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SATELLITE DETECTION OF THE 1982 EL CHICHON ERUPTIONS AND STRATOSPHERIC DUST CLOUD

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RESUMEN

Las erupciones del volcán El Chichón del 28 de marzo y del 3 y el 4 de abril de 1982 fueron percibidas y observadas mediante los satélites ambientales geoestacionarios y de órbita polar. Con base en los datos de dichos satélites se concluyó que la erupción del 28 de marzo, la segunda de las dos erupciones del 3 de abril y la del 4 de abril inyectaron materiales terrestres en la estratosfera a alturas entre 17 y 31 km. Se observó en las imágenes de satélite que la nube de polvo estratosférico resultante de la erupción del 4 de abril completó su viaje alrededor de la Tierra en un período de tres semanas. Se pudo determinar que la altitud de la nube de polvo fue aproximadamente de 24 km.

ABSTRACT

The March 28, April 3, and April 4, 1982 eruptions of El Chichón volcano were detected and monitored using geostationary and polar-orbiting environmental satellites. Based on the satellite data it was concluded that the March 28 eruption, the second of two eruptions on April 3, and the April 4 eruption injected material into the stratosphere at heights between 17 and 31 km. The resultant stratospheric dust cloud from the April 4 eruption was observed on the satellite imagery to travel completely around the Earth in a 3 week period. The altitude of the dust cloud was determined to be approximately 24 km.

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The 1982 activity began on March 28 at 2332 local time (all eruption dates and times are local) with a violent eruption, the first of four major eruptions. The NOAA Geostationary Operational Environmental Satellite (GOES) first recorded the eruption at midnight. Images from this satellite are acquired approximately every 30 minutes in both the visible (0.55-0.75 μm) and thermal infrared (10.5-12.5μm) bands at a maximum resolution of 1 and 8 km, respectively. GOES digital data on March 29 at 0230 gave a lowest eruption cloud brightness temperature of -75.2^{o}C. Comparison with radiosonde temperature data at Veracruz, Mexico (19.15N, 96.12W) taken at 0600 showed that the satellite temperature correspond to a height of 16.3 km or 18.5 km. The satellite brightness temperature does not correspond to a unique height because it intersects two points on the radiosonde plot. As will be demonstrated, radiosonde wind data (i.e., speed and direction) can be used to resolve this ambiguity but the technique is only useful after the ash cloud has begun to spread. The Veracruz data also showed that the altitude of the tropopause was 16.5 km, thus the eruption column probably did reach and penetrate the tropopause.

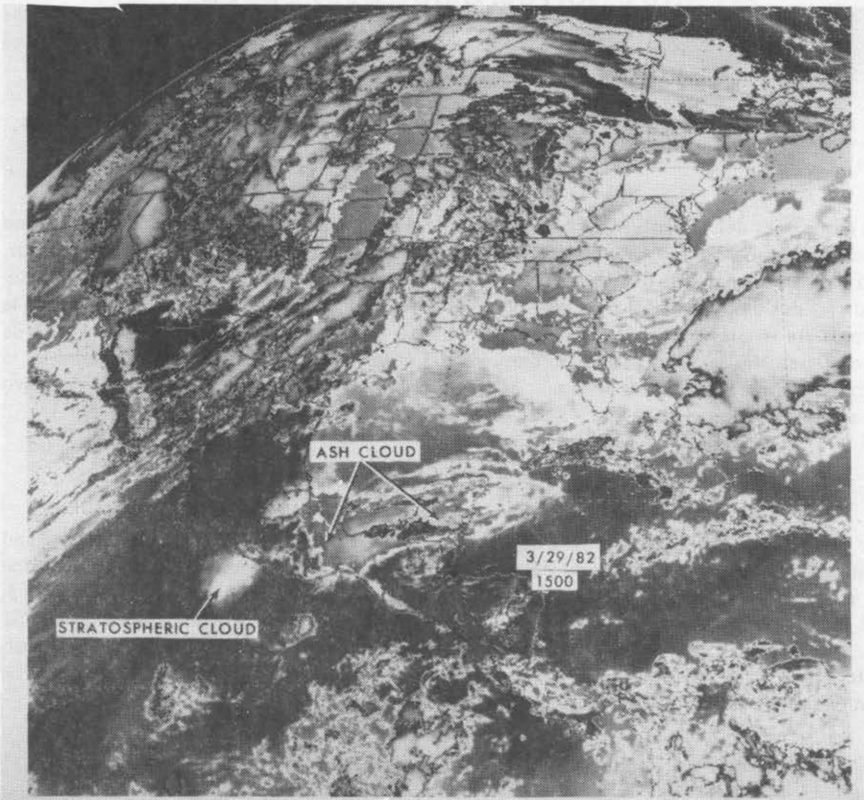

Fig. 1. GOES enhanced thermal IR image of the El Chichón ash cloud on March 29, 1982 at 1500 local time. Warm areas are black and colder areas are light gray or white.

