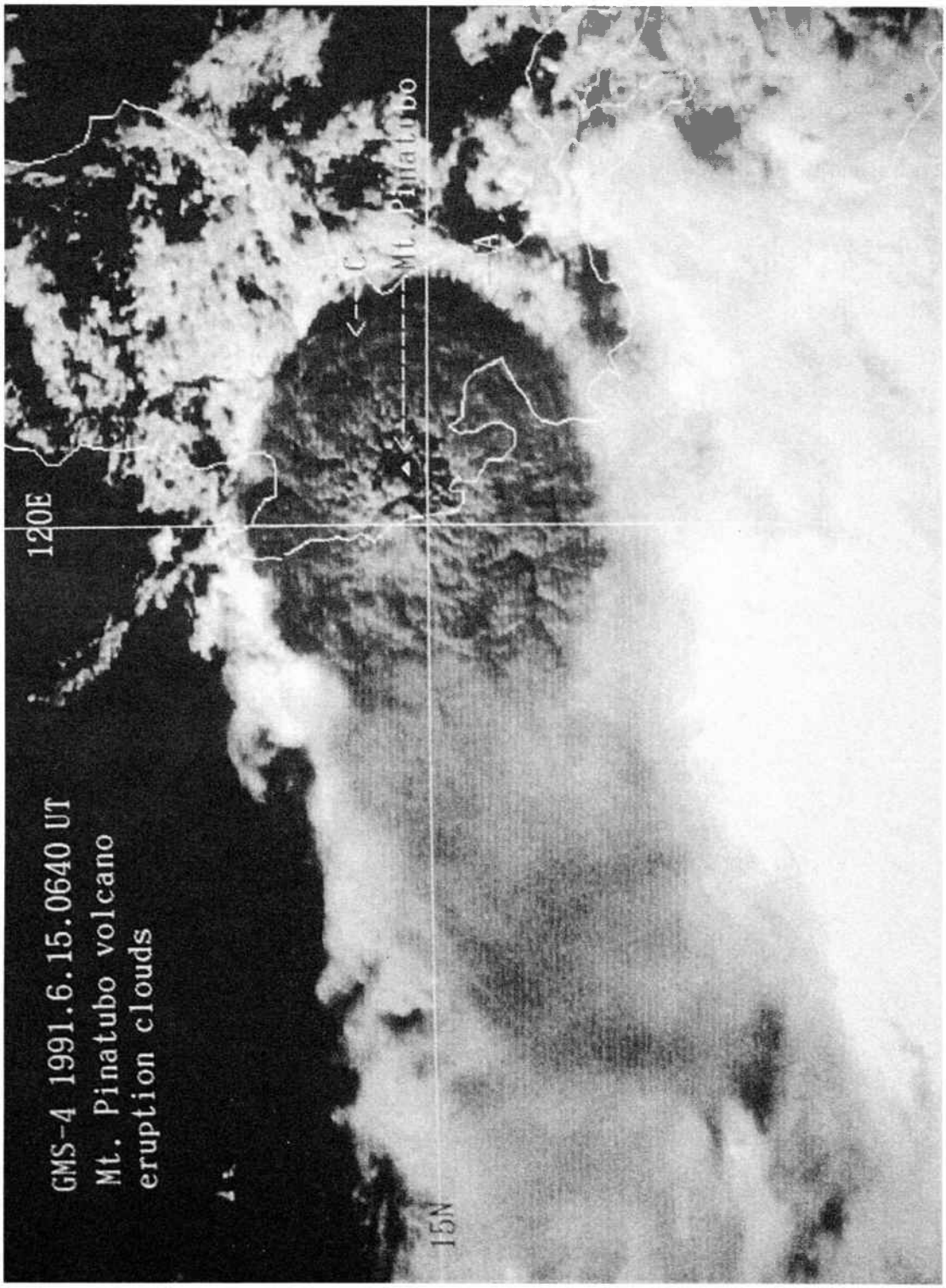

Figure 2 Visible imagery of 0640 UT. **A**, **B** and **C** respectively indicate a shadow of the disc-shaped VEC, tops of VECs which show a white appearance due to reflection of sunlight, and 'wave' textures.

