Polar Stratospheric Cloud Sightings by SAM II

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ABSTRACT

Sightings of polar stratospheric clouds (PSC's) by the SAM II satellite system during the northern and southern winters of 1979 are reported. PSC's were observed in the Arctic stratosphere at altitudes between about 17 and 25 km during January 1979, with a single sighting in November 1978, and in the Antarctic stratosphere from June to October 1979 at altitudes from the tropopause up to about 23 km. The measured extinction coefficients at 1 μm wavelength were as much as two orders of magnitude greater than that of the background stratospheric aerosol, with peak extinctions up to 10^{-2} km^{-1}. The PSC's were observed when stratospheric temperatures were very low with a high probability of observation when temperatures were colder than 190 K and a low probability when temperatures were warmer than 198 K. In the Antarctic, clouds were observed in more than 90% of the events in which the minimum temperature was 185 K or less, and were observed in fewer than 10% of the occasions when the temperature was greater than 196 K.

1. Introduction

In this paper, observations made with the SAM II satellite-borne sun photometer of layers of enhanced extinction in both the Arctic and Antarctic stratospheres during local winters are described, and the results obtained from these measurements and their corresponding temperature data are presented. For descriptive purposes, we will call these regions of enhanced extinction polar stratospheric clouds (PSC's), since they are well above background in their extinction properties.

Although reports of stratospheric clouds and haze layers are rare, there are well-documented reports of such sightings extending back to at least 1870. According to the compilation of Stanford and Davis (1974), during the period 1870–1973 there were 148 days on which stratospheric clouds were reported in the Northern Hemisphere. Although this indicates a little over one sighting per year, the frequency of observations is actually quite variable. No high-latitude stratospheric clouds were reported during the 30 years between 1895 and 1926, whereas there were 24 days in 1932 when stratospheric clouds were sighted and on four of those days there were multiple sightings. The number of recorded sightings in the Antarctic is much smaller, probably due to the sparsity of observers, yet our satellite data indicate that stratospheric clouds are much more prevalent in the Antarctic than in the Arctic. Most of the previous reports of Northern Hemisphere cloud sightings have referred to them as mother of pearl clouds (MPC's) or nacreous clouds, while in the Southern Hemisphere some of the clouds are reported as stratospheric veil clouds (Stanford and Davis, 1974). According to the Stanford and Davis tabulation, the Northern Hemisphere stratospheric cloud sightings were distributed by month as follows: 17% in December, 40% in January and 27% in February. Similarly, the majority of the Antarctic sightings were made during the winter months (June–September). The first year of SAM II observations (November 1978–October 1979) agree with this temporal distribution, with PSC's observed in the Northern Hemisphere only in January except for a single cloud in November, and in the Southern Hemisphere the sightings extend from June to late September. SAM II found that the clouds were much more prevalent

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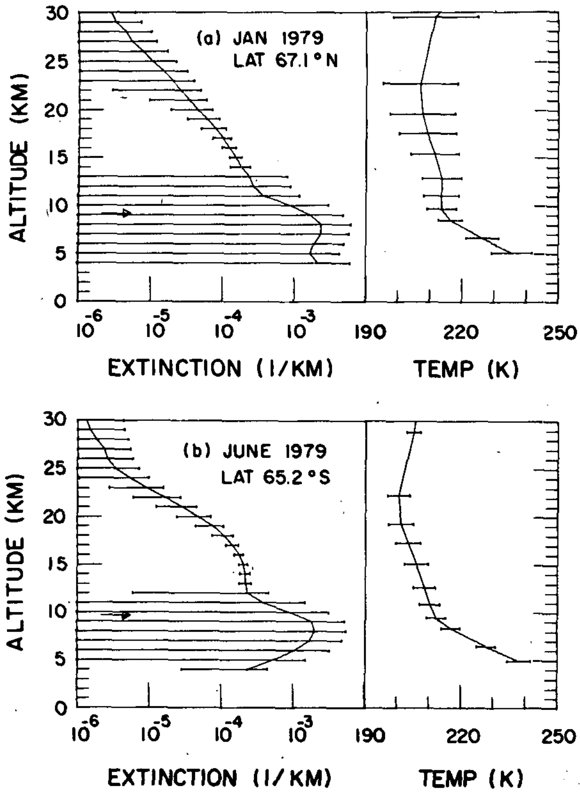

FIG. 1. (a) Average extinction and temperature profiles for the Northern Hemisphere, January 1979. (b) Average extinction and temperature profiles of the Southern Hemisphere, June 1979. The horizontal bars indicate the range of one standard deviation of the data from the mean. Arrows show average tropopause height.

over the Antarctic and persisted for longer periods of time.

2. The SAM II system

The Stratospheric Aerosol Measurement II (SAM II) experiment has been described fully by McCormick *et al.* (1979); a brief outline of some pertinent aspects of the system is given below.

The SAM II instrument consists of a single-channel sun photometer centered at 1.0 μm wavelength, mounted on the Nimbus 7 spacecraft which was launched into a Sun-synchronous orbit on 23 October 1978. During each sunset encountered by the satellite (as it passes into the shadow of the Earth) the instrument is turned on and measures the 1 μm solar intensity during the time the Sun descends from an apparent altitude of about 300 km above the Earth's surface until the Sun is occulted by clouds or the horizon. During sunrises this procedure is carried out in reverse. The field of view of the instrument is quite small (0.01°), and during each measurement opportunity the solar disk is scanned up and down very rapidly allowing for several measurements of solar intensity at each altitude level. The radiance data obtained during each sunrise and sunset are reduced to give transmission profiles. These are then inverted by the methods described by Chu and McCormick (1979) to give profiles of aerosol extinction with a 1 km vertical resolution.

Due to the characteristics of the Nimbus 7 orbit, sunsets all occur in the Northern Hemisphere in the latitude band extending from 65 to 84°N. Sunrises occur in the Southern Hemisphere between 64 and 81°S. The measurements progress in latitude from one extreme to the other over a period of three months with the minimum and maximum latitudes measured at the solstices and equinoxes respectively. The orbital period of Nimbus 7 is 104 min, so the measurements are separated by about 26° longitude and there are approximately 14 measurements in each hemisphere each day. The latitudinal progression of the observation point is slow, 1–2° per week, depending on latitude, so that for a given hemisphere the measurements made on subsequent days are very nearly at the same latitude but shifted toward the west by about 4° in longitude. Consequently, an interesting event can be observed on consecutive days if its spatial extent covers at least 4° in longitude (~200 km at 65°) and it persists at least 24 h.