After the initial eruption the subsequent ash cloud spread in a northeastward direction, although some westward drift was also evident (Figure 1). Upper air data at Veracruz at 1800 showed winds from the southwest between 10.4 and 13.7 km and winds from the northeast at the surface, 5.6 km and 20.7-24 km. The tropospheric southwest winds were 13-15 m/sec, the lower-level northeast winds were 4 m/sec, and the stratospheric (20.7-24 km) northeast winds were 9-10 m/sec. The ash cloud over the Pacific (Figure 1) was probably entrained in this stratospheric northeast wind as evidenced by the distance it traveled from El Chichón. This is further evidence that the March 28 eruption penetrated the tropopause. The part of the ash cloud over western Mexico did not move as far, therefore it was probably associated with the lesser northeast wind at lower levels. The ash cloud moving toward Cuba was entrained in the tropospheric winds between 10.4 and 13.7 km. By the end of the day the main ash cloud stretched from 83W to 97W longitude and covered an area of approximately 600,000 km^2.

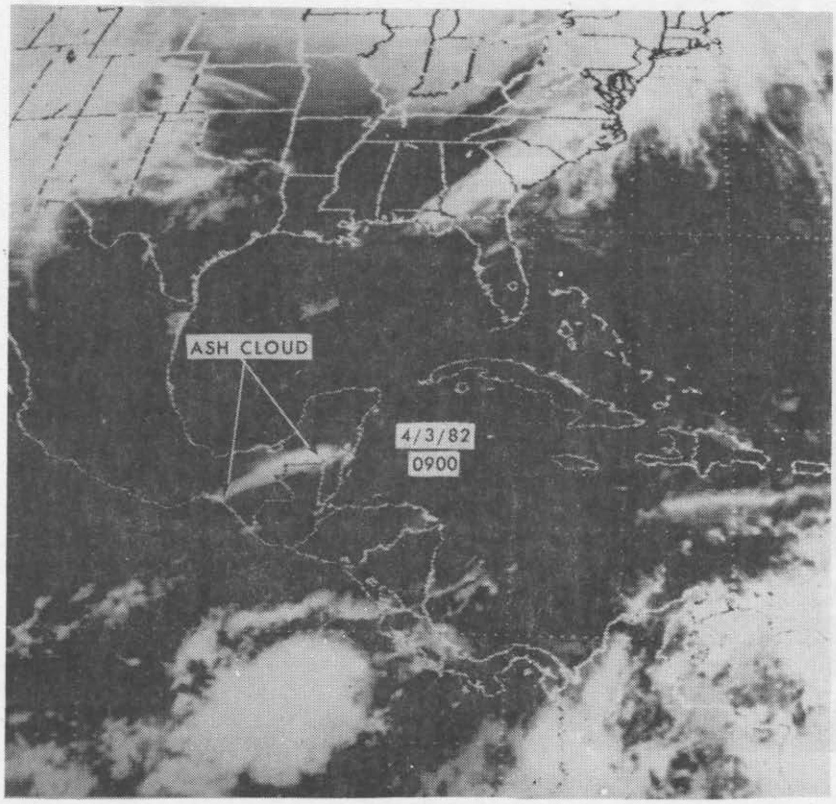

Fig. 2. GOES unenhanced thermal IR image of the El Chichón ash cloud on April 3, 1982 at 0900 local time. Warm areas are black and colder areas are white.