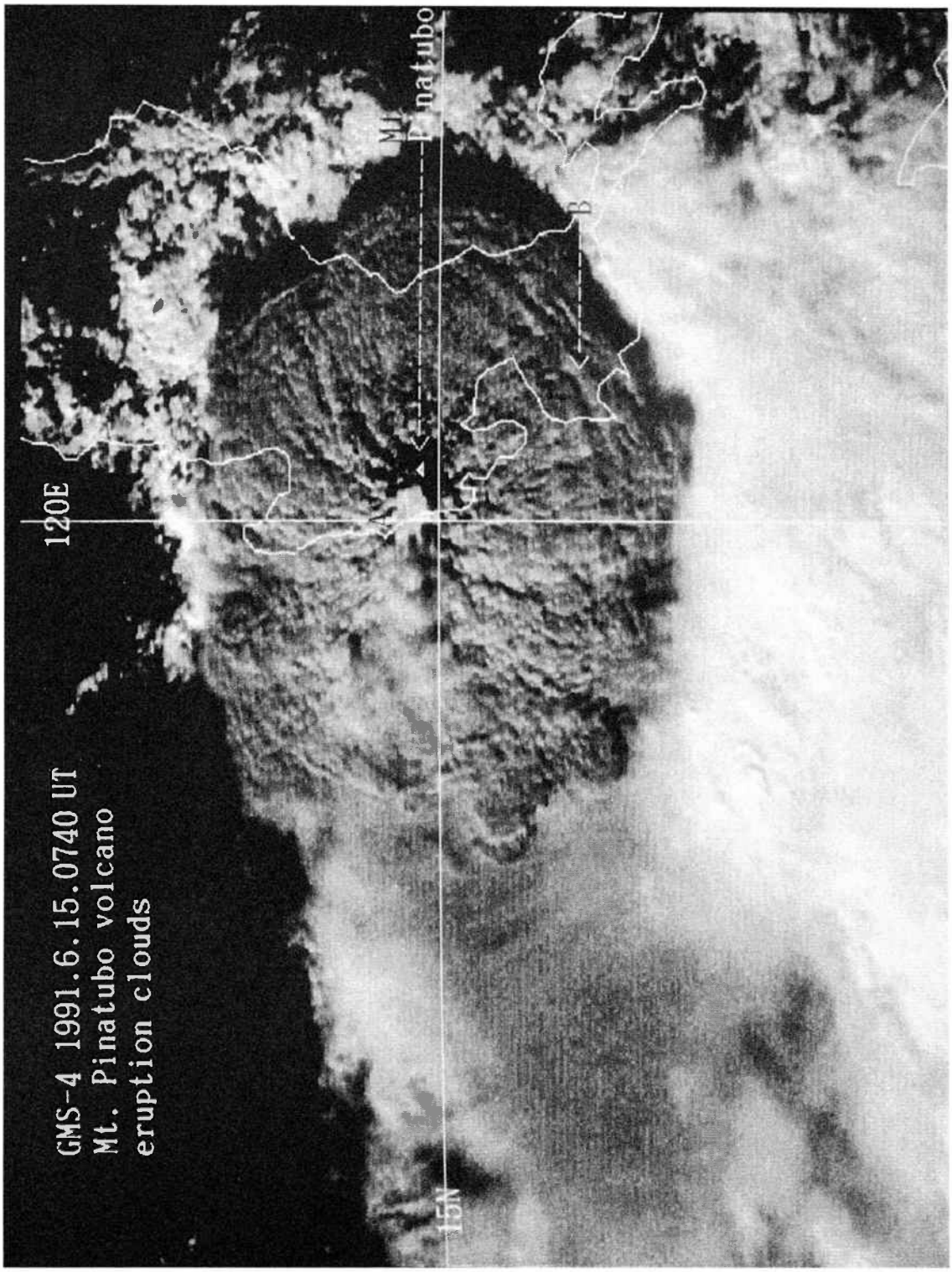

Figure 3 Visible imagery of 0740 UT. **A** and **B** respectively indicate the tops of VECs having a white appearance and a shadow of the disc-shaped VEC.