3. The stratospheric aerosol

The stratospheric aerosol is a layer of large particles ($r \approx 0.1$ μm) residing in the lower stratosphere. In high latitudes the layer begins shortly above the tropopause at about 8 km and extends vertically to ~25 km. At mid-latitudes the tropopause is higher and the layer is shifted upward. The aerosol is composed of particles which are believed to be primarily highly concentrated sulfuric acid solution droplets.

Since its discovery by Junge and co-workers some 20 years ago using balloonborne impactors (Junge *et al.*, 1961), the layer has been extensively studied with dustsondes (Rosen *et al.*, 1975), lidar systems (Russell *et al.*, 1976; McCormick *et al.*, 1978), supersaturation chambers (Kaselau *et al.*, 1974), and other instruments such as polar nephelometers and quartz crystal microbalances (Chuan *et al.*, 1981). After the SAM II system was launched, a series of large-scale correlative (ground truth) experiments were performed to validate the satellite measurements. Since each instrument measures a different property of the aerosol, the task of interpreting the different measurements is complex. Nevertheless, as shown by Russell *et al.* (1981), the satellite data are in very good agreement with measurements obtained by other methods.

The general characteristics of the polar aerosol layer are discussed elsewhere (McCormick *et al.*, 1981); however, it is useful to present here a brief description of the aerosol layer as measured by the SAM II system so that "background" properties of the layer can be compared with the observations of the polar stratospheric clouds which are discussed below.

The basic data product of the SAM II system is the extinction profile. One such profile is generated at each measurement opportunity. Fig. 1 shows two monthly-averaged extinction profiles formed by taking the average of all the extinction profiles obtained in the northern polar region during January 1979 (Fig. 1a) and in the southern polar region during June 1979 (Fig. 1b). The PSC profiles which will be discussed in Sections 4 and 5 have not been included in these averages. The bars in Fig. 1 represent the range of one standard deviation of the data from the mean, and the horizontal arrows show the average tropopause height over the month. Approximately 400 individual profiles were used to form each of these averages. Fig. 1a shows that in the Northern Hemisphere during January 1979, the average stratospheric aerosol extinction fell off monotonically with altitude, from a value of $1.6 \times 10^{-4}\ km^{-1}$ at 15 km to a value of $2.0 \times 10^{-5}\ km^{-1}$ at 23 km. The shape of the Southern Hemisphere June average profile is quite different. The peak extinction is about $2.0 \times 10^{-4}\ km^{-1}$ from 12 to 16 km, and the extinction shows a more rapid falloff with altitude above 20 km.

Temperature profiles at the locations of all SAM II measurements are generated by the Climate Analysis Center of NOAA using a gridded analysis which incorporates all available radiosonde data and some satellite information. The averaged temperature profiles for January 1979 and June 1979 are presented adjacent to the corresponding extinction profiles in Fig. 1, where again the bars represent the 1-sigma fluctuation of the data. The northern polar January stratosphere is about 7° warmer than the southern June stratosphere, having a minimum temperature at 23 km of 207 K and an average temperature in the 15–20 km layer of about 211.5 K.

The 14 extinction profiles obtained during one day, span 360° in longitude. These can be used to construct a 1-day extinction isopleth plot in which the extinction is displayed as a function of altitude and longitude. A typical plot of this type is shown in Fig. 2a which was generated using the data for 19 January 1979. The tick marks on the horizontal axes indicate the locations (longitudes) at which the measurements were made. The data are not continuous; the smooth curves were determined by a computer curve-fitting routine using cubic splines with a tension of 2.5. The particular extinction isopleth plot shown was selected because it clearly shows a stratospheric cloud at a longitude of 43°E. The ratio of two adjacent contours is 1.32. Fig. 2b gives the temperature isotherms for the same day and location. Note the low temperature at the location of the cloud. Each temperature contour is separated by 3 K.

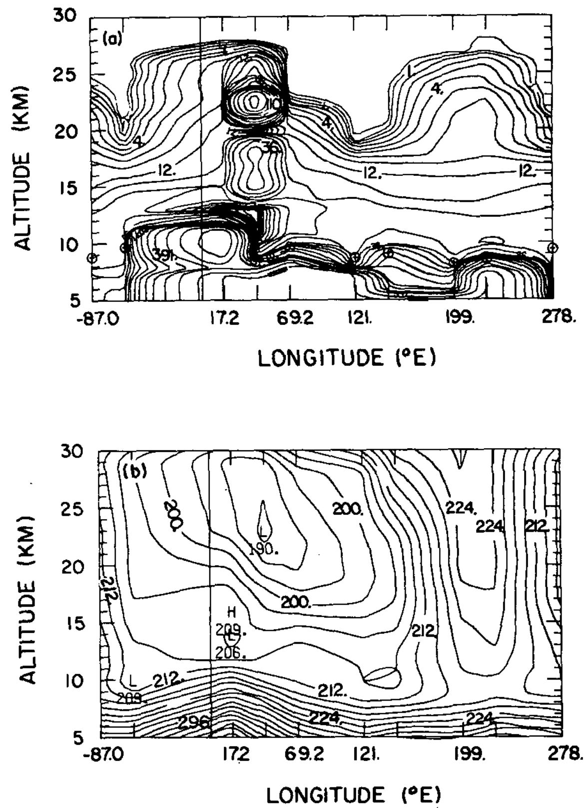

FIG. 2. (a) Isopleths of aerosol extinction for 19 January 1979 at 67.8°N. Values are to be multiplied by $10^{-5}\ km^{-1}$. The solid vertical line shows the Greenwich longitude. A cloud can be seen at 43.2°E. (b) Isotherms, labelled in Kelvins, and separated by 3 K, for 19 January 1979. Note the cold temperature at the location of the cloud.