At 0250 on April 3, 1982, El Chichón erupted again and the first GOES satellite recording of the event occurred at 0300. GOES digital data at 0400 gave lowest brightness temperatures of $-71.2^{o}C$, corresponding to an altitude of 15.2 km or 18.8 km when compared to Veracruz radiosonde temperature data taken at 1800 on April 2 (no data were available at 0600 on April 3). The tropopause was at 17 km. After the eruption the ash cloud spread toward both the northeast and the southwest (Figure 2). Veracruz upper air data at 1800 on April 3 showed southwest winds from 16.3 km (15 m/s) to 18.5 km (7 m/s). Northeast winds were present from the surface (5 m/s) to 3 km (3 m/s) and from 20.7 km (5 m/s) to 24 km (8 m/s). Figure 2 shows that the northeastward moving ash cloud had traveled approximately three times as far as the southwestward moving ash cloud. This fact when compared to the wind speeds indicates that the northeastward moving ash cloud was near the tropopause (17 km) and the southwestward moving ash cloud was most likely near-surface (0-3 km).

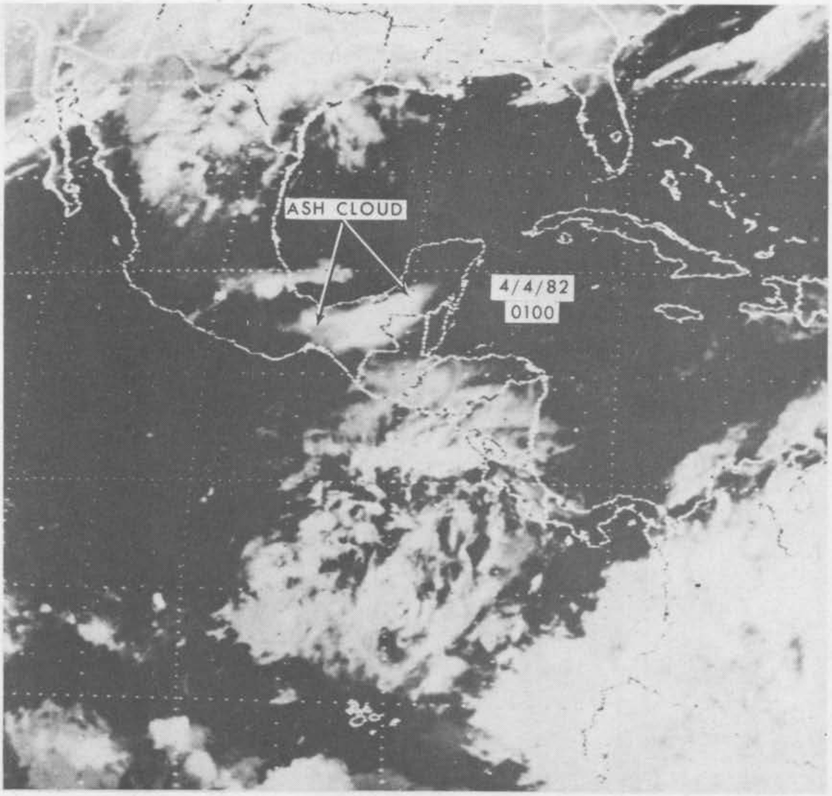

Fig. 3. GOES unenhanced thermal IR image of the El Chichón ash cloud on April 4, 1982 at 0100 local time. Warm areas are black and colder areas are white.

Late on April 3, 1982, and again early on April 4, 1982, El Chichón erupted twice, the second eruption occurring within 10 hours of the first. The first eruption began about 2000 and at 2200 the lowest satellite brightness temperature recorded was $-78.2^{\circ}C$, lower than the lowest Veracruz radiosonde temperature of $-77.5^{\circ}C$ at 16.9 km (tropopause). The subsequent ash cloud from this eruption spread over southern Mexico, Belize, and northern Guatemala (Figure 3). Upper air data taken at 1800 on April 3 (data was incomplete at 0600 on April 4) at Veracruz showed northeast winds from the surface to 3 km (3-5 m/s) and between 20.7 to 24 km (5-8 m/s). Southwest winds were present between 16.3 and 18.5 km (15-7 m/s). Figure 3 shows that the northeastward moving cloud traveled twice as far as the southwestward moving cloud. Comparison of these distances with the above listed wind speeds shows that the northeastward moving cloud was near the tropopause (16.9 km) and the southwestward moving cloud was stratospheric 20.7-24 km).