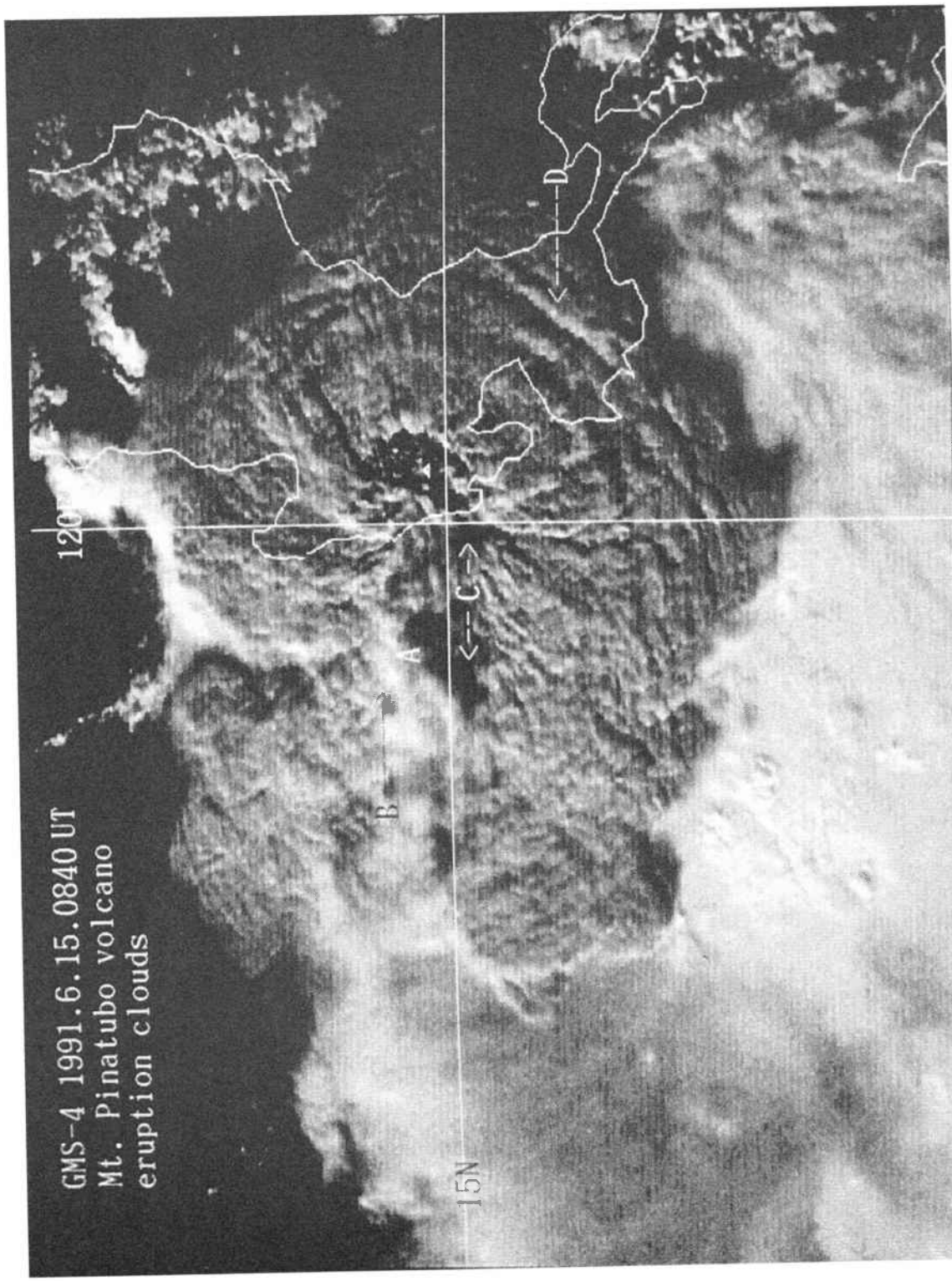

Figure 4 Visible imagery of 0840 UT. **A**, **B**, **C** and **D** respectively indicate dispersed VECs, white areas due to reflection of sunlight, VEC shadows, and 'wave' textures.

island. The formation and dispersion of these clouds repeatedly appeared in all the satellite imageries taken on the morning of that day. Another visible gray area (B) is shown as the fuzzy pattern which is dispersing westward from the volcano.

In the next VIS image (Fig. 2, 0640 UT), a remarkable disc-shaped VEC is observed, having its center ≈20 km west of the volcano and extending up to 300 km in diameter. A shadow (A) from the disc-shaped VEC appears on the surrounding white cloud as can be seen on the east edge of the VEC. The top of the VECs (B), located west of the center of the disc-shaped VEC, appear white due to the reflection of sunlight on them. These VECs cast shadows on the disc-shaped VEC, thus indicating that they are at a higher altitudes.

One hour later (Fig. 3, 0740 UT), the disc-shaped VEC further expands up to 400 km in diameter. The white appearing tops of the VECs and their shadows to the east are clearly observed as they travel westward away from the volcano (A).

The last VIS image (Fig. 4, 0840 UT) shows both further extension up to 600 km in diameter, especially 200 km upwind from the volcano, and also westward dispersion of VECs (A). White areas (B) seen on the northwestern side of the VECs and their shadows (C) on the southeastern side indicate these VECs are at higher altitudes than the disc-shaped one.

It should be noted that the textures of the VECs are revealed by "waves" shown in the image which result from the shadow and highlight effects caused by the sun angle (Fig. 2, (C); Fig. 3, (B); Fig. 4, (D)). Figure 5 shows the boundaries of the disc-shaped VEC obtained from succesive hourly VIS imageries (Figs. 1 - 4). Figures 6 (a) and (b) respectively show the distance between the volcano and the edge of the VEC and the VEC's extension speed when using Fig. 1 as a basis.

The initial extension of the VECs occurred from 0540 - 0640 UT, and as expected, the largest average velocity of this extension was on the volcano's westward side (47 m/sec), respectively followed by the southward (39 m/sec), northward (25 m/sec), and eastward (22 m/sec) directions.

The next major extension occurred from 0640 - 0740 UT. In this case the largest average VEC extension velocity occurred on the volcano's east side (≈20 m/sec), with all the velocities showing a significant decrease.

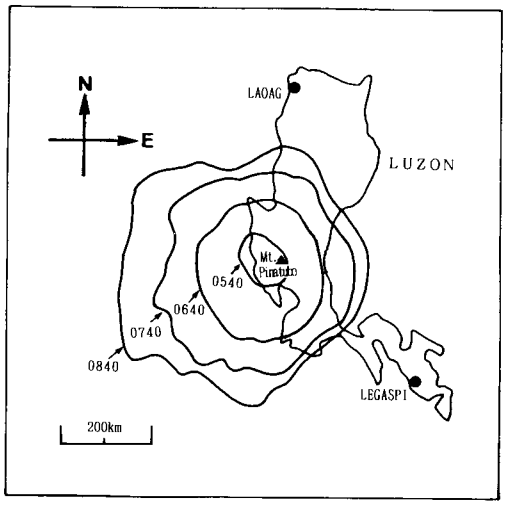

Figure 5 Extensions of VEC boundaries obtained from successive hourly VIS imageries (Fig. 1 - 4)

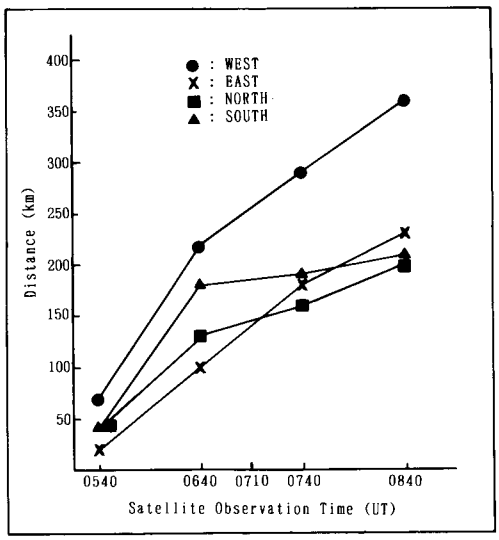

Figure 6 (a)

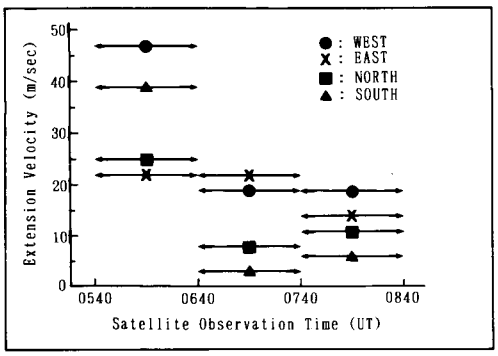

Figure 6 (b)

Figure 6 (**a**) Distance changes in the N, S, E, W directions between the volcano and the VEC boundary shown in Fig. 5. (**b**) Same as (a) except chages in VEC extension velocity. At 0710 UT a heavy fall of pumiceous lapilli occurred.