4. Observations of Northern Hemisphere stratospheric clouds

An analysis of the SAM II observations for the month of January 1979 revealed a number of seemingly anomalous extinction profiles in which the extinction was one to two orders of magnitude larger than expected. A careful study of the transmission profiles and the raw data showed that these very large extinction values were due to a dramatic reduction in the solar radiance received by the instrument and were not an artifact of data handling or inversion techniques. As mentioned earlier we call these events polar stratospheric clouds (PSC's). Since the SAM II measurements are made 26° apart in longitude, it is not possible to determine whether high extinction values recorded in consecutive profiles are manifestations of the same cloud or whether they correspond to different localized clouds. Similarly, if high extinction events are recorded on consecutive days in locations of close proximity, it is not possible to determine whether a cloud has remained for 24 h or whether two distinct clouds have been observed. Consequently, we have chosen to name all *events* in which

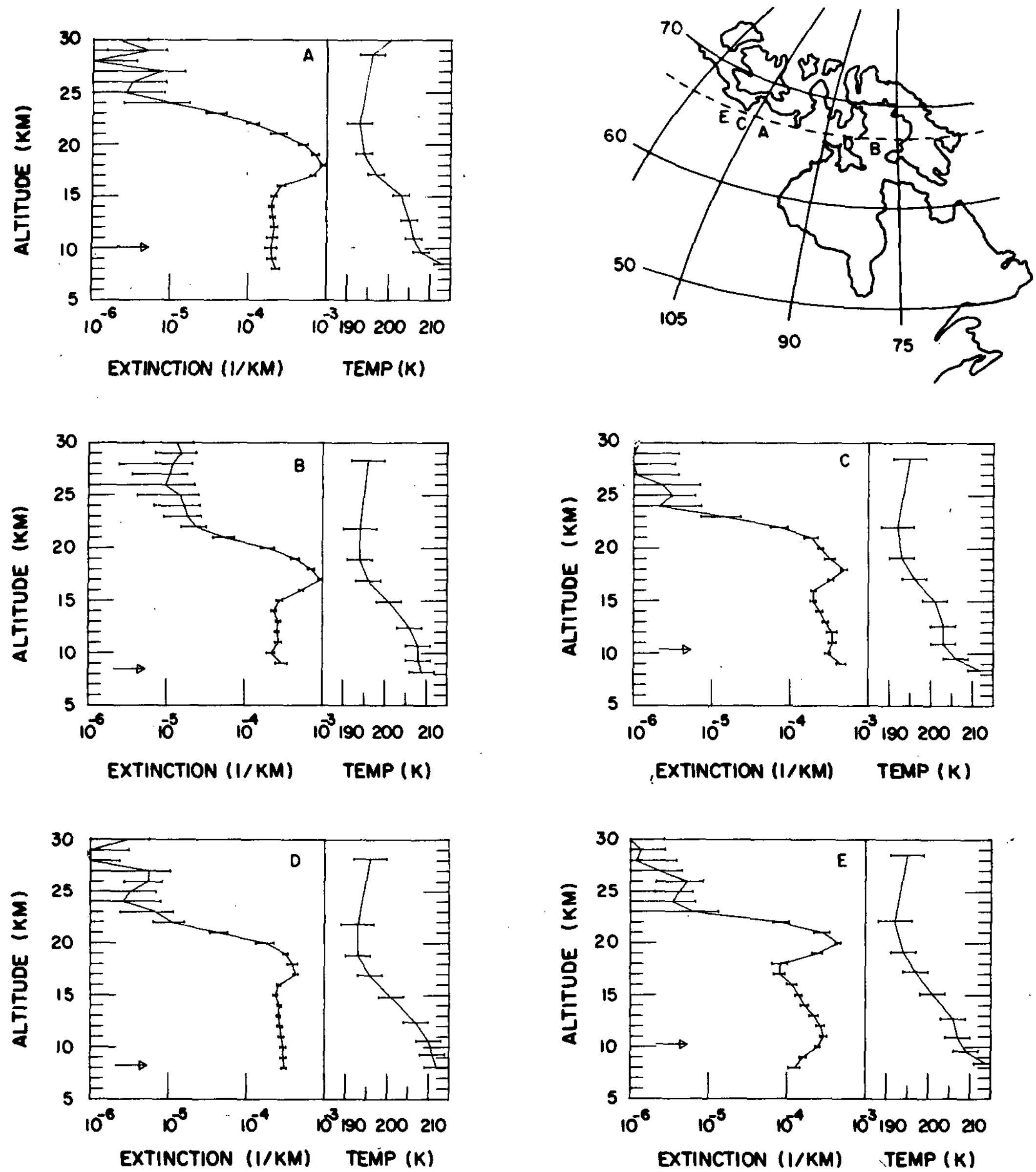

FIG. 3. Extinction and temperature profiles for clouds sighted near Hudson Bay on 11–13 January 1979. The letters on the map indicate the location of the corresponding profiles.

anomalously high extinctions were recorded a PSC even though the observations probably correspond to a lesser number of actual clouds.

A group of high extinction events occurring between 11 and 13 January 1979 was located in the general vicinity of Hudson Bay, Canada. These extinction profiles are presented in Fig. 3, where the horizontal bars represent the estimated 1-sigma error in the extinction values (Russell *et al.*, 1981) and the arrows show the tropopause height. The temperature profiles and their estimated 1-sigma errors are provided by NOAA. Comparison of Figs. 3a–3e with Fig. 1a shows that the extinction in the 17–20 km altitude range is as much as an order of magnitude larger than the background monthly average and is well beyond the 1-sigma range of the expected background variations. Furthermore, the shape of the profiles is quite different from the average profile, exhibiting a peak between 17 and 20 km, indicating a thick aerosol layer at these altitudes. The temperature profiles during these cloud sightings show a very cold stratosphere, with temperatures as low as 192 K (−81°C). In all the cases shown in Fig. 3, the temperature at the extinction peak was 196 K or lower, some 10–20 K colder than the average for the month.

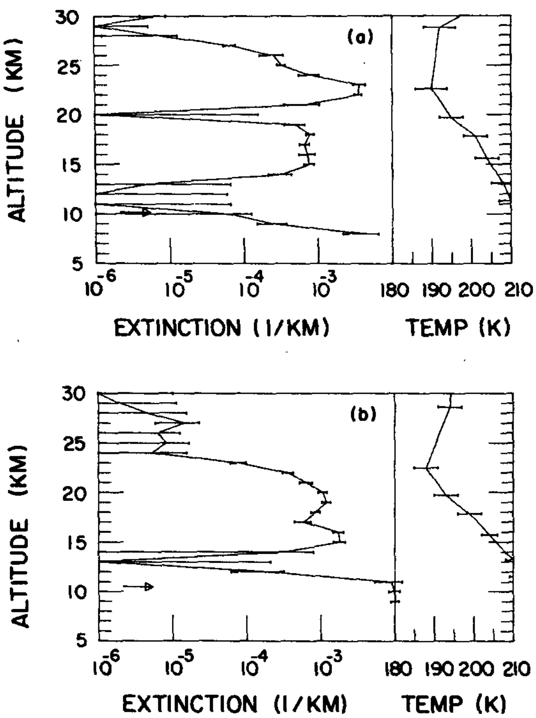

FIG. 4. Extinction and temperature profiles obtained on (a) 19 January at 43°E, 67.8°N and (b) 23 January at 27°W, 68.7°N.