The largest eruption of El Chichón began at 0522 on April 4. The eruption cloud was recorded by the NOAA-6 polar-orbiting satellite at 0744 in both the visible-band (0.58-0.68μm) and the thermal IR band (10.5-11.5μm) at a resolution of 1.1 km (Figure 4). The thermal IR data gave lowest satellite-brightness temperatures of $-83.0^{\circ}C$, a temperature well below the lowest Veracruz radiosonde tem-

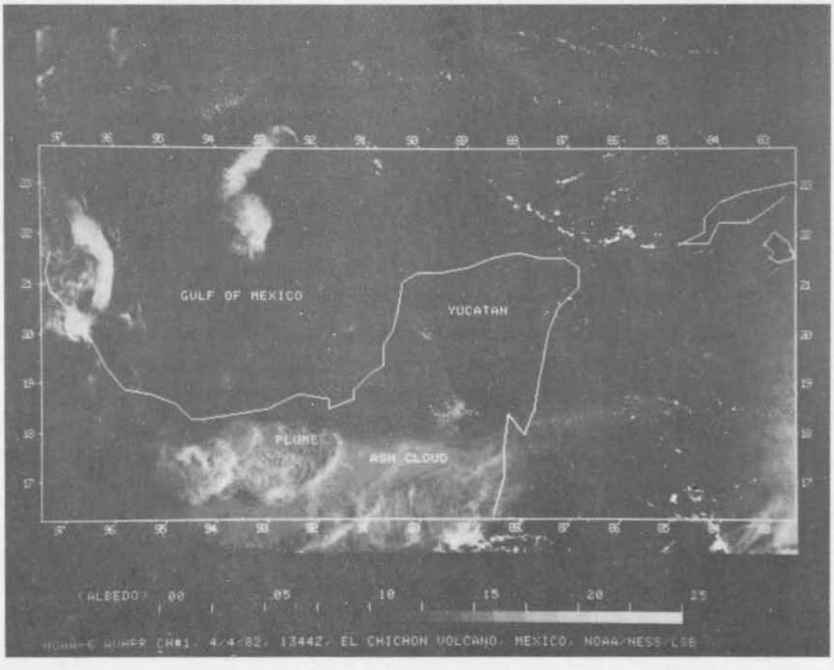

Fig. 4. NOAA-6 visible-band image of the April 4, 1982 eruption at 0744 local time. The imagery was processed on the NASA/GSFC HP-1000 interactive system, Code 972.

perature taken at 1800 on April 3 of $-77.3^{o}C$ at 16.9 km (tropopause). The ash cloud in Figure 4 is a result of the second April 3 eruption. Figure 5 shows the dispersal of the April 4 ash cloud. Veracruz radiosonde upper air data taken at 1800 on April 4 showed southwest winds between 9.2 and 18.5 km and northeast winds between 24 and 31 km. The tropopause was at 17.3 km. Once again the northeastward moving ash cloud was primarily tropospheric and the southeastward moving ash cloud was stratospheric. The height of the stratospheric cloud as derived from this analysis corresponds closely with satellite (Robock and Matson, 1983; Thomas, 1983; and Barth, 1983) and lidar (De Luisi, 1983; McCormick, 1983 and Swissler, 1983) measurements of the El Chichón ash and aerosol cloud that subsequently circled the earth. It appears that the source of this globe-girdling stratospheric cloud was the April 4 eruption.