Form 0740 - 0840 UT the VEC further expanded up to 50 km upwind with a velocity of 15 m/sec.

3. VEC Infrared Imagery Features

In the infrared (IR) images, IR radiances emitted from the surface of the VEC were observed. The VEC surface is assumed to be a parallel plane homogeneous cloud layer in an isothermal atmosphere overlying a non reflecting lower boundary. Sawada (1987) used GMS IR imageries to investigate VECs and reported that the lowest VEC surface temperature occurred at its origin, with the temperature in the lee area being higher than the origin's because of the penetration of warmer temperature from under the surface. This phenomenon is generally considered to be applicable to VECs occurring in the troposphere.

However, the highest temperatures in Pinatubo's VECs were contrastingly observed in the vicinity of the volcano, thus it is believed that these VECs were injected into the stratosphere.

Figures 7 - 10 show psudocolor IR imageries taken at the same observation times as in Section 2.

In Fig. 7 (0540 UT) the disc-shaped VEC is coincident with the area enclosed by the −80 °C isotherm (A), and has wave patterns (B) less than −80 °C which appear east of the VEC.

The temperature of the dispersed VECs (Fig. 1, (B), and Fig. 7, (C)) is less than −80 °C and is equivalent to that in the tropopause. An area warmer than −70 °C (HT1) is observed in the surrounding of the volcano. The warmest area which is greater than −60 °C (HT2) is in the center of HT1, whereas another warmer area (−60〜−70 °C) is observed in a fan-shaped disperesed VEC (D) located to the far west of the volcano.

Figures 11 (a) and (b) respectively show the air temperature, dew point, and wind speed at LAOAG (18.2N, 120.5E) and LEGASPI (13.1N, 123.7E), being correspondingly located to the north and south of volcano (Fig. 5). The temperature and wind speed at 100 mb (approximately in the tropopause/≈16 km above sea level) are about −83 °C and 20 m/sec. It is believed that at temperatures less than −80 °C the VEC height is equivalent to the tropopause, while HT1 and HT2 (>−80 °C) occur in the stratosphere. The heights