A search through the first year of SAM II data revealed the existence of seven more clouds in the Northern Hemisphere. Three clouds were seen over northeast Scandinavia on 18, 19 and 20 January and one cloud in this location on 30 November 1978. One cloud was observed over the Norwegian Sea on 5 January, one over the west coast of Greenland on 22 January, and one over the east coast of Greenland on 23 January. Two of these cloud profiles, shown in Fig. 4, exhibited the highest values of peak extinction as much as two orders of magnitude greater than the background value at 20–25 km.

In the cases where very high peak extinction values were recorded, the extinction appears to drop to zero below the cloud [compare the extinction at 12 and 20 km (Fig. 4a) and at 13 km (Fig. 4b)]. This is most likely due to the method of inversion. The inversion computation treats the atmosphere as a series of thin concentric shells, where the particulate matter in each shell is assumed to be homogeneously distributed throughout the shell. Since sunlight must traverse all higher shells, one must subtract off the contributions due to the higher shells to determine the extinction in a particular shell. If there is a large amount of particulate matter in one shell distributed inhomogeneously, the extinction at lower altitudes can be underestimated. Consequently, the dropoff below the high extinction peak implies that the particulate layer probably does not extend throughout the shell. For the cases illustrated in Fig. 4, this means that the horizontal extent of the cloud layer along the sun-satellite line is less than 300 km. The assumption of homogeneous distribution of aerosol throughout a particular shell will also cause our recorded extinction peak value to be an underestimation of the actual maximum extinction in a localized cloud.

Table 1 gives a summary of all the PSC events noted in the first year of SAM II Arctic data. The peak extinction for the clouds appeared at altitudes between 15 and 23 km. In all cases temperatures were very low, with minimum temperature always lower than 198 K. The coldest temperature in our January records was 188 K on 23 January (orbit 1261) when intense layers were observed at 15 and 19 km. The appearance of the clouds is closely related to temperature, as will be considered more fully below.

TABLE 1. Summary of all Arctic PSC events during first year of SAM II operation.

Identification		Location		Maximum value of extinction (km^{-1})	Altitude of maximum extinction (km)	Temperature at maximum extinction (K)	Minimum temperature (K)	Altitude of minimum temperature (km)	Ratio of PSC maximum extinction to non-cloud January average extinction
Date	Orbit	Latitude (°N)	Longitude						
30 Nov 1978	512	66.5	25°E	5.5×10^{-4}	20	197	197	19–23	12.0
5 Jan 1979	1011	65.7	2°E	6.1×10^{-4}	20	196	194	22.3	13.4
11 Jan 1979	1098	66.5	103°W	9.1×10^{-4}	18	196	193	22.0	11.2
12 Jan 1979	1111	66.6	81°W	9.4×10^{-4}	17	196	194	19–22	9.1
12 Jan 1979	1112	66.7	107°W	4.9×10^{-4}	18	195	192	22.0	6.0
13 Jan 1979	1125	66.8	86°W	4.3×10^{-4}	17	196	193	19–22	4.2
13 Jan 1979	1126	66.8	112°W	4.5×10^{-4}	20	193	192	22.1	9.9
18 Jan 1979	1190	67.7	22°E	6.0×10^{-3}	22	197	195	23.0	226.4
19 Jan 1979	1203	67.8	43°E	3.7×10^{-3}	23	190	190	22.6	184.1
20 Jan 1979	1217	68.1	39°E	4.0×10^{-4}	21	197	191	28.8	11.5
22 Jan 1979	1248	68.5	49°W	4.7×10^{-3}	22	192	191	22.7	178.5
23 Jan 1979	1261	68.7	27°W	1.8×10^{-3}	15	206	188	22.5	11.7

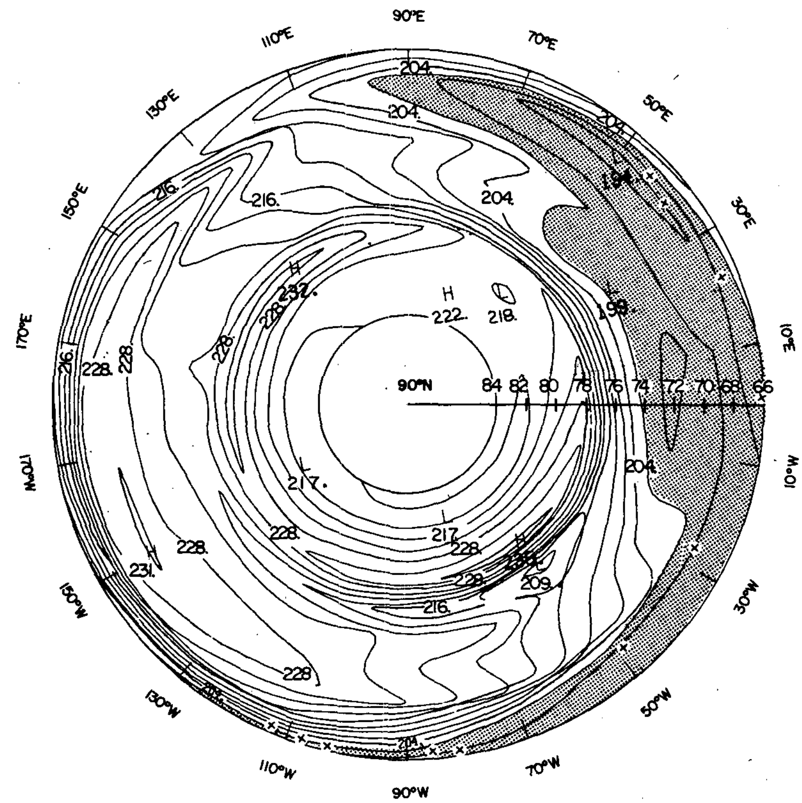

FIG. 5. Polar projection of temperature contours at 20 km for polar region covering 10 weeks from December 1978 to March 1979, between latitudes 66 and 84°N. Shaded region shows temperatures below 201 K. X's mark the locations of stratospheric clouds.

The meteorological maps for January 1979 at 50 and 70 mb show a deep low-pressure region centered at about 70°N on the days when PSC's were observed at these altitudes. In all cases the position of the low-pressure center was such that the area where clouds were observed was subjected to the advection of very cold polar air from the north or northwest. These meteorological conditions resemble those described by Dieterichs (1950) for days when mother of pearl clouds were reported over England and Scandinavia.