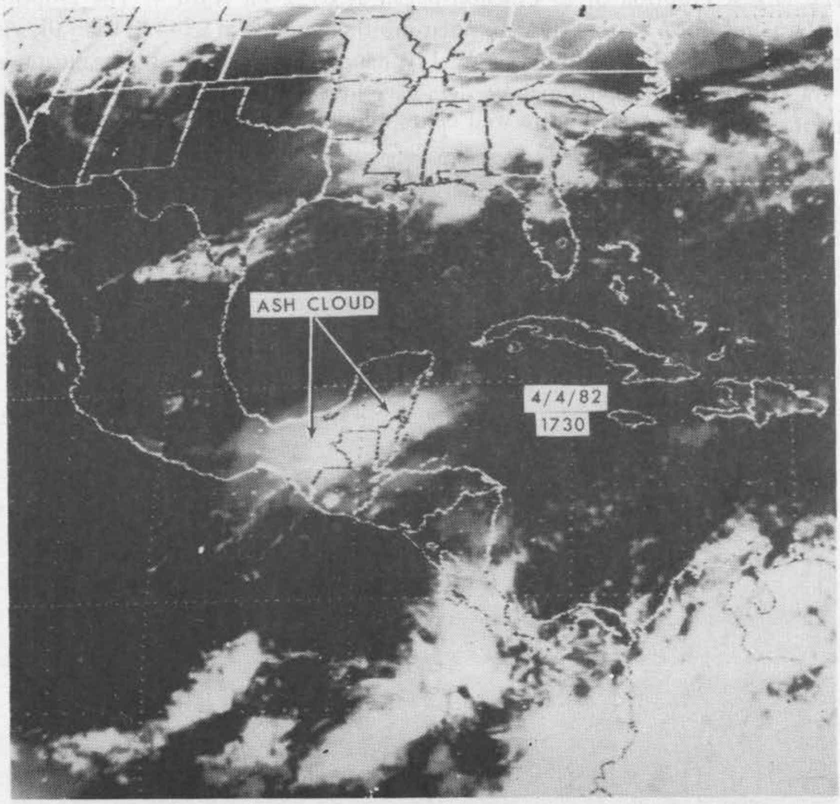

Fig. 5. GOES unenhanced thermal IR image of the El Chichón ash cloud on April 4, 1982 at 1730 local time. Warm areas are black and colder areas are white.

THE APRIL 4 STRATOSPHERIC DUST CLOUD

Figures 6a-6c show maps of the location of the dust cloud for each day after the eruption until April 25, when the cloud had circled the globe. After this time, although the dust was still visible on some images, it was very difficult to detect the edge of the dust cloud. For longitudes in the Western Hemisphere west of the volcano, imagery from the GOES satellites were used. These portions of the maps are plotted at 0000 Greenwich Mean Time (GMT). For the Eastern Hemisphere, and westward across the Atlantic, images were used from the polar-orbiting NOAA-7 satellite which produces one daytime image at approximately 1500 local time at the latitude of the dust (18°N). These portions of the maps are plotted to correspond to the images and thus are for 0300 GMT at longitude 180°, 0400 GMT at 165°E, and so on up to 2000 GMT at 75°W. The dust could be detected for only a few days after the eruption with GOES thermal IR imagery, and this cloud boundary is also plotted on the maps.

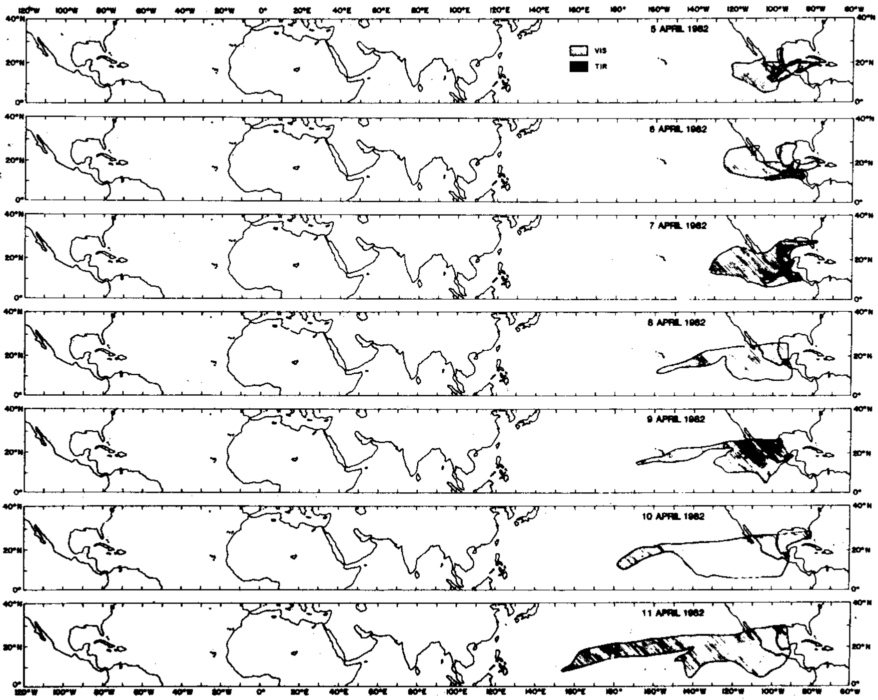

Fig. 6a. Location of the dust cloud from the El Chichón eruption as observed with visible (VIS) and thermal infrared (TIR) imagery from April 5 - April 11, 1982. Dash-dot lines indicate difficulties in observing the exact location of the edge of the cloud.