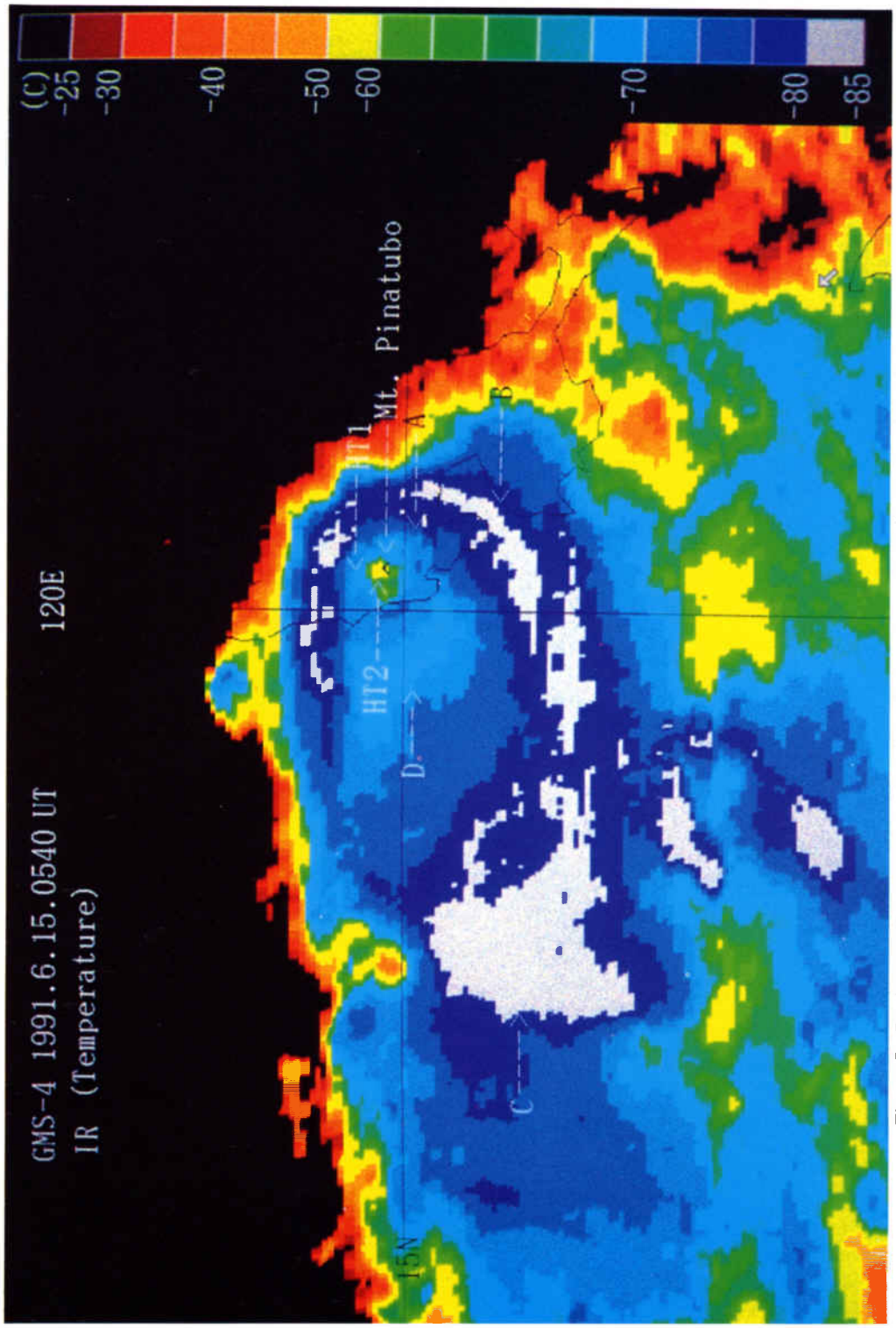

Figure 7 Psudocolor IR imagery at 0540 UT. Temperatures are indicated by the color scale on the right side. **A**, **B**, **C** and **D** respectively indicate the disc-shaped VEC enclosed by the −80 °C isotherm, wave patterns with temperatures lower than −80 °C, dispersed VECs less than −80 °C, and a dispersed VEC (−60～−70 °C). **HT1** and **HT2** are areas warmer than −70 °C and −60 °C, respectively.

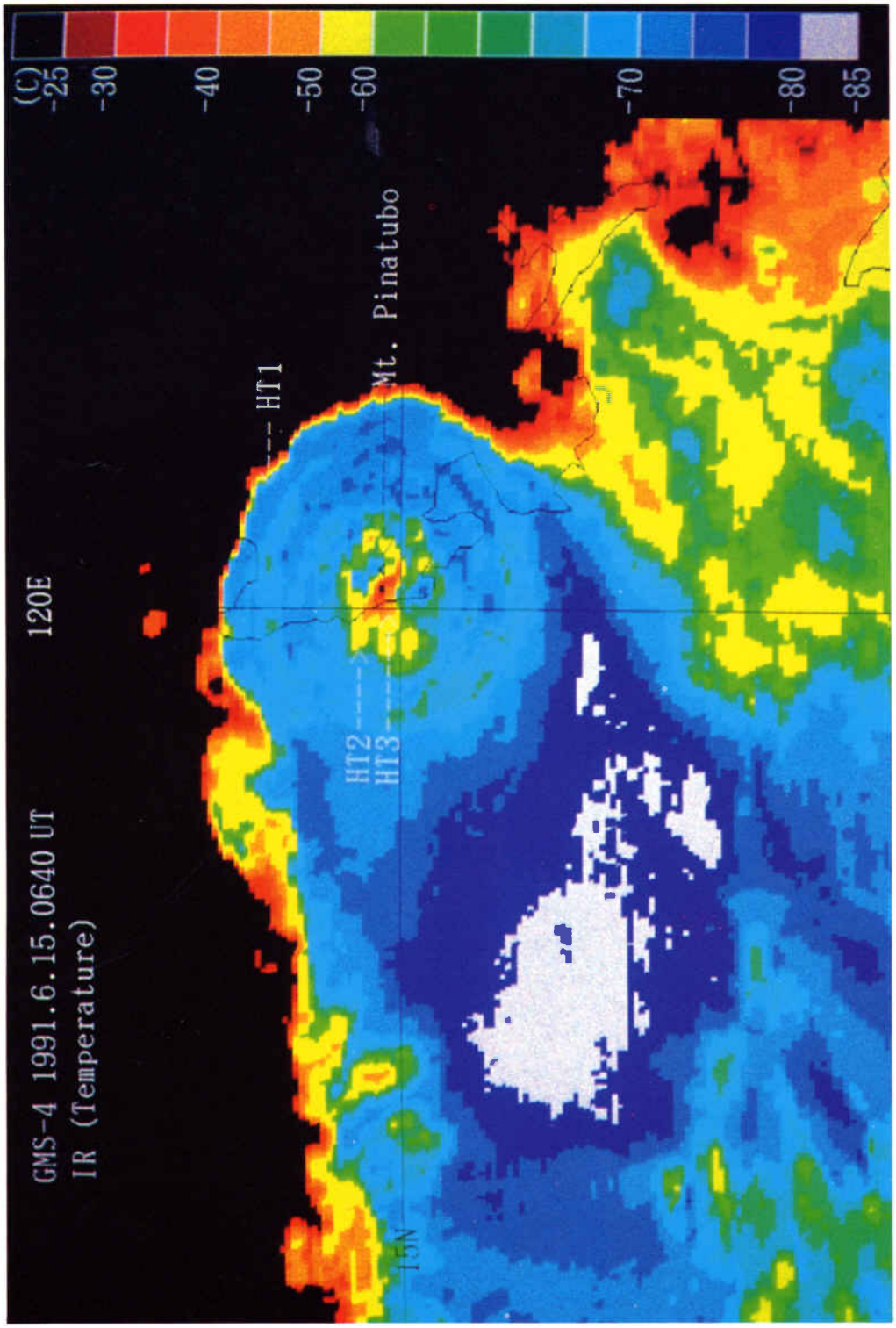

Figure 8 Same as Fig. 7 except at 0640 UT. **A**, **B** and **HT3** respectively indicate the edge of the VEC, wave patterns with lower temperatures (−70～−80 °C), and a temperature area greater than −50 °C.