Fig. 5 shows a polar projection of temperature contours at 20 km altitude, generated using the temperature profiles of a 10-week period as the satellite swept from 66 to 84°N. The plot does not, therefore, represent an instantaneous snapshot of temperatures for the Arctic, but rather a compilation of the 20 km temperatures at the points where satellite measurements were taken. The locations of the high extinction profiles are indicated by the symbol ×. All of these events lie in the shaded region which represents temperatures lower than 201 K.

5. Observations of Southern Hemisphere stratospheric clouds

As mentioned previously, stratospheric clouds were even more prevalent in the Southern Hemisphere local winter than in the Northern Hemisphere. In general, these clouds are at somewhat lower altitudes than the Northern Hemisphere clouds and are frequently observed during several subsequent orbits. They often appear to persist for several days. The extinction values measured are similar to the highest values observed in the Northern Hemisphere clouds in January and range from 10^{-3} to 10^{-2} km^{-1}.

Fig. 6 shows the extinction and temperature values observed on 25 July 1979, at 68°S, and is fairly typical of the data recorded throughout the Antarctic winter. Again one can see a distinct correlation between low temperatures and the appearance of clouds, but here there is a large region of high extinction, rather than an isolated cloud event, and a corresponding large region of cold temperatures. An extinction value of 12–20 (1.2×10^{-4}–2×10^{-4} km^{-1}) is a typical background aerosol value for the 15–20 km region.

The large number of PSC's occurring during the Antarctic winter allows for a statistical survey of their correlation with low temperatures. For the purposes of this analysis it is necessary to attach some definition to a "cloud" in order to permit a computer search through the data for cloud occurrences. In the

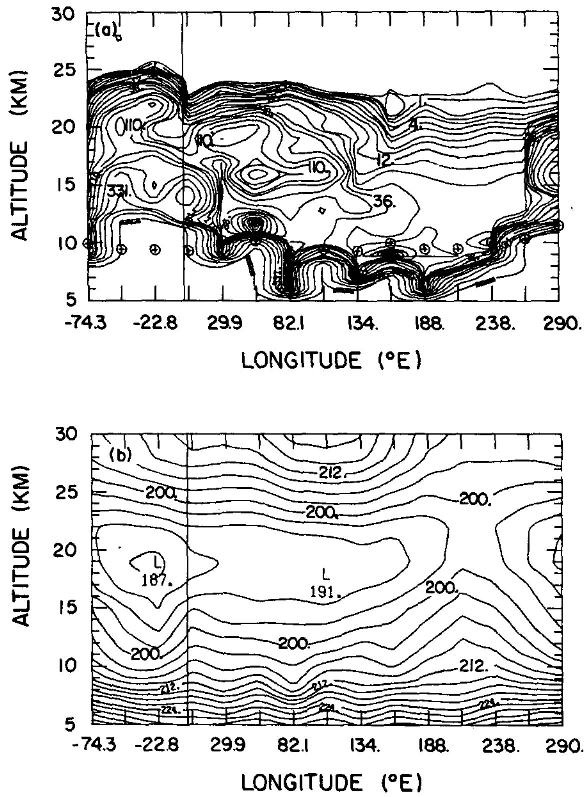

FIG. 6. (a) Isopleths of aerosol extinction for 25 July 1979 at 68°S. Labels are scaled by 10^5 km^{-1}. The solid vertical line shows the Greenwich longitude. A region of enhanced extinction can be seen extending from 48°W to 134°E. (b) Isotherms, labelled in Kelvins, and separated by 3 K, for 25 July 1979.

Northern Hemisphere winter it was an easy task to distinguish cloud events from a normal background profile, as the enhancement in the extinction was observed well above the tropopause at altitudes where the normal aerosol extinction shows a monotonic falloff with altitude. However, in the southern winter, extensive regions of enhanced extinction were observed, and it is no longer easy or necessarily objective to define a "cloud" profile. To investigate the question of whether two distinct sets of profiles exist (clouds and background), a survey of the range of observed peak extinction values was undertaken. Fig. 7 shows the number of profiles in which a given maximum extinction was observed. The maximum extinction between 3 km above the tropopause and 30 km was found for each SAM II profile in the Southern Hemisphere between April and September 1979 and "binned" according to its value. In Fig. 7 the dashed histogram shows data from April through June, a cloud-free period. The solid histogram is for the period July through September, the Antarctic winter. Clearly, during cloud-free periods there were essentially no measurements in which the maximum extinction exceeded 5×10^{-4} km^{-1}, whereas during the winter period a large number of events with extinctions as high as 10^{-2} km^{-1} were observed. Based on these data we have chosen to define PSC's in the Antarctic as events in which the maximum extinction exceeded 8×10^{-4} km^{-1}. This value is about four times the average extinction observed in June between 12 and 15 km (Fig. 1b). If a double peak occurs in the extinction profile, only one cloud is rec-

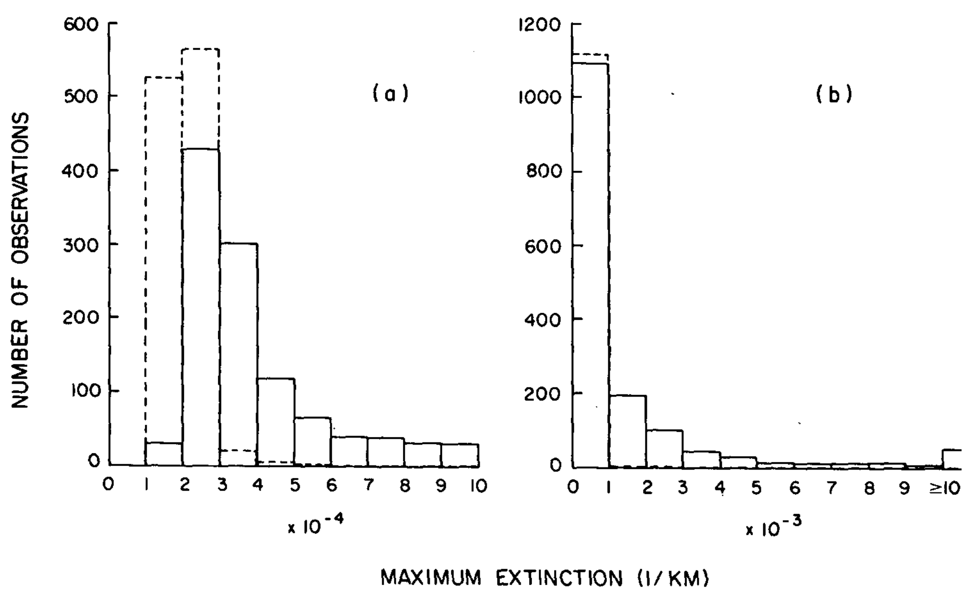

FIG. 7. Number of Antarctic extinction profiles having a given peak extinction value. Dashed lines show data for April-June 1979 (prior to Antarctic winter); solid lines show data for July-September 1979 (during Antarctic winter). (a) Number of events with peak extinction between 10^{-4} and 10^{-3} km^{-1}, (b) All events.