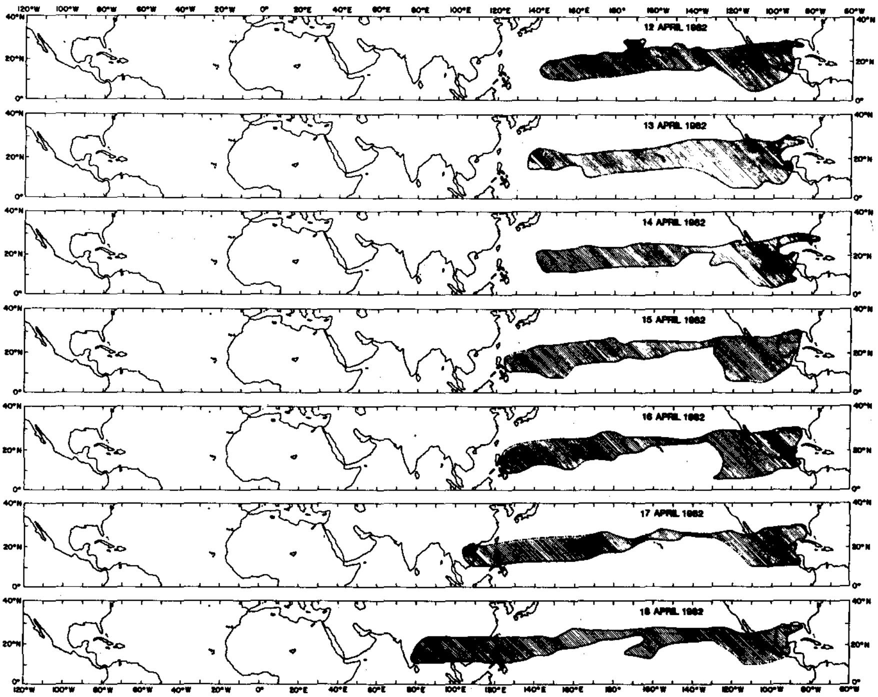

Fig. 6b. Location of the dust cloud from the El Chichón eruption with visible imagery from April 12 - April 18, 1982. Dash-dot lines indicate difficulties in observing the exact location of the edge of the cloud.

It can be seen in Figures 6a-c that the leading edge of the dust moved toward the west during the entire period. Winds at 30 mbar, at an altitude of approximately 24 km, had just begun to blow from the east at the time of the eruption as the circumpolar stratospheric circulation began its shift into the summer pattern of easterlies. The quasi-biennial oscillation was at its maximum easterly phase, so that stratospheric winds over the region between 10^{o}N and 10^{o}S were at approximately 25 m/sec from the east. The dust cloud appears to stretch out in longitude during the period but exhibits very little latitudinal motion, remaining in the band from 10^{o}N to 30^{o}N.

The vertical and horizontal distribution of the dust depends on a number of factors. The source of the dust was a brief (several hours) injection at one point. Additional particles formed *in situ* from sulfur gases after the eruption. The stretching out of the dust cloud in longitude may be due to vertical wind shear, giving different transport velocities at different heights.