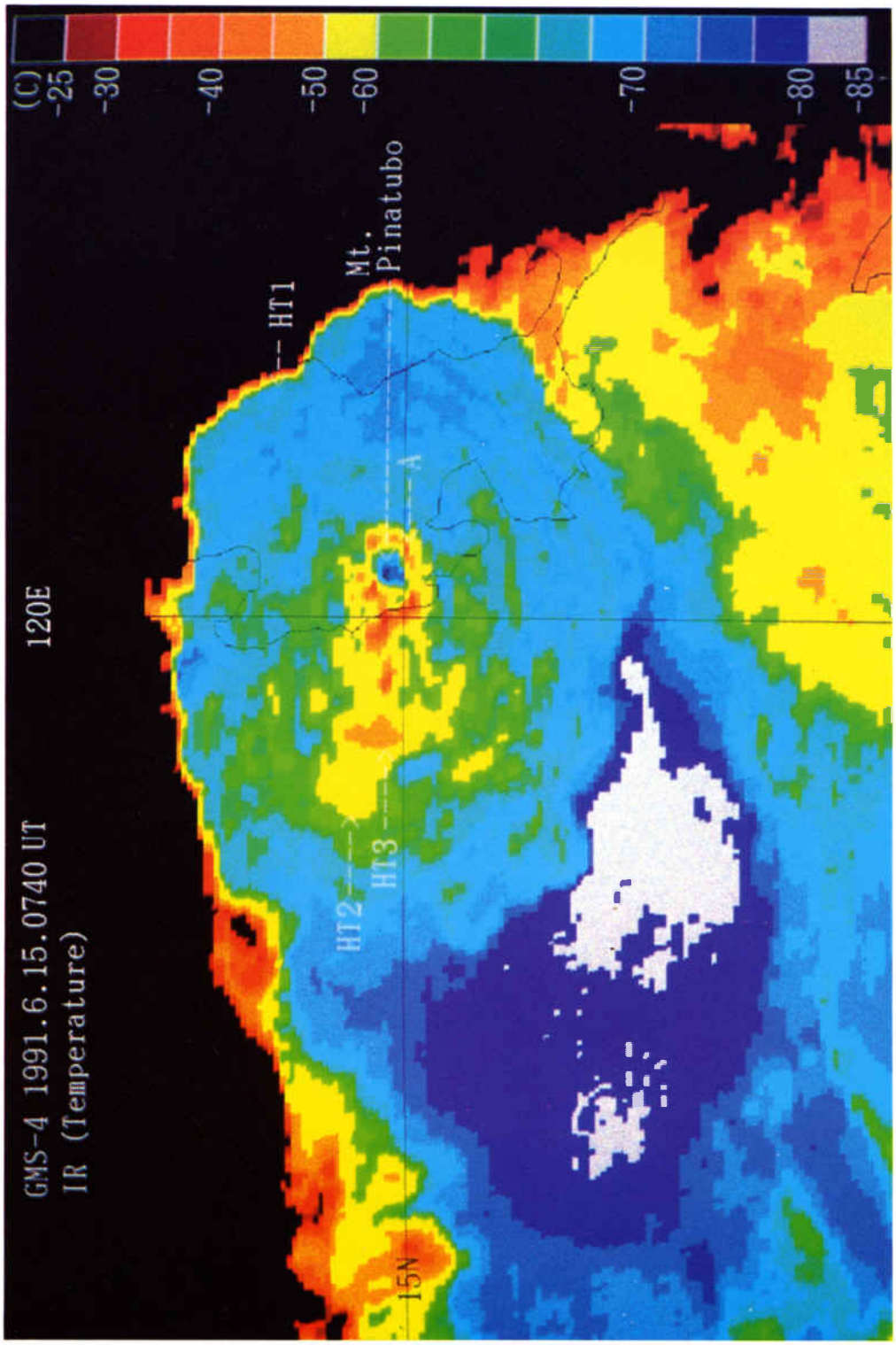

Figure 9 Same as Fig. 8 except at 0740 UT. **A** indicates a higher temperature area having several hot spots (≈ -30 °C).