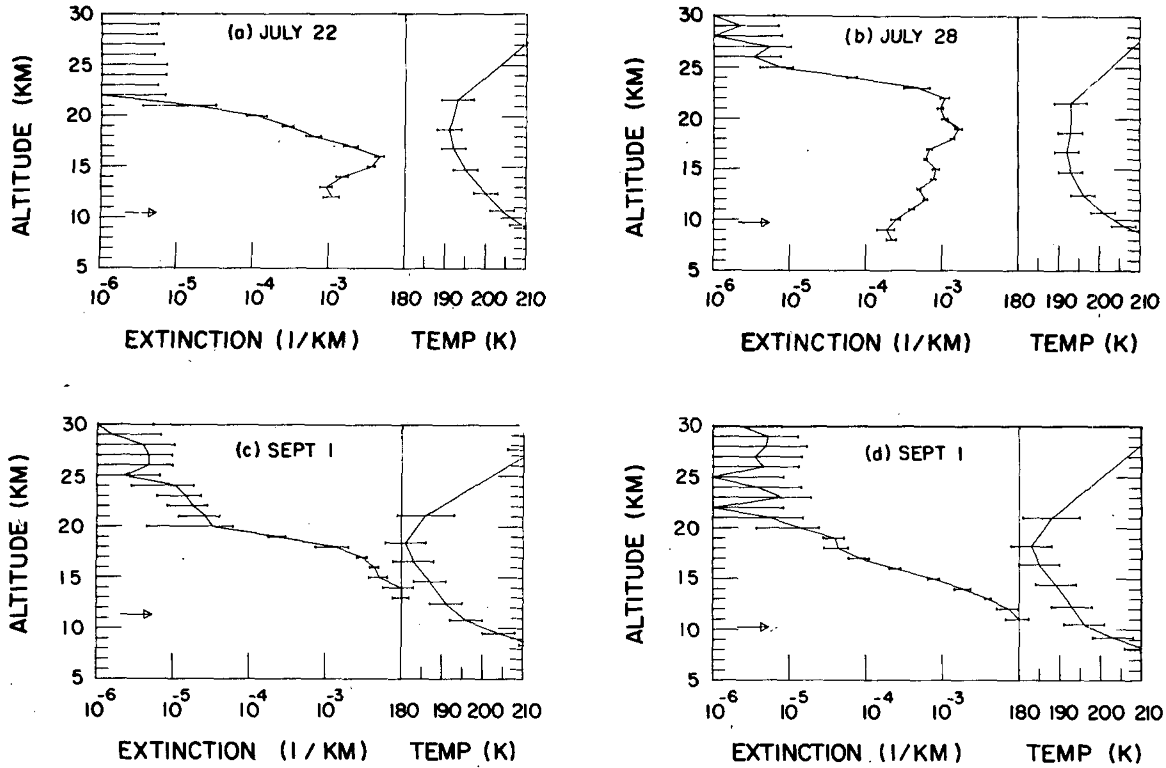

FIG. 8. Four extinction and temperature profiles obtained in the Antarctic winter between 22 July and 1 September. All show peak extinctions greater than 10^{-3} km^{-1}.

orded. According to this definition, in the Antarctic winter 538 clouds were sighted by SAM II during a period of 14 weeks from 24 June to 29 September 1979.

Fig. 8 shows examples of four PSC's observed in the Antarctic winter whose extinction profiles have very different shapes. The cloud in Fig. 8a, seen on 22 July, has a distinct peak of about 4.7×10^{-3} km^{-1} at 16 km. The layer is 4–5 km thick. In Fig. 8b the profile shows a very thick layer extending to 23 km with extinction values up to 1.7×10^{-3} km^{-1}. In Figs. 8c and 8d the extinction is cut off at 10^{-2} km^{-1}, and the cloud layer appears to extend down to the tropopause. The cutoff at 10^{-2} km^{-1} represents the minimum signal level resolvable by the SAM II instrument. The corresponding temperature profiles and their estimated errors are also shown. Comparison with Fig. 1b shows the stratospheric temperatures observed on the occasions these clouds were sighted were some 10–20 K colder than the June Antarctic average.

The trend in cloud formation and temperature throughout the Antarctic winter is depicted in Fig. 9. The abscissa shows the minimum temperature at altitudes above the tropopause plus 3 km, and the ordinate gives the frequency of occurrence of such a temperature. For example, in the week 17–23 June there were five events where the minimum temperature was 200 K and 14 events where the minimum temperature was 201 K. Each histogram displays one week's data. The shaded areas represent events during which a PSC was recorded and, therefore, the clear areas are the events for which no extinction greater than 8×10^{-4} km^{-1} was reached in the stratosphere. As the minimum temperature falls, more clouds appear. All events for temperatures 185 K or colder are included in the 185 K bin. In the week 2–8 September, for example, 43 events were recorded when the temperature fell to 185 K or below, and PSC's occurred on all but one such occasion. As the stratosphere warmed, the clouds became less frequent until they disappeared completely in the beginning of October.