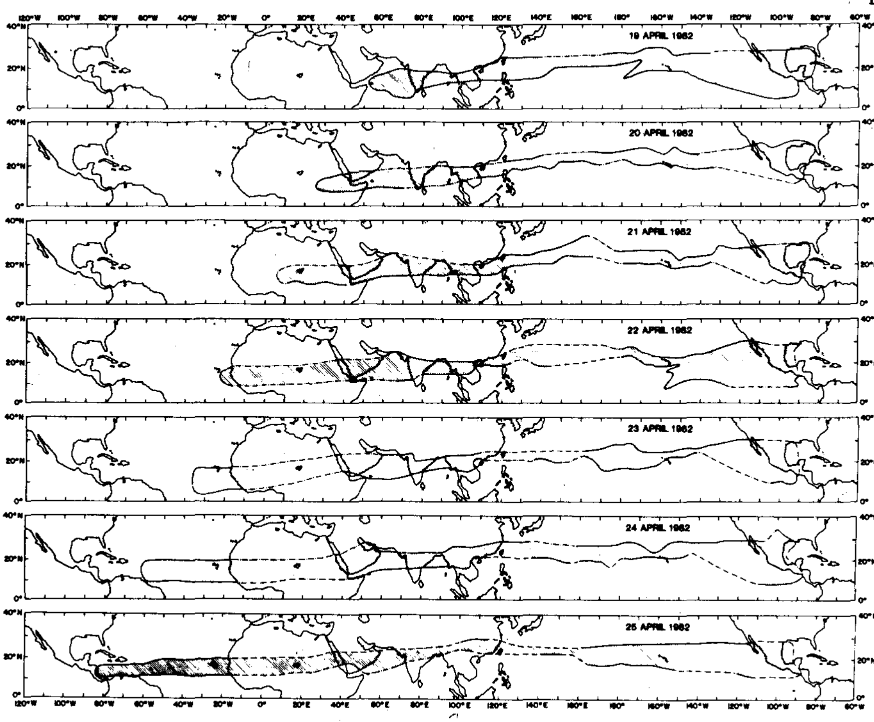

Fig. 6c. Location of the dust cloud from the El Chichón eruption with visible imagery from April 19 - April 25, 1982. Dash-dot lines indicate difficulties in observing the exact location of the edge of the cloud.

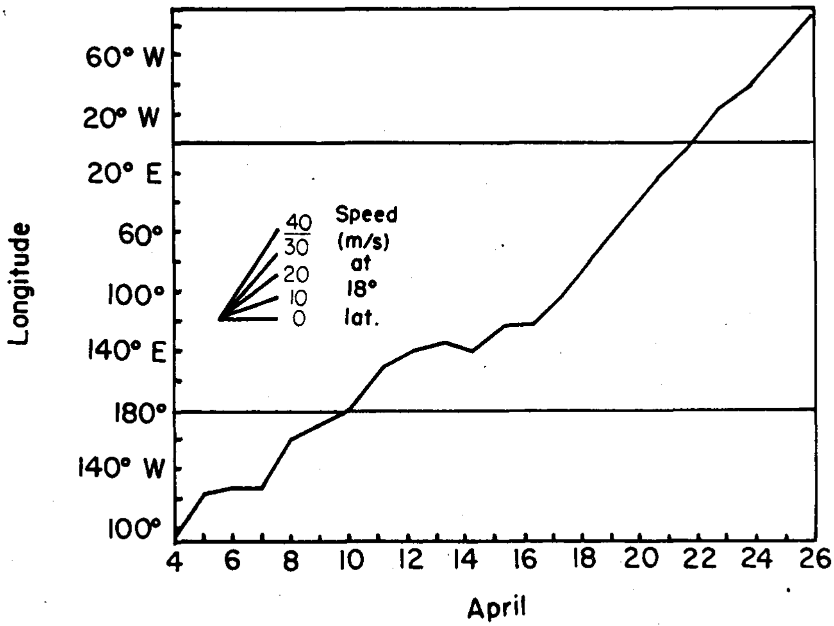

Fig. 7. Longitude of the leading edge of the dust as a function of time.

Figure 7 shows the longitude of the leading edge of the dust as a function of time. Also plotted are lines with slopes representing different speeds at the latitude of the dust. The dust moved more slowly during the first 12 days after the April 4 eruption and then speeded up as the summer stratospheric circulation established itself. The average speed during the entire period was 22 m/sec. An attempt was made to compare the observed 30-mbar winds at the leading edge of the dust with the velocity of the dust itself, but it was found that in all but a few cases there were no wind observations near the dust edge. (For these few cases, the observed winds were in agreement with the observed transport speed of the dust). The satellite observations of the transport of the dust thus provide a better measure of winds at this altitude and latitude than is available from the conventional radiosonde network.

CONCLUSIONS

The 1982 El Chichón eruptions were among the largest documented by operational satellite data since the inception of such data in 1966. Only the May 18, 1980 eruption of Mount St. Helens and the April 27, 1981 - May 1, 1981 eruptions of Alaid volcano in the U.S.S.R. rivaled the El Chichón eruptions in terms of size and intensity as seen in satellite images. Neither, however, gave evidence of such strong stratospheric penetration as revealed for El Chichón by the GOES and NOAA satellites. The resultant stratospheric dust cloud from the April 4 eruption is the only one that has ever been dense enough to be observed by operational satellites throughout its initial circumglobal transport. This fact reinforces the conclusion that the last El Chichón eruption was among he largest in this century in terms of material injection into the stratosphere.

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