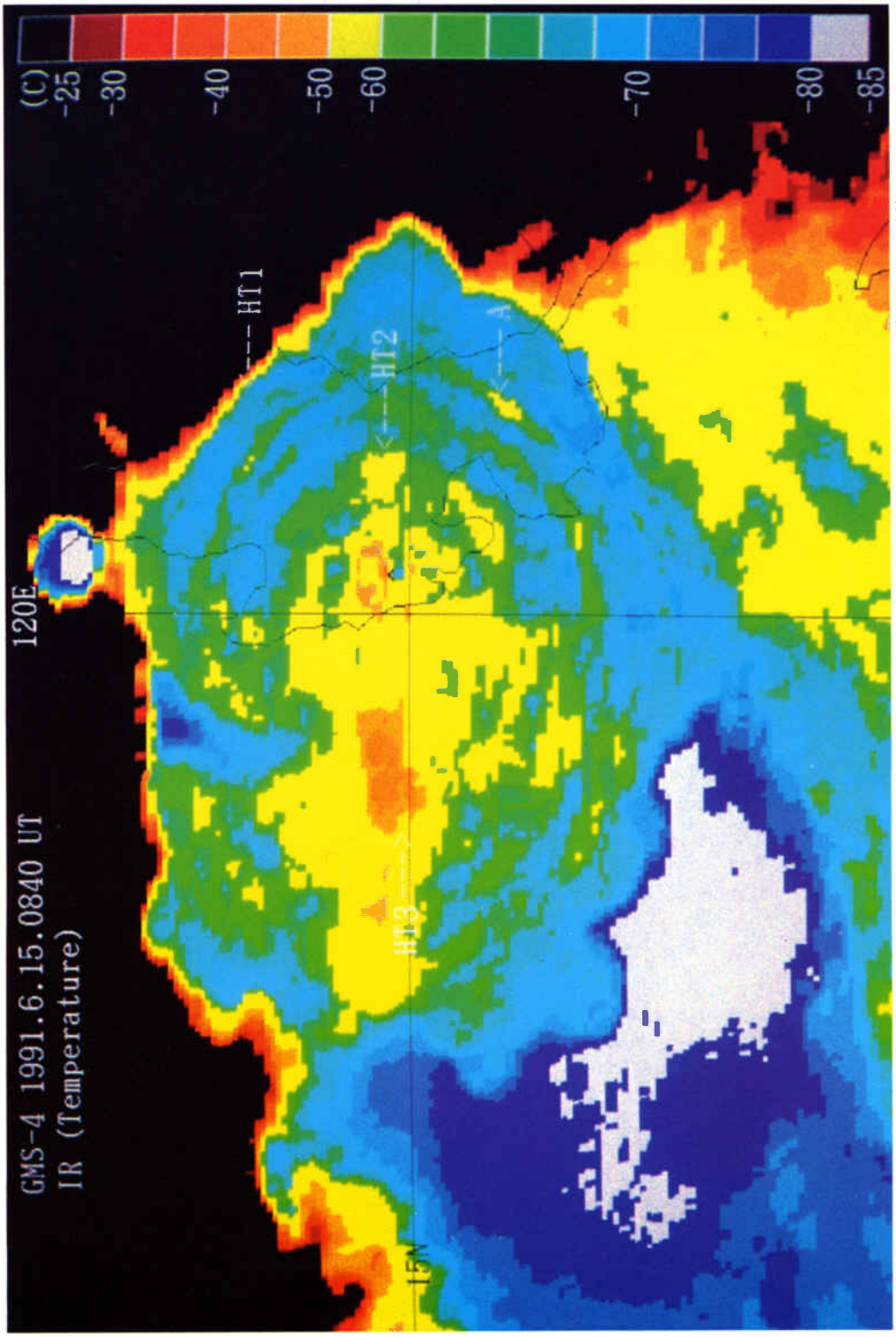

Figure 10 Same as Fig. 8 except at 0840 UT. A indicates higher temperature wave patterns (−50～−60 °C).

of HT1/HT2 are measured at 18/21 km above sea level using the assumption that the VEC temperature is equivalent to ambient temperature derived from a vertical profile based on the tropical atmosphere model (McClatchey et. al., 1972).

In Fig. 8 (0640 UT) the IR image shows that both HT1 and HT2 have extended to 3 times larger than at 0540 UT. Furthermore, a new temperature area appears greater than −50 °C (HT3) (maximum temperature of −27 °C), being located in the center of HT2 at a height of 23 km above sea level.

The next IR image (Fig. 9, 0740 UT) shows the eastward extension of HT1, the rapid westward extension of HT2, the westward dispersion of HT3, and the increase of surface temprerature surrounding the volcano. White VECs shown in the 0740 UT VIS image (Fig. 3, (C)) correspond to the high temperature areas west of the volcano. The volcano's activity is considered to have continued based on the appearance of a higher temperature area having several hot spots (≈−30 °C) which surrounds the volcano (Fig. 9, (A)).

The last IR image (Fig. 10, 0840 UT) shows the westward dispersion of HT3, the decrease in the surface temperature surrounding the volcano, and the further eastward expansion of HT2. It is interesting to note that higher temperature wave patterns (−50∼−60 °C) appear on the VEC's eastward side (Fig. 10, (A)).

Figures 12 (a) - (c) respectively show the hourly distance variations between the volcano and the boundary isotherm of HT1 (−70 °C), HT2 (−60 °C), and HT3 (−50 °C). It is important to recognize that from 0740 - 0840 UT the extension of HT2 occurred in all directions (30 minutes after a heavy fall of pumiceous lapilli was observed on the ground), especially up to 100 km upwind.

As compared to the dispersions of HT1 and HT3 this additionally suggests that a radial flux of injected hot material occurred after 0740 UT.

4. Summary

Visible and IR imageries of the gigantic vol-

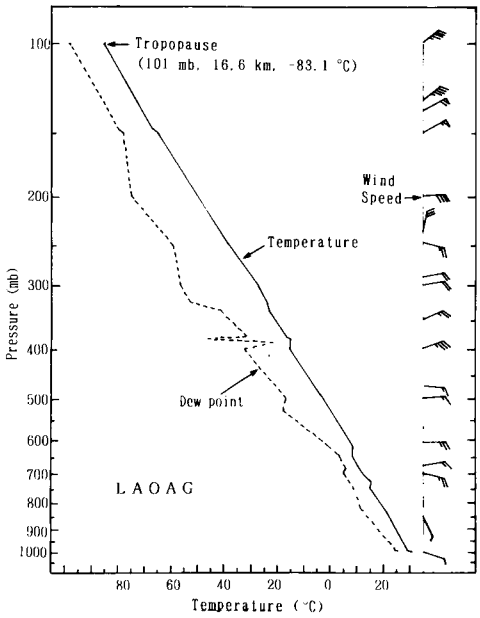

Figure 11 (a)

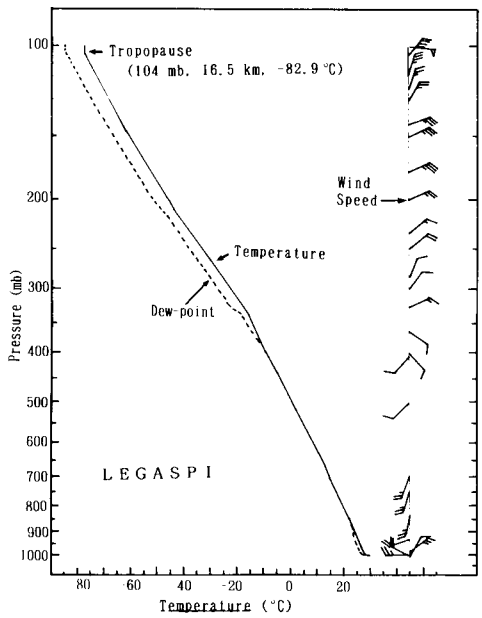

Figure 11 (b)

Figure 11 Air temperature, dew point, and wind at (a) LAOAG (18.2N, 120.5E), (b) LEGASPI (13.1N, 123.7E), 00 UT June 15, 1991.