6. Summary

The statistical information in Fig. 9 has been summarized in Fig. 10a (Antarctic), which shows the correlation between the occurrences of low temperatures and PSC observations. Fig. 10a shows that a cloud was observed in more than 90% of the events in which the minimum temperature was 185 K or less, and in at least 45% of the events in which the temperature was 193 K or less. One can clearly see the falloff in PSC occurrence with increasing temperature, with clouds sighted on fewer than 10% of the occasions when the temperature was greater than 196 K. Fig. 10b shows the equivalent information for the Arctic winter. Since only 12 clouds were seen in the Arctic region, these data are not as statistically significant; however, the same trend in decreasing cloud occurrences with increasing temperature is apparent. The overall data displayed in Fig. 10 indicate that there is a high probability of stratospheric

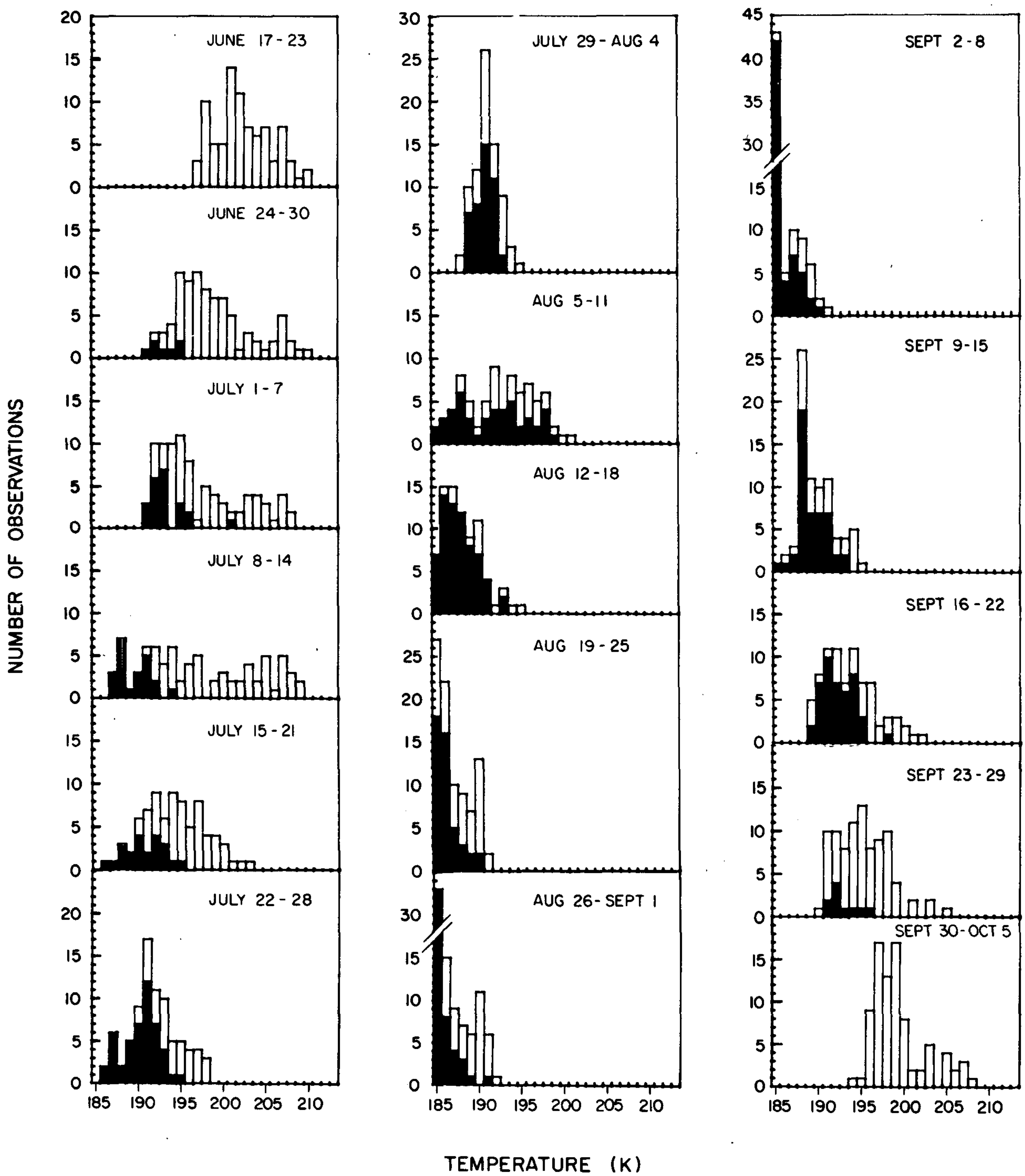

FIG. 9. Number of cloudless events (open areas) and cloud observations (shaded areas) as a function of minimum stratospheric temperature for 16 weeks during the Antarctic winter. Note the changes of scale for the weeks of 26 August–1 September and 2–8 September. All events for temperatures ≤185 K are included in the 185 K bin.

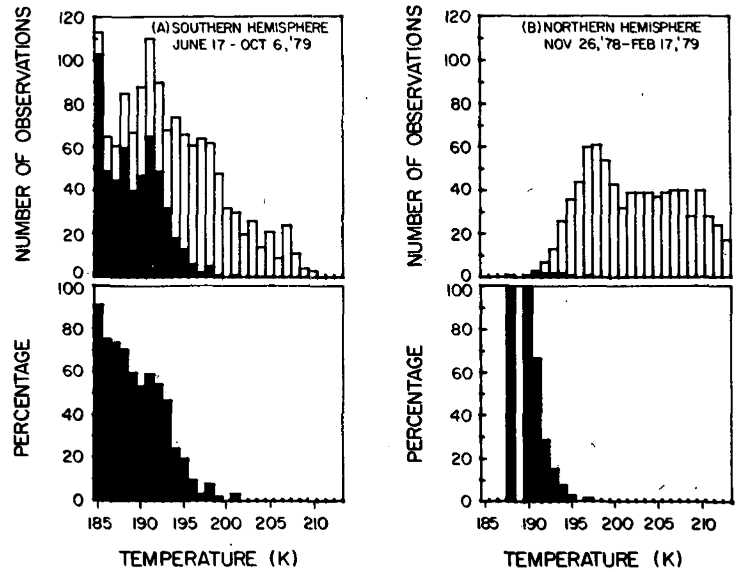

FIG. 10. (a) Histogram showing the total number of profiles having a given minimum temperature for the Southern Hemisphere winter. The shaded events represent cloud observations. The lower graph shows the frequency of cloud observations as a percentage of the total events with the same minimum temperature. (b) The equivalent information for the Northern Hemisphere winter. All events for temperatures ≤185 K are included in the 185 K bin.

cloud formation when the minimum temperature falls below about 190 K, and a very small probability when the temperature is greater than 198 K.

The altitudes of the clouds reported in this paper are somewhat lower than those estimated by earlier observers. Stormer (1929) observed nacreous clouds over England and Scandinavia with heights between 22 and 26 km, while Hesstvedt (1969) suggests that 23 km is their mean altitude. The heights of those observed in the Antarctic expedition of 1950–51 (Liljequist, 1956) are not well known, but they are thought to occur at pressure levels of 30–50 mb (Stanford, 1977) which would correspond to altitudes of 19–22 km. Table 1 indicates that the average altitude of the Northern Hemisphere clouds observed by the SAM II system is about 20 km, lower than previous reports suggest. The Antarctic clouds occur even lower, at 15–17 km in the first weeks of winter when they are isolated events clearly distinct from tropospheric clouds. At this time, the minimum temperature occurs between 19 and 21 km. As winter progresses the clouds occur at still lower altitudes, and by the end of August appear to extend to the tropopause and possibly below, with the extinction peaking below 14 km. At the end of winter the minimum temperature occurs at an altitude of about 16 km.

A feature of the 1979 winter is the stratospheric warming. The Arctic warming has been documented by Quiroz (1979) and Labitzke (1981), who report three warming peaks. The first of these occurred around 25 January, with a secondary peak following on 7 February. These were followed by a further temperature gradient reversal in late February. The disappearance of the Arctic clouds coincides with the first of these warmings. A similar phenomenon takes place in the Antarctic at the end of September (McCormick *et al.*, 1981). This warming is much more dramatic and appears to be an annual feature of the Antarctic spring (see, e.g., Weyant, 1966). Again the clouds disappear at this time.

7. Conclusions

The transitory nature of polar stratospheric clouds, their altitude, association with very cold temperatures, and location in sparsely populated areas, do much to hinder their observation. The high density of measurements afforded by the SAM-II satellite system has allowed detection of many stratospheric clouds which might otherwise have passed unnoticed. Furthermore, we now have quantitative values for a number of parameters which were previously only estimated roughly. Thus, for a given PSC observation we can specify the 1.0 μm extinction as a function of altitude, the temperature as a function of altitude, and the spatial and temporal location of the cloud. This new information allows us to reach conclusions as to the characteristics of the clouds and to carry out calculations on the microphysical processes involved in the formation of PSC's. Although the Antarctic polar region accounts for only about 5%

of the global stratospheric area, these PSC's should be accounted for in future stratospheric water vapor, sulfate and radiative budget studies. The more important characteristics of the 1979 PSC events are emphasized below.

1) PSC's were much more prevalent in the Antarctic winter than in the Arctic winter.

2) There is a clear negative correlation between the occurrence of PSC's and temperature.

3) The altitudes of the clouds are lower than those previously reported.

The SAM-II satellite data are presently being archived on magnetic tape in the National Space Sciences Data Center at NASA's Goddard Space Flight Center, Greenbelt, MD, and the first year of data will be available for general release in late 1981. The satellite sensor continues to provide high-quality data. Processing of the subsequent wintertime periods will provide more information on the characteristics of these polar stratospheric clouds.

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REFERENCES

Chu, W. P., and M. P. McCormick, 1979: Inversion of stratospheric aerosol and gaseous constituents from spacecraft solar extinction data in the 0.38–1.0 μm wavelength region. *Appl. Opt.*, **18,** 1404–1413.

Chuan, R. L., D. C. Woods and M. P. McCormick, 1981: Characterization of aerosols from eruptions of Mount St. Helens. *Science*, **211,** 815–838.

Dieterichs, H., 1950: Uber die entstehung der perlmutterwolken. *Meteor. Rundsch.*, **3,** 208–213.

Hesstvedt, E., 1969: The physics of nacreous and noctilucent clouds. *Stratospheric Circulation*, W. L. Webb, Ed. Academic Press, 209–217.

Junge, C. E., C. W. Chagnon and J. E. Manson, 1961: Stratospheric aerosols. *J. Meteor.*, **18,** 81–108.

Kaselau, K. H., P. Fabian and H. Rohrs, 1974: Measurements of aerosol concentration up to a height of 27 km. *Pure Appl. Geophys.*, **112,** 877–885.

Labitzke, Karin, 1981: The amplification of height wave 1 in January 1979: A characteristic precondition for the major warming in February. *Mon. Wea. Rev.*, **109,** 983–989.

Liljequist, G. H., 1956: Halo-phenomena and ice-crystals. *Norwegian-British-Swedish Antarctic Expedition, 1949–52: Scientific Results*, Vol. II, Part 2A. Norsk Polarinstitutt, Oslo.

McCormick, M. P., T. J. Swissler, W. P. Chu and W. H. Fuller, Jr., 1978: Post-volcanic stratospheric aerosol decay as measured by lidar. *J. Atmos. Sci.*, **35,** 1296–1303.

——, Patrick Hamill, T. J. Pepin, W. P. Chu, T. J. Swissler and L. R. McMaster, 1979: Satellite studies of the stratospheric aerosol. *Bull. Amer. Meteor. Soc.*, **60,** 1038–1046.

——, W. P. Chu, G. W. Grams, Patrick Hamill, B. M. Herman, L. R. McMaster, T. J. Pepin, P. B. Russell, H. M. Steele and T. J. Swissler, 1981: High-latitude stratospheric aerosols measured by the SAM II satellite system in 1978 and 1979. *Science*, **214,** 328–331.

Quiroz, R. S., 1979: Tropospheric-stratospheric interaction in the major warming event of Jan.–Feb. 1979. *Geophys. Res. Lett.*, **6,** 645–648.

Rosen, J. M., D. J. Hofmann and J. Laby, 1975: Stratospheric aerosol measurements II: The worldwide distribution. *J. Atmos. Sci.*, **32,** 1457–1462.

Russell, P. B., W. Viezee, R. D. Hake, Jr. and R. T. H. Collis, 1976: Lidar observations of the stratospheric aerosol: California, October 1972 to March 1974. *Quart. J. Roy. Meteor. Soc.*, **102,** 619–639.

——, M. P. McCormick, T. J. Swissler, W. P. Chu, J. M. Livingston, W. H. Fuller, J. M. Rosen, D. J. Hofmann, L. R. McMaster, D. C. Woods and T. J. Pepin, 1981: Satellite and correlative measurements of the stratospheric aerosol. II: Comparison of measurements made by SAM II, dustsondes, and an airborne lidar. *J. Atmos. Sci.*, **38,** 1295–1312.

Stanford, J. L., 1977: On the nature of persistent stratospheric clouds in the antarctic. *Tellus*, **29,** 530–534.

——, and J. S. Davis, 1974: A century of stratospheric cloud reports: 1870–1972. *Bull. Amer. Meteor. Soc.*, **55,** 213–219.

Stormer, Carl, 1929: Remarkable clouds at high altitudes. *Nature*, **123,** 260–261.

Weyant, W. S., 1966: The Antarctic Atmosphere: Climatology of the troposphere and lower stratosphere. Folio 4, *Antarctic Map Folio Series*, Amer. Geogr. Soc.