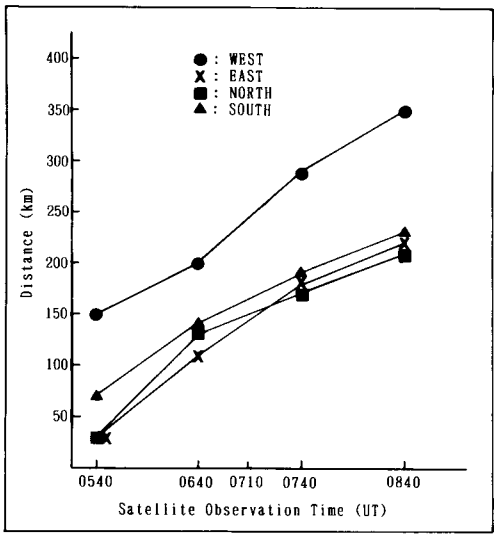

Figure 12 (a)

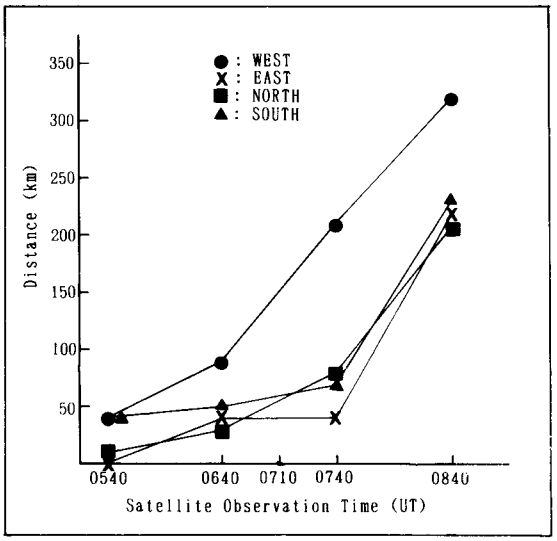

Figure 12 (b)

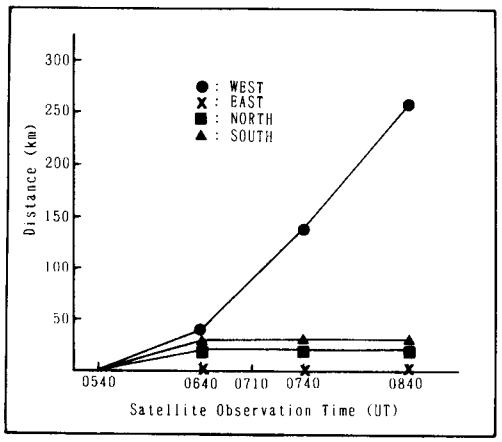

Figure 12 (c)

Figure 12 Distance changes in the N, S, E, and W directions between the volcano and the isotherm boundary of (**a**) HT1 (−70 °C), (**b**) HT2 (−60 °C), (**c**) HT3 (−50 °C).

canic eruption clouds (VECs) from Mt. Pinatubo, Philippines were taken on June 15, 1991 from 0540 - 0940 UT at one hour intervals by the GMS-4 satellite. These imageries were studied and indicated the following:

1) A giant VEC showing "wave" textures appeared in the 0640 UT visible image and covered an area 300 km in diameter.

2) The largest average velocity of the VEC extension (47 m/sec) occurred from 0540 - 0640 UT was on the volcano's westward side.

3) At 0640 UT the surface temperature of VEC

was more than 10 °C higher than the temperature of tropopause (−80 °C), and a temperature area (>−50 °C) with a small hot spot (a maximum temperature of −27 °C) appeared at the center of the VEC.

4) The height of the high temperature area (>−50 °C) was ≈23 km above sea level.

5) The VEC radially expanded up to 400 km in diameter against an easterly wind of 20 m/sec. An increase in its surface temperature occurred from 0640 - 0740 UT, with several hot spots (≈−30 °C) surrounding the volcano being present.

6) At 0840 UT the VEC further expanded up to 600 km in diameter, especially up to 200 km upwind of the volcano. The surface temperature greater than −60 °C spread to 100 km upwind, whereas the surface temperature surrounding the volcano decreased, thereby suggesting that a radial flux of injected hot material occurred after 0740 UT.

Acknowledgments

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GMS−4号によるフィリピンのピナツボ火山噴火の火山雲の観測

徳野　正己

気象衛星センター解析課

フィリピンにあるピナツボ火山は，1991年6月15日大噴火をし，それによる巨大な火山雲が発生した。1991年6月15日5時40分から9時40分（世界標準時）の間に日本の静止気象衛星「ひまわり4号」が観測した毎時間の可視・赤外画像からこの巨大な火山雲の特徴を解析した結果，次のことがわかった。直径約300 kmの円盤状の巨大な火山雲が6時40分の可視画像に現れた。この火山雲の表面には，波状性の隆起が見られた。火山雲の表面温度は中心付近に−27 °Cの高温点を持ち，圏界面温度（約−83 °C）より10 °C以上も高く観測された。このことは，火山雲が成層圏に突入したことを意味している。7時40分には，約−30 °Cの高温域が，火山上空の周囲をリング状に取り巻くようにこの火山雲に現れた。更に，この円盤状の火山雲は表面温度を上昇させながら，東風（約20 m/sec）に逆らって直径400 kmにまで拡大した。8時40分には，火山周辺の火山雲の温度は低下したが，−60 °C以上の高温域は更に風上100 kmまで拡大した。このことは，火山雲に注入された高温の物質が，7時40分の後に放射状に広がったことを示唆している。